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Research article

The effectiveness of spatial integration in a mathematics learning module on students' cognitive skills: An experimental study

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Abstract: Previous studies have demonstrated a positive relationship between spatial reasoning and cognitive skills, suggesting that spatial reasoning can forecast students' success in mathematics. This study aimed to assess the effectiveness of implementing a mathematics learning module with spatial integration on students' cognitive abilities (spatial reasoning and problem-solving), emphasizing the importance of spatial reasoning in mathematics education. This study's proposed learning module highlighted interactivity, which is absent in the current version's module. A total of 225 seventh-grade students from two public junior high schools in Indonesia volunteered for this research. The students participating in this study were divided into two groups: an experimental group and a control group, comprising 115 students in the experimental group and 110 in the control group. The experimental groups underwent mathematics learning conducted by teachers who had received spatial training and used the mathematics learning module with spatial integration, while the control groups received conventional learning. The training focused on enhancing teachers' knowledge about spatial learning in mathematics and how to use the learning module. Pre-test and post-test were conducted for both spatial reasoning and problem-solving. The gain score was considered to examine the effectiveness of the teachers' training on students' cognitive skills. The statistical analysis results indicate a significant difference between the experimental and control groups in both students' spatial reasoning and mathematics problem-solving, with the experimental group outperforming the control group. Furthermore, the implications and impacts of spatial reasoning on cognitive skills are discussed.

Keywords: spatial reasoning, problem-solving, geometry, spatial integration, learning module

1. Introduction

The use of a learning module in teaching and learning activities is a common approach that helps educators deliver educational content effectively to students, including in mathematics education. A learning module is also used as an instructional tool, providing students with comprehensive and essential information about the learning materials, such as activities, exercises, and assessments. It also allows teachers to tailor learning activities to the unique needs and characteristics of their students [1]. Schools and teachers are expected to provide students with learning modules that meet their needs, whether through independent development or by utilizing the existing learning module. To enable students to achieve their mathematics learning goals, education policymakers and, of course, teachers should create and implement effective learning interventions. Designing effective interventions involves understanding students' needs [2], recognizing individual cognitive differences [3], and promoting student engagement with the intervention [4,5]. Learning interventions in mathematics could be teaching methods or strategies that help students learn mathematics through activities. Moreover, the learning intervention could serve as a learning tool and instrument, such as a learning module, which is the focus of this study. Learning modules are the most common tools used by educators and students. This study aimed to provide mathematics teachers with new insights into a mathematics learning module that integrates learning theories not considered in current modules. The mathematics learning module employed in this study will be analyzed to evaluate its effectiveness on students' cognitive skills. The present study focuses on two core cognitive skills, namely spatial reasoning and mathematical problem-solving, as detailed in the later section.

A learning module may be defined as a structured compilation of instructional materials that includes learning objectives, sequenced learning activities, and evaluation components, and is known by several terms, such as learning packets, teaching kits, and educational kits [6]. Lately, the development of learning modules has evolved from textbook-type to integrated technology–type learning modules to accommodate the students' needs in the modern era of technology [6,7]. As explained previously, this study wanted to examine the effectiveness of a type of learning module and provide new insights for mathematics teachers about a new learning tool that can enhance students' spatial reasoning and problem-solving. The learning module promoted in this study was developed based on the mathematics school curriculum in Indonesia, where this study was conducted. Considering the objectives of the school curriculum, one of the aims for mathematics learning is to emphasize students' problem-solving abilities [8]. However, designing effective instruction to teach mathematics problem-solving could be challenging for teachers; some studies showed that teachers have difficulties in creating activities that can stimulate students' ability in problem-solving [9,10]. Practicing problem-solving with students for the first time could take time and demand more teachers' effort; however, this process is not about speed but creating a learning environment where students feel able to make mistakes and ask questions [11]. The learning module promoted in this study was expected to help teachers more easily create a mathematics problem-solving learning experience for students.

Meanwhile, an important element that has not been thoroughly examined in the school mathematics curriculum is spatial reasoning. Most school curricula tend to emphasize engaging students in mathematics and verbal reasoning; however, they often overlook spatial thinking and reasoning as critical components [12–15]. Spatial reasoning is a component of spatial thinking and involves cognitive processes such as the formation, maintenance, and manipulation of visual-spatial information to solve mathematical problems [16,17]. Spatial reasoning is closely associated with reading skills [18,19], language comprehension [20], and problem-solving skills [21,22], and can also serve as a predictor of misconceptions in mathematics [23]. Studies show that spatial reasoning is one of the essential thinking skills that determines a student's success in mathematics [22,24,25]. It has been discovered that spatial reasoning also involves interpreting and manipulating spatial information for problem-solving and decision-making [26]. The lack of achievement in geometry among students is attributed to their low spatial thinking skills [27,28]. Meanwhile, spatial reasoning has been significantly studied in relation to success in mathematics, particularly in geometry [29]. Moreover, it is a predictor of students' mathematics achievements. Engaging students in spatial reasoning activities can enhance their ability in mathematics problem-solving and higher-order thinking [30,31].

The current mathematics learning modules are unattractive, lack interactivity, and do not integrate problem-solving and spatial reasoning tasks [32,33]. For these reasons, this study focuses on creating a spatially integrated mathematics learning module for seventh-grade junior high school students in the Indonesian context and examining the module's effectiveness in improving students' spatial reasoning and problem-solving by comparing experimental and control groups that employed conventional learning. Seventh grade represents a critical period in cognitive development, during which students begin to transition from concrete to more abstract forms of reasoning [34]. Prior research has shown that spatial reasoning skills develop significantly during early adolescence and are strongly associated with success in geometry learning [29,31]. Therefore, focusing on 7th-grade geometry provides an appropriate context for examining the effectiveness of instructional interventions targeting spatial cognition.

This study was guided by these research questions (RQ):

RQ 1: Is there any significant difference in the students' spatial reasoning between the experimental group and the control group?

RQ 2: Is there any significant difference in the students' mathematics problem-solving between the experimental group and the control group?

These research questions direct this study to examine the strong link between spatial reasoning and mathematical problem-solving among students, with the aim of creating a learning tool that encourages spatial reasoning within an accessible mathematics learning module.

2. Literature review

2.1. The relation between spatial reasoning and problem-solving

Spatial reasoning is a mental process that involves recognizing, generating, inspecting, operating on, and reflecting on spatial objects, images, relationships, movements, and transformations [29]. When solving geometrical tasks, spatial reasoning is defined as understanding and logically explaining solutions using various subject entities, such as geometrical objects, diagrams, measuring tools, or even gestures [35]. The spatial properties considered in this study are (1) spatial orientation, which is the ability to understand different positions in space, and (2) spatial visualization, which involves the ability to manipulate objects mentally [36]. Numerous studies have demonstrated a positive correlation between spatial thinking and mathematical achievement. This is because, in an ideal world, studying subjects like science, mathematics, and social studies should involve significant spatial engagement [37]. To assist students in developing their spatial reasoning skills, teachers can adopt a variety of effective learning strategies. Through the study of visual representations, such as maps and graphs, teachers can help students develop their spatial learning capacity and reap the benefits of this experience [12,37]. Unfortunately, the lack of awareness about the importance of spatial thinking skills in education results in a limited number of countries that incorporate spatial skills into their curricula [38,39]. A longitudinal study conducted by Mulligan et al. [40] indicated that incorporating spatial reasoning in the mathematics school curriculum has a positive impact on students' achievement. This also occurred in Indonesia. Given the demonstrable positive effects of integrating spatial reasoning into mathematics teaching and learning, this study aims to develop an innovative educational tool that incorporates an embedded spatial-reasoning component. The focus of the mathematics school curriculum in Indonesia is mathematical problem-solving, which is the process of solving non-routine mathematics tasks using a problem-solving technique [41].

In mathematics education, a problem is typically defined as a non-routine task for which the solution pathway is not immediately apparent to the solver. Effective mathematical problem-solving involves a set of interrelated cognitive processes, including problem representation (e.g., drawing figures), analogical reasoning through related problems, problem reformulation, and systematic testing and verification of solutions [41]. As such, mathematics learning is inherently linked to the development of problem-solving ability, which is a central goal of mathematics education. Successful problem-solving performance is grounded in students' existing mathematical knowledge structures, as individuals draw upon their prior knowledge and experiences to interpret and resolve unfamiliar tasks [41]. Consequently, the design of problem-solving instructions requires careful consideration of the classroom context, including students' prior knowledge and typical learning behaviors. Tasks are considered genuinely challenging when students do not immediately know how to proceed and must engage in strategic reasoning rather than routine computation [35,36]. Importantly, the difficulty of a mathematical problem should constitute an intellectual impasse, requiring conceptual understanding and strategic decision-making, rather than mere computational complexity [34,37]. Thus, the design of effective problem-solving tasks involves creating intellectually demanding situations that prompt students to activate, adapt, and extend their mathematical knowledge and problem-solving strategies. Given the importance of spatial reasoning and problem-solving in mathematics education, this study aimed to integrate these cognitive aspects to provide valuable insights for teachers.

Spatial reasoning and mathematical problem-solving are closely intertwined cognitive processes, particularly in domains such as geometry, where the ability to represent, manipulate, and transform spatial information is essential. Spatial reasoning supports problem-solving by enabling learners to construct accurate mental representations of mathematical situations, identify relevant relationships, and anticipate the consequences of transformations, all of which are critical for effective solution strategies [16,42]. From a cognitive perspective, spatial reasoning facilitates the integration of visual–spatial information with symbolic and numerical knowledge, thereby reducing cognitive load and supporting schema construction during problem-solving tasks [40]. Empirical research has consistently demonstrated that individual differences in spatial ability are significantly associated with performance in mathematical problem-solving, including success in non-routine and complex tasks [14,30]. Consequently, spatial reasoning is increasingly recognized not merely as an auxiliary skill but as a foundational cognitive mechanism that underpins mathematical problem-solving across developmental levels and instructional contexts.

2.2. Spatial reasoning integration in the mathematics learning module

This study aimed to develop a mathematics learning module with a focus on geometry for 7th-grade junior high school students. Based on the Indonesian school curriculum, the geometry materials for 7th-grade junior high school students focused on plane geometry, including triangles and quadrilaterals. However, due to study limitations, the developed module would be designed to focus on the perimeter and area of triangle and quadrilateral materials. The developed mathematics learning module was designed by adapting the four module aspects (content, design, usability, and interactivity) based on Foster et al. [6] and integrated with GeoGebra to enhance interactivity and visualization, as shown in Figure 1.

Moreover, the design of the module was adjusted to the learning environment, which was limited by the supporting infrastructure, such as internet connections and digital learning media. Therefore, the developed learning module was designed as a digital learning resource in PDF format, allowing teachers and students to access it using smartphones. Spatial reasoning theory was also incorporated as a key aspect of the module, alongside mathematics problem-solving. Combining these two cognitive skills in the module was part of developing performance objectives and testing strategies, meaning that activities within the module were designed to support and enhance students' spatial reasoning and mathematics problem-solving.

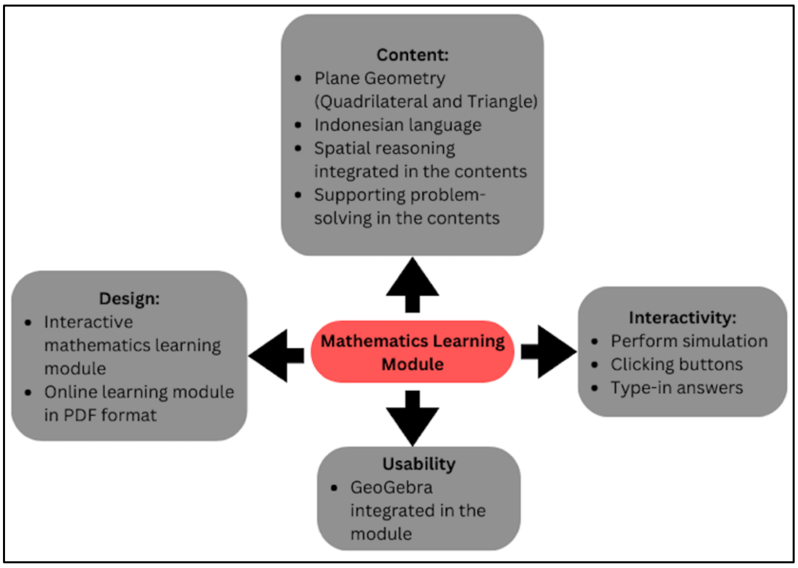

Figure 1. Design of the mathematics learning module.

3. Methodology

3.1. Participants of the study

This study examined the impact of implementing a mathematics learning module with spatial integration for 7th-grade junior high students in Indonesia. Two public junior high schools in Mojokerto, East Java Province, Indonesia, participated. A convenience sampling method was used to select teachers and 7th-grade students as participants. A total of 225 students and four mathematics teachers participated willingly in the study. The students were divided into two groups: an experimental group (n = 115) and a control group (n = 110). All participating teachers met the study's inclusion criteria, namely senior junior high school mathematics teachers with more than 10 years of teaching experience and a minimum qualification of a bachelor's degree in mathematics education. Each teacher was assigned to instruct one matched pair of classes—one experimental and one control—resulting in a total of eight classes, comprising four experimental and four control groups. Teachers in the experimental condition implemented the spatially integrated mathematics learning module, whereas teachers in the control condition used conventional instructional methods. This design was intended to minimize threats to internal validity.

3.2. Design of the study

Data from both the pre-test and post-test were collected simultaneously from the control and experimental groups.

Experimental Group	RO_1	X	RO_2
Control Group	RO_3		RO_4

Figure 2. The pre-test–post-test control group design (adopted from [43]).

The symbols represent different meanings based on the variables studied. X denotes the exposure of experimental groups to an experimental variable, which is the effect of implementing the spatial integrated mathematics learning module in this study. O refers to the observation process during the implementation phase, and observations were conducted on both groups. Lastly, R indicates assignments to separate treatment groups, including the pre-tests and post-tests that measure spatial reasoning and mathematics problem-solving in both groups.

3.3. Instruments

Two test instruments were used in this study. The instruments employed for assessing spatial reasoning included the Spatial Reasoning Instrument (SRI), developed by [44]. The SRI examined three students' spatial skills, including spatial orientation, visualization, and mental rotation. The SRI [44] consists of 30 multiple-choice items and is used to gather information regarding students' spatial reasoning. The SRI is not a predominant speed test, so students are given 45 minutes to complete the test. Mathematics problem-solving assessments were adapted from Programme for

International Student Assessment (PISA) problems from the years 2018 [45] and 2022 [46]. This study used a five-problem mathematics problem-solving test, giving students approximately 45 minutes to an hour to complete it. The spatial reasoning and mathematics problem-solving tests were administered as pre- and post-tests to assess the differences in students before and after the intervention.

3.4. Spatial integrated mathematics learning module

The product developed in this phase was a mathematics learning module with spatial reasoning as a key component. The spatially integrated learning module was designed as an interactive tool that allows students to operate it easily, with GeoGebra used as a supporting medium. While emphasizing spatial reasoning, the module also incorporated mathematics problem-solving. Formative evaluation processes were conducted to ensure the product was developed effectively. Several mathematics education experts served as validators who assessed the quality of the mathematics learning module using questionnaires focused on three areas: (1) design, including the appearance, colors, text choices, format, and image suitability; (2) content, including the appropriateness of the learning materials, their relevance to the students and learning objectives, the supporting learning activities for the targeted cognitive skills, and the suitability of selected images as illustrations; and (3) supporting media, confirming that all GeoGebra materials aligned with the module's content.

The Aiken's validity index [47,48] was used to determine the degree of agreement among validators regarding the relevance of each item to the construct being measured in this study. Meanwhile, Cronbach's alpha coefficient for the reliability was based on [49].

Table 1. Evaluation results.

Module aspects	CVI/Ave	Interpretation of CVI	Cronbach's alpha	Interpretation of Cronbach's alpha
Design	0.83	Valid	0.95	Excellent
Contents	0.76	Valid	0.96	Excellent
Supporting media	0.84	Valid	0.95	Excellent

Evaluation results are presented in Table 1, illustrating that the results were generally valid, with a validation value exceeding 0.4 and an excellent reliability index, as determined by the experts' evaluations. The figures below illustrate an example of spatially integrated content within the module, highlighting how GeoGebra serves as the innovative element for interactivity. Figure 3 presents a module focused on spatial reasoning. Developed in Indonesian, it encourages students to conceptualize designing a city with a police station at its core. The task assigned to students involves calculating angles between structures, supported by accompanying narratives. Meanwhile, Figure 4 illustrates how GeoGebra is used in the module and how students access the content. Students need to click the provided buttons in the module, as shown in the picture, and it will automatically direct them to the content in GeoGebra. All the content provided in GeoGebra was designed to align with the module's content and purposes.

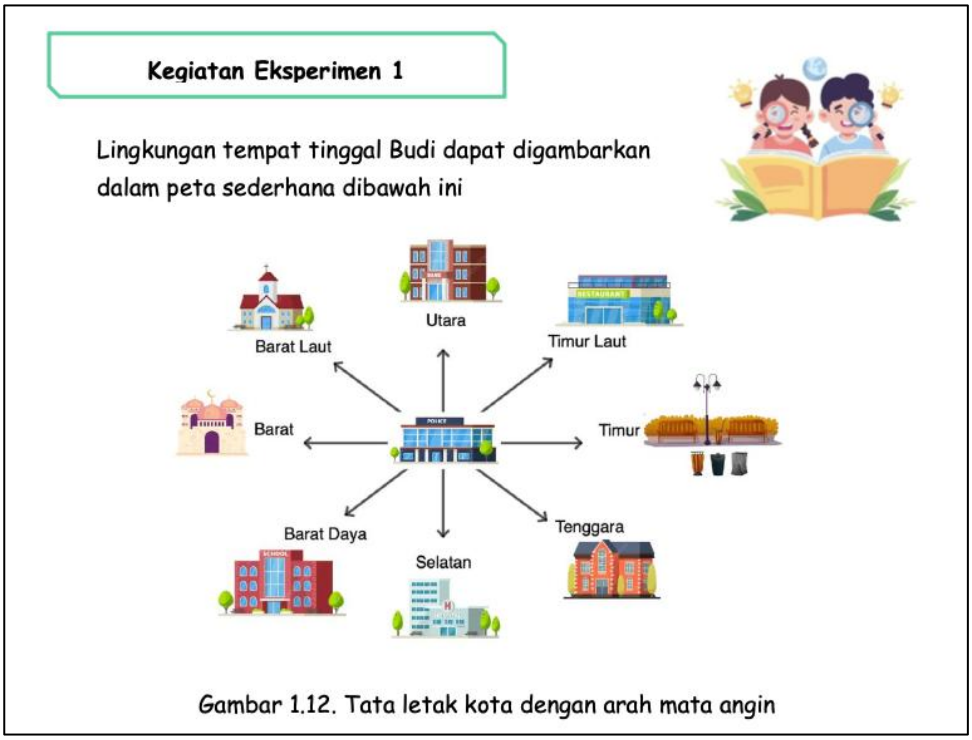

Figure 3. Activity for students with spatially integrated content (in Indonesian).

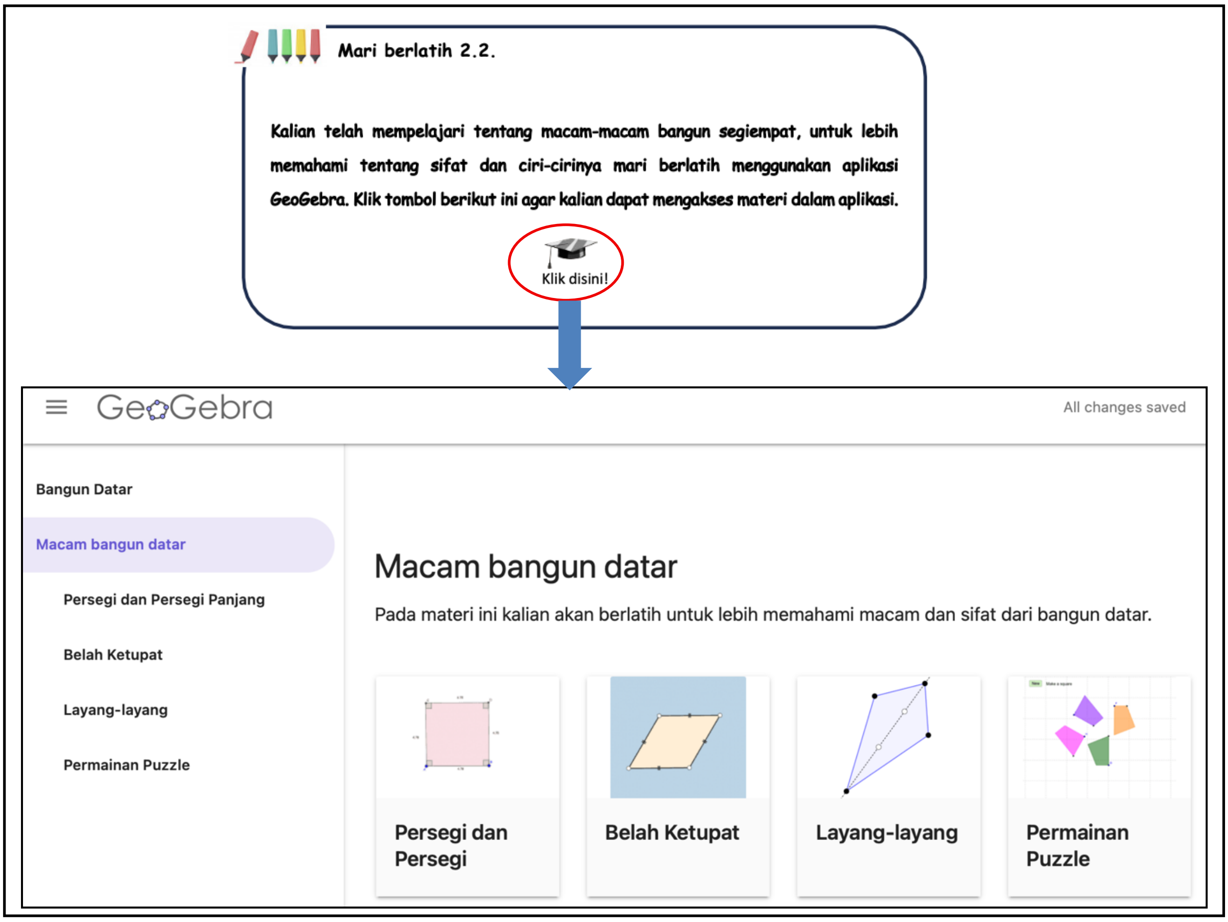

Figure 4. The use of GeoGebra as the supporting media.

3.5. Spatial training for teachers

To prepare teachers for implementation, a spatial training program was conducted to enhance their knowledge and competencies related to spatial learning in mathematics. The program also included guidance on how to utilize the newly developed mathematics learning module, as it was an innovative tool for them. The training lasted two weeks, considering the time constraints. Nevertheless, previous research has demonstrated that spatial thinking is adaptable [24,46], and even brief training sessions, such as a 40-minute spatial training [42], can have a positive impact on spatial abilities and mathematics achievement. Structured as a discussion forum, the training aimed to equip teachers with essential skills, particularly in spatial reasoning, prior to the integration of the mathematics module into classroom instruction. All teachers who participated in this study engaged in discussions at the conclusion of each session to identify potential challenges and collaboratively develop solutions. The training was structured as a discussion forum to help teachers develop essential skills and knowledge, especially in spatial reasoning, before implementing the new learning module in the classroom. The schedule and materials for the teachers are shown in Table 2.

Table 2. Training schedule and materials for the teachers.

Schedule	Training topic
Week 1	1. Introducing teachers to spatial reasoning. 2. What are the essential aspects of spatial reasoning? 3. Provide examples of how to incorporate spatial reasoning into learning activities. 4. Explaining the learning objectives of the new module. 5. Introducing parts of the new learning module with spatial reasoning aspects. 6. Discussion session.
Week 2	1. Introducing and explaining parts of the new learning module with spatial reasoning aspects. 2. Introducing and explaining parts of the learning module with mathematics problem-solving aspects. 3. Introducing GeoGebra and how to access the materials. 4. Explaining how to use the embedded GeoGebra in the learning module. 5. Discussion session.

3.6. Data analysis

Data analysis was conducted using SPSS version 29.0.2. Analysis of covariance (ANCOVA) was used to evaluate the effectiveness of the spatially integrated mathematics learning module by examining the significant differences between the experimental and control groups in students' spatial reasoning and mathematics problem-solving. The gain scores from pre- and post-tests were included in the ANCOVA analysis, with pre-tests as the covariate. The gain score is a highly reliable measure of the effect of an experimental treatment or period of instruction [51].

4. Results

The results demonstrate how employing a spatially integrated mathematics learning module enhances students' spatial reasoning and their ability to solve mathematical problems. This study compared two groups of students, the experimental group and the control group, to evaluate the effectiveness of the spatially integrated mathematics learning module. The innovative module was used to teach the experimental group, while a conventional learning method was applied to the control group. Both approaches were implemented over approximately three months in each group. At the end of the program, students in both groups took post-tests to assess their achievement, including spatial reasoning and mathematics problem-solving. The statistical analysis was conducted using SPSS version 29.0.2.0, and an ANCOVA analysis was performed, with the pre-test results used as the covariate. Data met certain assumptions, such as normality and homogeneity, before conducting the ANCOVA analysis. The gain scores were calculated by finding the difference between pre-test and post-test scores for both the spatial reasoning and problem-solving tests.

4.1. Effectiveness of the mathematics learning module with spatial integration on students' spatial reasoning

An ANCOVA statistical analysis was performed to assess the effectiveness of the mathematics learning module on students' spatial reasoning. The gain score of the pre- and post-tests for spatial reasoning from both the experimental and control groups was analyzed using ANCOVA, with the pre-test serving as the covariate. The normality of the data was assessed by considering the Skewness and Kurtosis values of both the experimental (1.069 and 0.42) and control groups (0.56 and 1.152), with Q-Q plots provided for both groups (Figure 3). The data can be considered normally distributed if the values of Skewness and Kurtosis lie between -2 and 2 [51,52].

Table 3. Levene's test for homogeneity of spatial reasoning gain scores.

F	df1	df2	Sig.
30.951	1	223	<0.001

Note: Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

The homogeneity test result from Lavene's test was significant ($F = 30.951$, $p < 0.05$). In this case, the p-value was less than 0.001, indicating that the null hypothesis is rejected. This means the variances of the dependent variable were not equal across groups (experiment and control). Levene's test indicated a violation of homogeneity; however, due to the small difference in student numbers between the two groups, the violation of the homogeneity assumption could be ignored. If the cell sizes (number of data) are nearly equal, then the violation of homogeneity indicated by ANCOVA Levene's test may not be a major concern [53]. Since all ANCOVA assumptions were satisfied, further steps could be taken. The table below presents the results of the ANCOVA on the gain score of the spatial reasoning test, with the pre-test as the covariate.

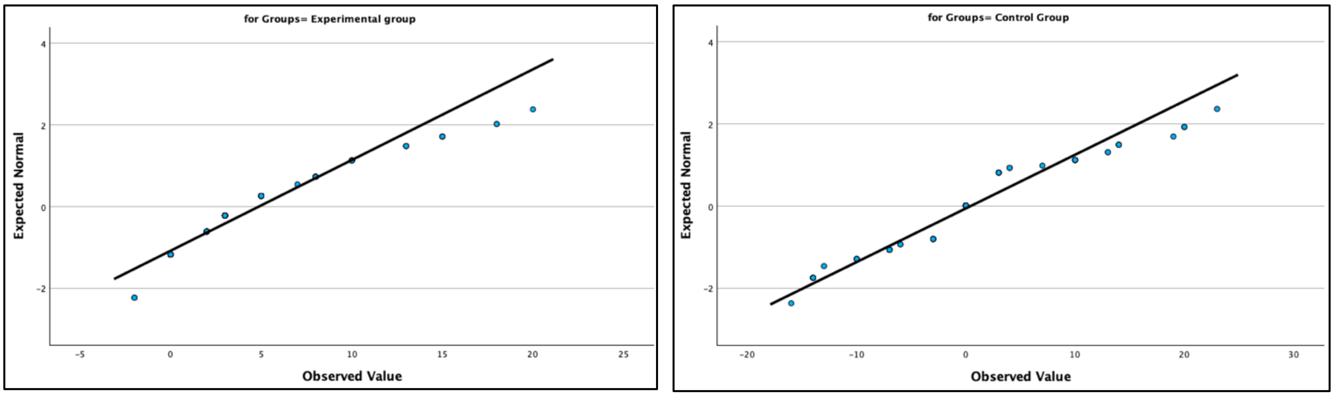

Figure 5. Q-Q plot for spatial reasoning.

The ANCOVA results showed a statistically significant effect of group on students' spatial reasoning [F (1, 222) = 23.80, p < 0.001], with a partial Eta squared of 0.097, indicating a moderate effect size. This suggests that group membership explained approximately 9.7% of the variance in spatial reasoning scores after controlling for the covariate [43,53].

Table 4. ANCOVA analysis results for students' spatial reasoning.

Source	Type III sum of squares	df	Mean square	F	Sig.	Partial Eta squared (η^2)
Corrected model	4807.317[a]	2	2403.658	106.575	<0.001	0.490
Intercept	4068.048	1	4068.048	180.372	<0.001	0.448
Groups	536.679	1	536.679	23.796	<0.001	0.097
Error	5006.905	222	22.554			
Total	11441.000	225				
Corrected total	9814.222	224				

[a]R-squared = 0.490 (adjusted R-squared = 0.485).

Further investigation is required to ascertain which group performed more effectively, and the estimated marginal means illustrate the differences. The table below presents the mean comparison of the spatial reasoning gain score tests between the experimental and control groups, showing that the experimental groups outperformed the control groups, as indicated by the higher means.

Table 5. Estimated marginal means of the spatial reasoning gain score test.

Groups	Mean	Std. error	95% confidence interval	
			Lower bound	Upper bound
Experimental group	4.219[a]	0.446	3.341	5.097
Control group	1.089[a]	0.456	0.191	1.988

[a]Covariates appearing in the model are evaluated at the following values: spatial reasoning (pre-test) = 86.71.

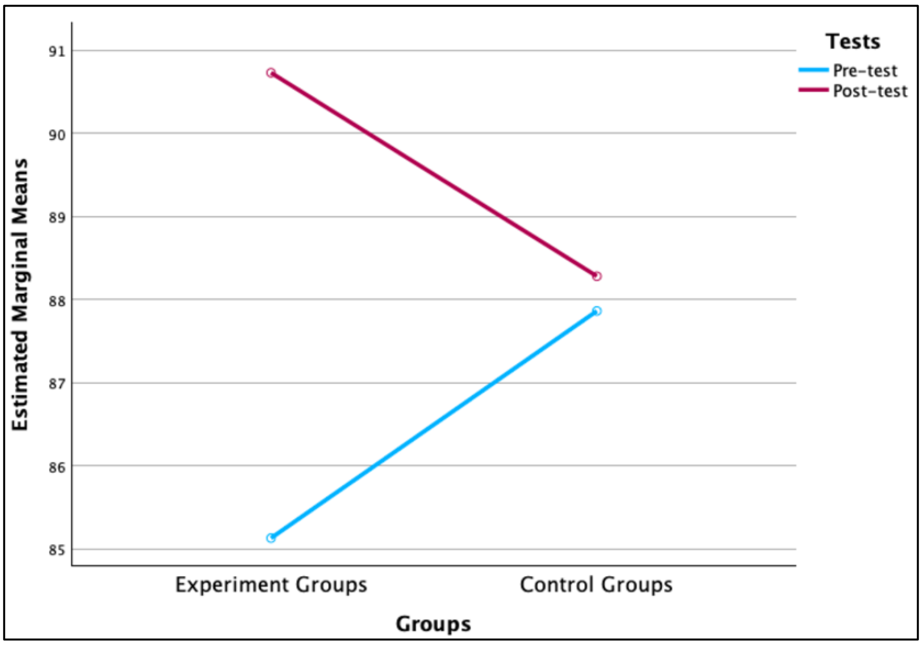

Figure 6. Comparison of the experimental and control groups' spatial reasoning test results.

Figure 6 shows the changes in students' spatial reasoning before and after the intervention by comparing the pre- and post-test results. As shown in the graph, students in both the experimental and control groups improved their spatial reasoning test scores. However, there is a clear improvement in the experimental group, despite its initial lower pre-test score compared to the control group. Overall, there was a statistically significant difference between the experimental and control groups in spatial reasoning gain scores, with the experimental group outperforming the control group. This also suggests that the intervention, which utilized the mathematics learning module with spatial integration, was effective in improving students' spatial reasoning.

4.2. Effectiveness of the mathematics learning module with spatial integration on students' mathematics problem-solving

The same procedures were used to examine the effectiveness of the mathematics learning module with spatial integration on students' mathematics problem-solving. The gain score of the data, including problem-solving pre- and post-tests, must meet the normality and homogeneity assumptions before we can conduct an ANCOVA analysis. The problem-solving test gain scores were normally distributed, as indicated by the Skewness and Kurtosis values [51,52] of the data for both experimental (-0.373 and 0.623) and control groups (-0.019 and -0.531), with Q-Q plots provided for both experimental and control groups.

Since all testing assumptions for ANCOVA were met, further analysis could proceed. The table below shows the ANCOVA results for the problem-solving gain score, with the pre-test as the covariate. The results indicate a statistically significant effect of group on problem-solving scores [$F(1, 222) = 90.94$, $p < 0.001$]. The partial Eta squared for the group effect was 0.291, meaning that approximately 29.1% of the variance in students' problem-solving was explained by the group after controlling for the covariate, showing a significant practical effect. Further examination of the estimated marginal means is needed to determine which groups performed better.

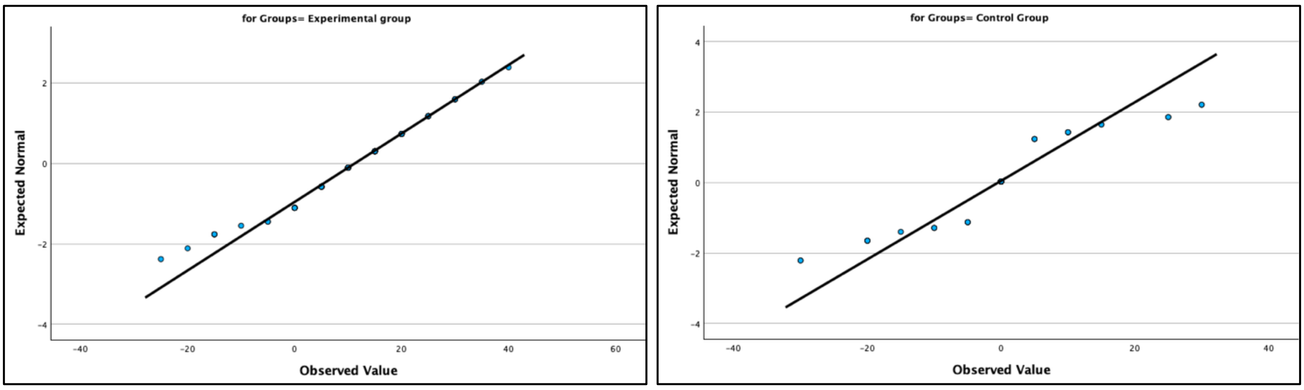

Figure 7. Q-Q plot for mathematics problem-solving.

Table 6. ANCOVA analysis results for students' problem-solving.

Source	Type III sum of squares	df	Mean square	F	Sig.	Partial Eta squared (η^2)
Corrected model	13718.446[a]	2	6859.223	81.925	<0.001	0.425
Intercept	8531.410	1	8531.410	101.897	<0.001	0.315
Groups	7613.668	1	7613.668	90.936	<0.001	0.291
Error	18587.109	222	83.726			
Total	39250.000	225				
Corrected total	32305.556	224				

[a]R-squared = 0.425 (adjusted R-squared = 0.419)

Table 7 shows the average problem-solving gain scores for the experimental and control groups, indicating that the experimental groups performed better with significantly higher averages. The negative mean value in the control groups suggests there was no improvement in students' problem-solving test scores before and after the intervention.

Table 7. Estimated marginal means of problem-solving gain scores.

Groups	Mean	Std. error	95% confidence interval	
			Lower bound	Upper bound
Experimental group	11.245[a]	0.853	9.564	12.927
Control group	-0.393[a]	0.872	-2.112	1.327

[a]Covariates appearing in the model are evaluated at the following values: problem-solving (pre-test) = 45.76.

These findings are highlighted in Figure 8, which shows a significant increase in problem-solving skills in the experimental groups, while a decrease occurred in the control groups. Overall, the results suggest that implementing the mathematics learning module with spatial integration had a positive effect on students' problem-solving skills.

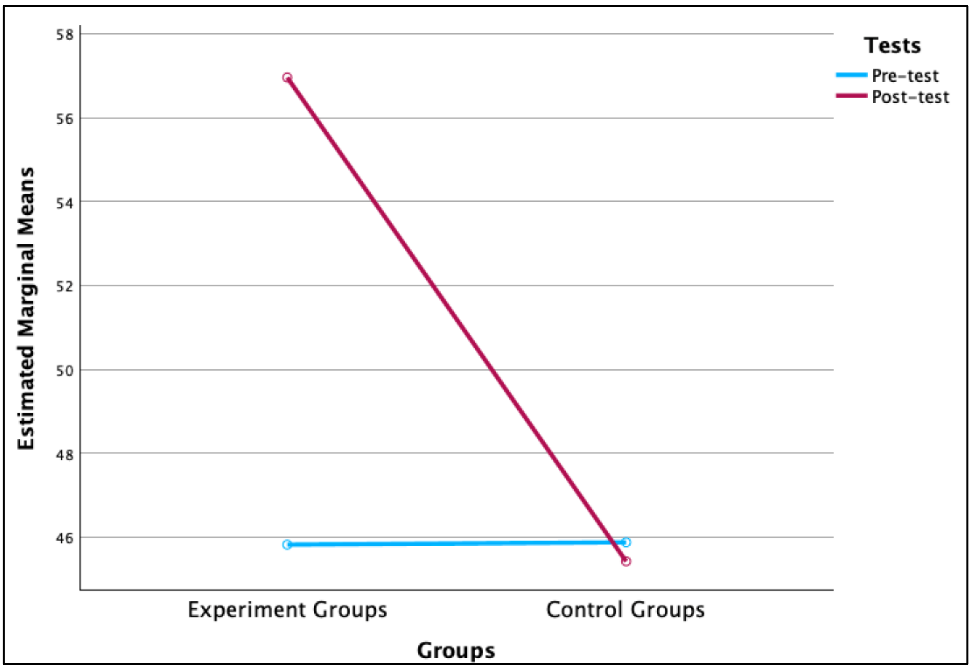

Figure 8. Comparison of the experimental and control groups' problem-solving test results.

5. Discussion

The learning module for this study was designed as an online learning module in PDF format, and its interactivity and usability were enhanced by GeoGebra as a supporting learning medium. The use of online learning modules has been proven by previous studies to effectively enhance student engagement during the learning process [54–56], especially in distance learning environments [57]. Moreover, GeoGebra was selected as the learning media for its illustrations and interactivity, which enhance students' spatial reasoning [58,59].

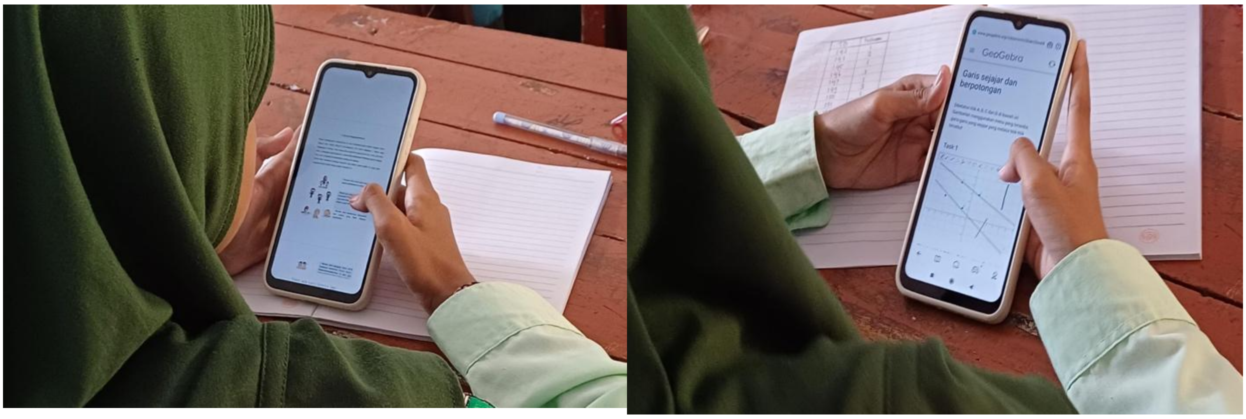

Figure 9. Interactive mathematics learning module.

GeoGebra assists students in visualizing geometric shapes and understanding how to manipulate them mentally. It significantly helps students to improve in spatial reasoning since visualization is the most challenging part of the spatial reasoning aspects [44]. The results show a significant difference between the experimental and control groups in improving students' spatial reasoning and mathematics problem-solving skills, with the experimental group performing better. The implementation of the mathematics learning module with spatial integration shows a positive effect on students' cognitive abilities, including spatial reasoning and mathematics problem-solving. These findings align with previous research, which suggests that implementing a spatial learning intervention benefits students' spatial reasoning and skills. A study by Winarti et al. [60], conducted in the Indonesian context, demonstrated that spatialized mathematics learning for middle school students resulted in significant improvements in both mathematics performance and spatial visualization skills—components of spatial reasoning—in the experimental group compared to the control group, who followed a traditional curriculum.

The results revealed a significant difference in problem-solving skills between the experimental and control groups. The comparison shows that students who used the learning module performed better in problem-solving than those in a traditional teaching setting. This study's findings regarding mathematics problem-solving align with a previous study conducted by Lawson & Chinnappan [61], which showed that students' problem-solving skills can be enhanced through involvement in geometry-related problems. The notable distinction between the experimental and control groups further demonstrates that incorporating spatial reasoning into the mathematics learning module effectively facilitates students' mathematical understanding and bolsters their cognitive skills. Hwang et al. [62] carried out another study with similar results, highlighting the vital connection between geometry and spatial reasoning in the learning intervention, which improved students' geometry skills. Although this study focused on the positive effects of spatially integrated mathematics learning on geometry performance, Mulligan et al. [40] also demonstrated that integrating spatial reasoning into mathematics education can have a positive influence on other mathematics skills, such as number concepts, measurement, patterns, and data representations. However, to achieve the best results from spatial learning in mathematics, teachers must understand how to effectively deliver it. Unfortunately, spatial learning is often not fully considered in mathematics instruction [22,33]. As a result, many mathematics teachers do not understand what spatial learning is or how to teach it to students.

Although the intervention had a statistically significant effect on both outcomes, the magnitude of the effect differed substantially. The effect on spatial reasoning was small to medium (partial $\eta^2 = 0.097$), indicating that group membership accounted for approximately 9.7% of the variance after controlling for the covariate. In contrast, the effect on problem-solving was large (partial $\eta^2 = 0.291$), explaining 29.1% of the variance. This suggests that the intervention was more effective in enhancing students' problem-solving skills than their spatial reasoning abilities. One possible explanation is that, besides spatial reasoning being a new term for both teachers and students, the instructional activities emphasized procedural reasoning, strategy use, and problem-solving practice more directly than spatial manipulation tasks. As a result, improvements in problem-solving were more pronounced, while gains in spatial reasoning may require longer or more targeted interventions. Providing spatial training to teachers was essential since they would be responsible for leading the learning processes, as indicated by these findings. This study implemented training lasting less than two weeks, which is an important factor to consider. Another study demonstrated the effectiveness of a spatial visualization training program over a three-week period [63], while a similar six-week spatial training study in mental rotation found that the training improved mental rotation skills [26]. The spatial training for teachers in this research received positive feedback, as it equipped teachers with valuable information to improve the quality of mathematics instruction.

6. Limitations of the study

Several limitations of this study should be acknowledged. First, the issue of sample representativeness warrants consideration. The participants consisted of teachers and seventh-grade students drawn from two junior high schools in Indonesia. Although this sampling approach was appropriate for the experimental design and the targeted educational context, it may limit the generalizability of the findings to other grade levels, school settings, or cultural contexts. Future studies involving more diverse samples across multiple regions and school types would strengthen the external validity of the results. Second, the scope of the mathematics content addressed in the learning module was limited. The module was designed to integrate spatial reasoning within seventh-grade geometry topics aligned with the Indonesian curriculum, specifically perimeter and area of triangles and quadrilaterals. While this focused scope allowed for in-depth investigation of spatial integration in geometry instruction, it constrains the extent to which the findings can be generalized to other mathematical domains. Further research examining the integration of spatial reasoning across a broader range of mathematical topics is therefore recommended. Third, implementation-related factors should be considered. Although participating teachers met predefined inclusion criteria and implemented the module as intended, variations in instructional delivery and fidelity of implementation may have influenced student outcomes. Future research could benefit from more systematic monitoring of teacher training and instructional fidelity. Finally, while the spatial reasoning instrument demonstrated acceptable psychometric properties, the construct validity of the measure may be further strengthened through the use of multiple assessment methods or triangulation with qualitative data. Addressing these limitations in future studies would help to provide a more comprehensive understanding of the role of spatial reasoning in mathematics learning.

7. Conclusions

This investigation shows that spatial integration within the mathematics learning module improves students' spatial reasoning and math problem-solving skills. The study assessed the effectiveness of the learning module in enhancing students' cognitive abilities in three areas: spatial reasoning and mathematics problem-solving. This was achieved by comparing two groups during implementation: the control group, which experienced traditional learning environments, and the experimental group, which used the mathematics learning module. Overall, there was a statistically significant difference between the groups in the gain scores for both spatial reasoning and mathematics problem-solving, with the experimental group performing better. At the classroom level, teachers can operationalize this integration by systematically incorporating visual representations, diagram-based reasoning, and spatially oriented tasks into daily instruction and assessment, thereby supporting students' development of transferable problem-solving skills.

8. Implications

This research focuses on the process of examining the effectiveness of a mathematics learning module with spatial integration, which has been shown to have a beneficial impact on students' spatial thinking and mathematical problem-solving. To enhance students' understanding of geometry, the learning module utilized GeoGebra as the learning medium, which incorporates spatial learning features. Integrating spatial concepts in mathematics learning modules has the potential not only to increase the level of engagement among students but also to broaden the information that instructors have about learning that is integrated with spatial thinking. Due to its strong connection to geometric reasoning [29] and potential as a new teaching intervention for instructors [64], spatial reasoning can be beneficial when delivering geometry materials.

Author contributions

All authors contributed to this study, including most of the research work, the experiments, the data analysis, and the manuscript.

Use of Generative-AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

The authors did not disclose any potential conflicts of interest.

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Ethics declaration

This research has received approval from the Universiti Malaya Research Ethics Committee (UMREC), with the approval code UM.TNC 2/UMREC.

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