

FROM IMAGES TO UNDERSTANDING: INFOGRAPHICS AS AN EFFECTIVE TOOL FOR SHAPING CHILDREN'S SPATIAL THINKING IN GEOGRAPHY

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Abstract: This study investigated the effectiveness of infographic-based learning in developing spatial thinking skills among primary students and examined the sustainability of these skills over time in geography learning environments. A quasi-experimental design was employed with an experimental group (n = 50) and a control group (n = 50) from private schools in the Al-Ahsa region of Saudi Arabia. Spatial thinking skills were assessed using a structured test, with pre-test scores serving as a covariate to control for initial differences between groups. Analysis of Covariance (ANCOVA) was conducted to determine the immediate impact of the intervention, while a paired samples t-test evaluated skill retention three months post-intervention. The results revealed that students in the experimental group, who received geography learning using infographics, achieved significantly higher adjusted post-test scores across all spatial thinking domains compared to their peers in control group, with large effect sizes (η^2 ranging from 0.64 to 0.95). These findings indicate that integrating visual and textual information through infographics facilitates meaningful learning, enhances students' ability to construct mental representations of spatial concepts, reduces cognitive load, and promotes higher-order thinking skills. The delayed post-test results further demonstrated stable or slightly improved performance, confirming that infographic-based learning supports the long-term retention and sustainability of spatial thinking skills. Pedagogically, the study contributes by demonstrating how infographic-based instruction can integrate foundational and complex spatial skills, strengthen cognitive processing, and provide teachers with an effective tool for enhancing students' spatial reasoning and problem-solving abilities. Based on these findings, it is recommended to incorporate infographic-based approaches into primary education curricula, train teachers in effective infographic usage, and adopt diverse assessment strategies, including observational and qualitative methods, to complement traditional tests. Overall, the study provides compelling evidence that infographic-based learning is an effective and sustainable pedagogical approach in geography teaching and learning, offering practical implications for curriculum design, instructional strategies, and educational innovation.

Keywords: Geography learning, infographic-based learning, spatial thinking skills, primary education, instructional intervention, skill retention, cognitive development

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INTRODUCTION

Thinking skills represent one of the fundamental pillars of modern education, aiming to enable children to process information, analyze it critically, and solve problems creatively from the earliest stages of learning. These skills form the foundation for developing children's capacity for self-directed learning, exploring their surroundings, and interacting with information from diverse and reliable sources (Fraihat et al., 2022; Hawamdeh et al., 2025).

Thinking skills encompass multiple domains, including critical, creative, logical, and spatial thinking. Among these, spatial thinking is particularly significant, as it allows children to visualize relationships between locations and geographical phenomena, analyze spatial patterns, and interpret environmental data deeply.

This capability equips children to make informed decisions in various contexts, linking theoretical knowledge to practical realities (AlAli & Al-Barakat, 2025; Santos et al., 2025; Shokhrukh et al., 2025). Developing these skills is therefore an educational imperative, as learning should extend beyond memorization to include independent thinking, problem-solving, and the ability to connect knowledge to everyday situations innovatively (Al-Hassan et al., 2012; Permanadewi et al., 2026; Sagatbayev et al., 2026). Research indicates that fostering thinking skills in children requires

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more than the mere presentation of information; it necessitates practical, interactive learning experiences that actively engage students in connecting theory to real-world contexts. When children participate in activities that involve observation, comparison, analysis, inference, and hands-on experimentation, they develop critical thinking and systematic problem-solving abilities (Kim & Bednarz, 2013; Ridha & Kamil, 2021; Thomas et al., 2024; Žoncová et al., 2026). In the context of geography education, spatial thinking is essential not only for memorizing locations or reading maps but also for understanding complex interrelationships between natural and human phenomena, analyzing them, and situating them within spatial and temporal contexts (Burlingame, 2023; Cho et al., 2026; Costley et al., 2026; Filipe et al., 2025). Spatial thinking requires children to accurately represent patterns and directions, interpret maps, diagrams, and charts, and link events and phenomena to their surrounding reality (Amagir et al., 2018; Angeli & Valanides, 2020; Aprilyanti & Wulansuci, 2023). Through these processes, children develop clear mental representations of locations and phenomena, analyze spatial distributions, predict environmental or social changes, and solve problems methodically and systematically (Duarte et al., 2022; Ridha & Kamil, 2021; Yang et al., 2020; Zhang et al., 2022).

Moreover, spatial thinking enables children to apply theoretical geographical concepts to practical scenarios, such as determining suitable areas for settlement or agriculture, analyzing human impacts on the environment, and understanding climatic and geographical patterns to make informed decisions (Gold et al., 2018; Kim et al., 2012; Zhang et al., 2022). It also helps children detect hidden patterns, identify relationships between phenomena, and employ visual representation tools to better interpret data, thereby enhancing their independent spatial reasoning and inferential skills (Ardoin & Bowers, 2020; Bakken et al., 2017). Previous studies suggest that nurturing spatial thinking contributes directly to improved quality of geographic learning, strengthens critical and creative thinking skills, and allows children to integrate theoretical knowledge with practical experiences (Ardoin & Bowers, 2020; Bakken et al., 2017; Gold et al., 2018; Kim et al., 2012; Kim & Bednarz, 2013). Additionally, it fosters self-directed learning, enhances the analysis of complex spatial problems, encourages innovative solutions, and deepens understanding of environmental and social patterns, making spatial thinking a central tool for cultivating comprehensive cognitive skills and preparing children to navigate real-life challenges effectively (Duarte et al., 2022; Gajić et al., 2025; Haque et al., 2026; Ridha & Kamil, 2021; Yang et al., 2020; Zhang et al., 2022).

Visual and interactive learning environments play a pivotal role in developing spatial thinking, offering children educational tools to visualize relationships between phenomena, analyze patterns, and understand connections within both natural and human environments (Mambrey et al., 2022; Mani et al., 2026; Matovu et al., 2023; Rütth et al., 2021; Wu et al., 2021; Zhang et al., 2026; Koç & Kanadli, 2025). Such environments transform theoretical information into tangible, experiential learning, facilitating comprehension and enabling application in new contexts.

Research demonstrates that children exposed to visual and interactive learning experiences achieve deeper understanding of spatial concepts and greater analytical skills compared to those taught through traditional methods (Filipe et al., 2025; Duarte et al., 2022; Gold et al., 2018; Kim et al., 2012).

Among visual educational tools, infographics have emerged as a highly effective and innovative medium, combining text, symbols, colors, and charts to present information in a visually appealing and simplified manner (Mistry, 2026; Zulaikah et al., 2026). Infographics provide children with opportunities for active learning, self-discovery, organized analysis of spatial information, and accelerated comprehension of complex geographical concepts compared to traditional approaches (Kim & Bednarz, 2013; Ridha & Kamil, 2021; Yang et al., 2020; Zhang et al., 2022). They enhance visual thinking, facilitate the integration of different spatial phenomena, and stimulate student engagement, initiative, and motivation. Moreover, infographics support long-term retention of information, foster sustainable spatial thinking skills, and increase focus and active participation in learning activities (Al-Halalat et al., 2024; Al-Hassan et al., 2012; Huseynov et al., 2025; Keller, 2026).

Despite these advantages, the literature reveals a notable gap in research examining the effectiveness of infographics in developing spatial thinking among typically developing primary school children, particularly in Arab contexts (Santos et al., 2025; Shokhrukh et al., 2025). Most previous studies focused on immediate comprehension or relied on traditional teaching methods without integrating spatial thinking with innovative visual tools.

Few studies investigated the sustainability of learning outcomes over time or children's ability to apply spatial concepts in new and complex real-life situations. This gap underscores the need for research that systematically combines visual learning with spatial thinking and evaluates its long-term effectiveness.

This study seeks to address this gap by providing a clear and unique contribution to the field of spatial thinking education for children, through the integration of infographics as an innovative teaching tool within geography lessons (Filipe et al., 2025). It aims to clarify the role of infographics in enhancing children's ability to visualize and analyze spatial phenomena, understand complex geographical patterns, and develop independent, systematic thinking, while assessing the sustainability of these effects over time. Unlike previous studies, this research integrates spatial thinking skills with an innovative educational medium and evaluates its short- and long-term impacts within a practical Arab context - a perspective rarely explored in prior research. Consequently, the study offers a practical framework for primary classrooms to inform educational policies and instructional strategies that promote spatial thinking among children.

Accordingly, the main research question was formulated as follows: *What is the effect of using infographics as an educational tool on the development of spatial thinking skills among children while learning geographical concepts?* The following sub-questions were derived to further clarify the study's objectives:

1. What is the effectiveness of infographic-based learning in developing spatial thinking skills among typically developing primary school children at a significance level of ($p = 0.05$)?
2. To what extent is the effect of infographic-based learning on spatial thinking skills sustained three months after the intervention, at a significance level of ($p = 0.05$)?

LITERATURE REVIEW

Geography education in early childhood is widely recognized as a fundamental pillar for developing children's awareness of the world around them. From the earliest years, geography enables children to understand place, environment, and the spatial relationships that guide their daily interactions with their surroundings (Al-Barakat et al., 2026). The significance of geography education extends beyond the mere acquisition of geographical knowledge; it also nurtures higher-order thinking skills, including observation, analysis, exploration, and the ability to make connections. These skills allow children to comprehend the relationships between natural and human phenomena at both local and global levels, thereby contributing to the formation of an integrated cognitive representation of the world (Nairn & Kraftl, 2016).

Geography education also fosters children's curiosity and inquisitiveness, encouraging them to ask questions about their surroundings, weather, nature, and people. Through this process, children begin to interpret environmental and social phenomena in a simplified yet meaningful way, aligned with their daily experiences. Such learning builds a foundational knowledge base that supports logical thinking and enhances the ability to observe, compare, and classify-key cognitive skills that serve as gateways to analytical thinking and problem-solving in subsequent educational stages (Al-Barakat et al., 2026).

Early childhood geography education typically begins with simple concepts related to the child's immediate environment, such as home, school, neighborhood, and basic directions, and gradually progresses to broader concepts, including geographical regions, weather, landforms, and natural resources. This systematic progression promotes cumulative knowledge building, whereby new concepts are developed based on prior experiences, enhancing retention and deepening understanding. It also equips children to connect diverse geographical information and apply it in practical contexts, establishing a strong foundation for the development of spatial thinking skills-essential for understanding spatial relationships between natural and human elements in the environment (Nairn & Kraftl, 2016).

Through geography education, children develop spatial awareness and gain an understanding of the interactions between humans and their environment. They learn about the characteristics of places, how people utilize resources, and the environmental impact of human behavior. Geography instruction further promotes respect for cultural and social diversity and instills values of citizenship and belonging by helping children understand the location and features of their country within a broader global framework (Al-Barakat et al., 2026). In this context, modern educational approaches emphasize active learning strategies-such as learning through play, illustrated maps, geographic stories, and diverse visual media-which place children at the center of the learning process and cultivate higher-order thinking skills (Al-Barakat et al., 2023).

With the rapid advancement of technology, integrating digital educational tools that leverage visual representation has become a pedagogical necessity (Miao et al., 2022; Nelson & Olander, 2024; Wu et al., 2021; Zhang et al., 2026; Koç & Kanadlı, 2025). These tools provide interactive learning environments that accommodate individual differences among children. Research indicates that such tools enhance learning outcomes, support the development of spatial thinking and problem-solving skills, and strengthen learners' ability to organize and process information visually-aligning with the human brain's natural capacity to process visual information more rapidly and efficiently than textual content (Mani et al., 2026; Matovu et al., 2023; R  th et al., 2021). In this context, infographics have emerged as one of the most effective educational tools, transforming complex information into organized and visually engaging content. Infographics facilitate active learning and enhance both analytical and spatial thinking skills in children.

Educational studies (Miao et al., 2022; Nelson & Olander, 2024; Nairn & Kraftl, 2016; R  th et al., 2021; Wu et al., 2021) demonstrate that using various types of infographics-static, animated, and interactive-improves academic achievement, facilitates the integration of new knowledge with prior experiences, and enables children to visualize patterns and relationships among different concepts. Such visualization forms a foundation for developing spatial thinking skills, which are critical for understanding geographical phenomena and analyzing spatial relationships between natural and human elements (Al-Barakat et al., 2026; Nairn & Kraftl, 2016).

Despite these positive outcomes, literature reviews reveal a gap regarding the impact of infographics on the development of spatial thinking skills in students (Kim & Bednarz, 2013; Nairn & Kraftl, 2016). Most previous studies focused primarily on academic achievement or knowledge retention, overlooking the qualitative dimension of higher-order thinking, particularly spatial reasoning and the ability to analyze relationships among different phenomena.

This underscores the need for research examining how visual information representation, such as infographics, affects students' ability to perceive spatial patterns and analyze relationships among geographical elements (Al-Barakat et al., 2026; Ridha & Kamil, 2021). Spatial thinking skills are foundational for geographical learning, enabling students to comprehend the spatial structure of their environment, analyze temporal changes, and make informed decisions regarding location and resource management (Gold et al., 2018; Kim et al., 2012; Kim & Bednarz, 2013). These skills develop progressively, beginning with basic abilities such as observation and spatial navigation and advancing to complex competencies including spatial analysis and decision-making (Yang et al., 2020; Zhang et al., 2022). Lee & Bednarz, (2012) and Shin et al. (2016) categorized spatial thinking into seven core skills: spatial navigation, mental visualization of locations, recognition of spatial patterns and gradations, understanding spatial interrelationships, comprehension of temporal-spatial changes, spatial prioritization, and hierarchical representation of geographical phenomena.

Several researchers (Duarte et al., 2022; Gold et al., 2018; Kim et al., 2012; Kim & Bednarz, 2013) further identified complementary skills, including spatial comparison, spatial impact assessment, spatial measurement, and spatial analysis, reflecting the progressive complexity of spatial thinking and the need for comprehensive early educational training.

Empirical evidence demonstrates that developing spatial thinking skills significantly enhances students' ability to read maps, interpret visual representations of their surroundings, identify spatial patterns and relationships among phenomena, and analyze changes over time. These competencies enable students to make informed decisions regarding specific

locations and manage spatial resources effectively (Xiang & Meadows, 2025). However, literature reviews indicate that the integration of these skills into educational curricula remains limited, particularly when it comes to innovative instructional tools such as infographics. This reveals a critical research gap, highlighting the need for specialized studies to evaluate the effectiveness of infographics in enhancing spatial thinking skills and linking visual content with the analytical and inferential competencies essential for geography education. Despite the recognized importance of spatial thinking, previous studies report multiple limitations in its curricular implementation. Liu et al. (2019), McLaughlin & Bailey (2023), and Yalçın et al. (2025) emphasized that geography textbooks often present spatial concepts without providing sufficient opportunities for students to practice spatial thinking skills, with exercises focused on basic recall rather than pattern analysis or spatial decision-making.

Similarly, Gengchen et al. (2025), and Peterson et al. (2020) reported that most high school geography textbook questions emphasize memorization, with few tasks requiring analytical spatial reasoning. Studies on technological tools, including Al-Barakat et al. (2023) and Kim & Bednarz (2013), show that Geographic Information Systems (GIS) can enhance critical spatial thinking, yet their application is largely restricted to higher educational levels, with minimal focus on younger students or innovative visual tools such as infographics. These gaps highlight the limited exploration of spatial thinking skills, particularly in early geography education and through innovative visual tools. The present study addresses this gap by investigating the effect of educational infographics on the development of spatial thinking skills in children, focusing on the relationship between different types of infographics-static, animated, and interactive-and the degree of spatial skill enhancement. Unlike previous studies, this research targets a specific age group, integrates a clearly defined independent variable (infographics) and dependent variable (spatial thinking skills), and implements measurable, practical learning activities, thereby addressing the limitations of prior literature that primarily emphasized academic achievement or traditional instructional methods. In conclusion, the literature review highlights clear inconsistencies in prior research regarding the effectiveness of visual tools in developing spatial thinking, as well as a lack of studies focusing on primary-level geography education. The current study aims to bridge this gap through an applied research design that combines theoretical insights with practical implementation, emphasizing the role of infographics in enhancing spatial skills and providing empirical evidence to inform educational practices and the effective integration of visual learning tools.

MATERILES AND METHODS

Study Design

This study employed a quasi-experimental design, in which participants were divided into two equal groups: an experimental group and a control group. The primary objective was to examine the effect of using infographics on the development of spatial thinking skills within the geography curriculum. The experimental group received instruction through infographic-based teaching, whereas the control group followed the traditional teaching method. This design allows for a systematic comparison between the two instructional approaches and facilitates monitoring changes in children's spatial thinking skills before and after the educational intervention. As a result, it provides a precise and methodical evaluation of the effectiveness of infographics, which visually connect abstract geographical concepts with images and symbols that are easily comprehensible for children. The study design is illustrated in Figure 1.

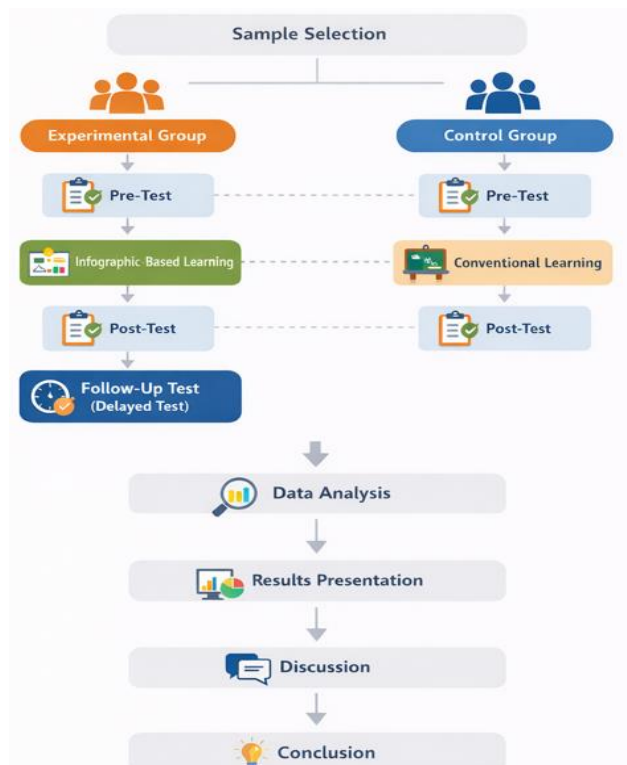


Figure 1. Research Design

Study Sample

The study sample consisted of 100 third-grade students from private schools in the Al-Ahsa region of the Kingdom of Saudi Arabia. The sample included only male students due to societal norms that prevent male researchers from accessing female-only schools. The students were evenly divided into two groups, each comprising 50 participants. The experimental group received instruction using infographics, whereas the control group was taught through the traditional method. The sample was selected using a convenience sampling technique, based on the willingness of school administrators, teachers, and parental consent, while ensuring that both groups were balanced in terms of academic level, prior knowledge, and learning behaviors. This approach aimed to guarantee accurate and reliable comparisons between the groups.

Students' performance was categorized into five academic levels: Excellent (90–100), Very Good (80–89), Good (70–79), Average (60–69), and Below Average (below 60). The distribution of students in each group according to these academic levels is presented in Table 1 and Figure 2.

Table 1. Distribution of Students by Academic Performance Levels in Experimental and Control Groups

Group	Excellent (90–100)	Very Good (80–89)	Good (70–79)	Average (60–69)	Below Average (<60)	Total
Experimental (n=50)	8	12	15	10	5	50
Control (n=50)	7	13	14	11	5	50

As illustrated in Table 1 and Figure 2, the distribution of student performance across the two groups is highly comparable prior to the educational intervention. The experimental group included 8 students in the “Excellent” category, while the control group had 7, and the differences across other categories range from one to two students. This balance confirms that the groups were equivalent in terms of academic performance before the study commenced. Furthermore, both groups were matched for social and cultural characteristics to ensure a valid comparison. These characteristics include age (8–9 years), middle socioeconomic status, parents' educational level (generally high school or higher), a similar home learning environment with access to books, the Internet, and educational resources, and prior familiarity with basic geographical concepts. Such alignment ensures that any observed differences in spatial thinking skills between the groups can be attributed primarily to the educational intervention using infographics, rather than external or confounding variables.

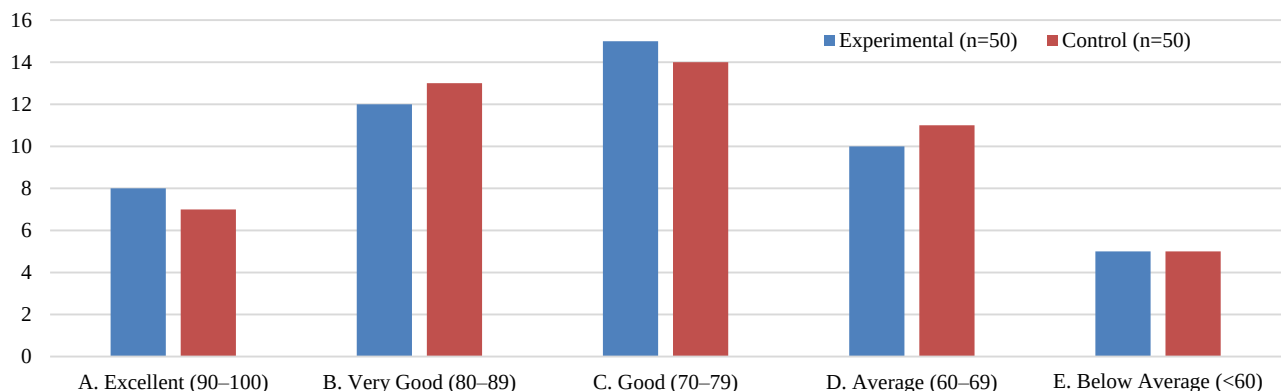


Figure 2. Distribution of Students by Academic Performance Levels in Experimental and Control Groups
(Note: The Y-axis represents the number of students (n) across the academic performance levels)

Infographic-Based Learning Design

The instructional unit entitled “*Map of My Country and Methods of Locating Places*” was specifically designed for third-grade students to facilitate infographic-based learning. The unit aimed to develop spatial thinking skills and enhance children's understanding of their surrounding world through clear visual representations. It included key lessons targeting directionality, map comprehension, and interpretation of visual cues, such as basic directions, cardinal points, the national map, and the significance of colors and symbols on maps. This unit was selected for its ability to establish a strong foundational knowledge and simplify complex spatial concepts for young learners through visual representation.

The instructional plan incorporated hands-on activities using images and illustrative symbols, helping children link concepts visually. The content was carefully analyzed and organized into fundamental elements, including concepts, skills, generalizations, and spatial problem-solving exercises, ensuring a coherent and child-friendly learning sequence.

After defining the learning objectives for each lesson, emphasis was placed on developing spatial thinking skills, including directionality, understanding locations on a map, distinguishing between colors and symbols, and applying them correctly. To optimize the use of infographics, visual resources were meticulously designed, selecting appropriate images and symbols for each spatial concept. Clarity, simplicity, and alignment with children's cognitive abilities were prioritized. Professional software such as Photoshop and Canva was used to refine colors, fonts, and visual appeal, enhancing students' focus, engagement, and overall visual learning experience.

Teacher Training on Infographic Implementation

To ensure effective implementation and consistency in teaching, a comprehensive training program was conducted for teachers assigned to the experimental group. The program spanned 16 hours over two weeks, combining theoretical and

practical components. Teachers were introduced to principles of designing and using infographics in education, including selecting suitable colors and symbols, organizing information to link visual elements with geographical concepts, and fostering students' spatial thinking skills. The training emphasized interactive activities, such as educational games, visual questions, and hands-on exercises, designed to enhance observation, analysis, and reasoning skills among students.

Teachers were trained to guide students during visual activities, monitor their progress continuously, and employ real-time assessment tools to record and analyze student performance. This facilitated identification of strengths and weaknesses and enabled individualized support when necessary. Furthermore, teachers received guidance on preparing performance reports and using data to refine instructional strategies and adjust activity difficulty according to students' abilities.

Consistency of teaching methods between the experimental and control groups was maintained to ensure that any observed differences in outcomes could be attributed solely to the use of infographics. Ongoing monitoring and evaluation of teacher performance were conducted through classroom observations and weekly meetings, providing immediate feedback and support to maximize the effectiveness of visual learning activities.

Spatial Thinking Skills Test

The Spatial Thinking Skills Test was developed to measure students' acquisition of basic spatial skills within the "My Country Map and Ways of Locating Places" unit for third-grade students. The test was designed to assess students' ability to apply spatial skills in realistic contexts related to maps, directions, and locations. Initially, the test included 24 questions; following validity and reliability evaluations, it was refined to a final version comprising 20 written questions. The purpose of the test was to determine the extent to which students had mastered the fundamental spatial skills covered in the unit.

The test evaluates four primary spatial skills, with five carefully designed questions for each skill to accurately reflect the nature of the ability being measured:

- **Skill 1: Spatial Perception** – This domain assesses the child's ability to recognize the locations of objects and their relationships within the surrounding environment. Students are asked to identify locations such as the school, park, mosque, and other landmarks on simplified maps, as well as to visualize these locations mentally and relate them to their relative positions on the map. Questions in this domain aim to enhance children's capacity to perceive spatial arrangements and understand their environment visually and practically, forming a foundation for developing spatial thinking skills.
- **Skill 2: Orientation and Directionality** – This domain includes five items designed to assess the child's ability to use cardinal directions (north, south, east, west) to locate and navigate between places. Students may be asked to draw arrows indicating directions, trace a path from one location to another on a map, or identify the position of a landmark relative to the cardinal directions. These questions aim to develop the child's ability to link maps with real-world spatial contexts and understand spatial relationships through directionality, a core skill for geographic knowledge and early navigation.
- **Skill 3: Spatial Relationships** – This domain contains five items that measure the child's ability to understand relationships among different landmarks and locations on a map. Students are asked to compare distances, identify the closest and farthest landmarks, and determine the relative positions of landmarks (e.g., which landmark is at the center or which is north or east of another). These questions promote logical spatial thinking and enable students to comprehend and apply spatial arrangements practically.
- **Skill 4: Map and Symbol Interpretation** – This domain includes five items assessing the child's ability to read and interpret map symbols and colors. Students may be asked to match symbols with the correct locations, identify landmarks based on colors and symbols, or plan a route on the map from one location to another. Questions in this domain aim to strengthen the link between visual representation and real-world spatial locations, enabling children to use maps effectively and intuitively.

The test items were designed to be clear, age-appropriate, and focused on practical understanding and visual interaction with maps and symbols rather than rote memorization. The test provides accurate data for statistical analysis, allowing a comparison of performance between the experimental and control groups and enabling the evaluation of the effectiveness of using infographics in developing spatial thinking skills.

Validity and Reliability of the Research Instrument

The researchers ensured the validity of the Spatial Thinking Skills Test prior to its application on the study sample. The initial version underwent thorough review by a panel of experts in geography education, instructional methods, and children's performance assessment. The review verified the scientific accuracy of the items, the clarity of the language, and their suitability for the educational objectives and the difficulty level of spatial skills for third-grade students. Based on expert feedback, several items were revised in terms of wording, visual quality of maps and illustrations, and distractor options to align more closely with the skills being measured. The final version included 20 items assessing the four spatial skills: spatial perception, orientation and directionality, spatial relationships, and map and symbol interpretation.

To evaluate the test's reliability, it was first administered to a group of 20 students outside the main study sample, and then re-administered to the same group two weeks later. The Pearson correlation coefficient between the two administrations was 0.89, indicating strong reliability and temporal stability. Item analysis further showed that difficulty indices ranged from 0.43 to 0.78, while discrimination indices ranged from 0.46 to 0.77. These values confirm that the items were well-designed and able to distinguish effectively between high- and low-performing students.

The study also assessed construct validity using Macdonald's Omega and Composite Reliability (CR). The internal consistency estimates ranging from 0.895 to 0.905 for Omega and 0.892 to 0.907 for CR—surpassed the recommended minimum of 0.70. Convergent and discriminant validity were likewise confirmed. Average Variance Extracted (AVE)

values ranged from 0.597 to 0.703, exceeding the 0.50 threshold for convergent validity. Discriminant validity was established by demonstrating that the square root of the AVE for each construct was greater than its correlations with other constructs. Additionally, the inter-construct correlations showed that each skill was distinct and non-overlapping, providing further support for construct validity. A summary of these results appears in Table 2.

Table 2. Construct Validity and Reliability Indices for the Study Constructs
(Note: CR = Composite Reliability; AVE = Average Variance Extracted; $\sqrt{\text{AVE}}$ = Square Root of AVE)

Constructs	Items	Macdonald's Omega (ω)	CR	AVE	$\sqrt{\text{AVE}}$
Spatial Perception	5	0.902	0.896	0.597	0.772
Orientation and Directionality	5	0.912	0.907	0.607	0.779
Spatial Relationships	5	0.905	0.898	0.698	0.835
Map and Symbol Interpretation	5	0.895	0.892	0.703	0.838

Data Collection

To ensure the equivalence of the two groups prior to implementing infographic-based instruction, a pre-test was administered to all students in both the experimental and control groups to assess their spatial thinking skills. The results were analyzed using an independent samples t-test to confirm the absence of significant differences between the groups before the intervention, thereby enhancing the validity of subsequent comparisons of their performance in post-tests and follow-up assessments. Table 3 and Figure 3 present the results of the independent samples t-test for the pre-test scores:

Table 3. Independent Samples t-test Results for Pre-Test Spatial Thinking Skills Scores between Experimental and Control Groups
(Note: Means are calculated out of a total score of 100)

Group	N	M.	SD	df	t-value	Sig. (2-tailed)
Experimental	50	9.20	2.25	98	-0.109	0.913
Control	50	9.25	2.35			

The results in Table 3 and Figure 3 indicate no statistically significant difference between the mean scores of the two groups ($t = -0.109$, $p = 0.913 > 0.05$). This confirms that the experimental and control groups were equivalent in terms of basic spatial thinking skills before the educational intervention, supporting the validity of subsequent results and ensuring a reliable comparison of their post-test performance. Following the instructional intervention, a post-test was administered to both groups, with the experimental group receiving infographic-based instruction and the control group receiving traditional instruction. Additionally, a follow-up test was conducted three months later for the experimental group to assess the sustainability of the educational effect and the retention of spatial skills over time.

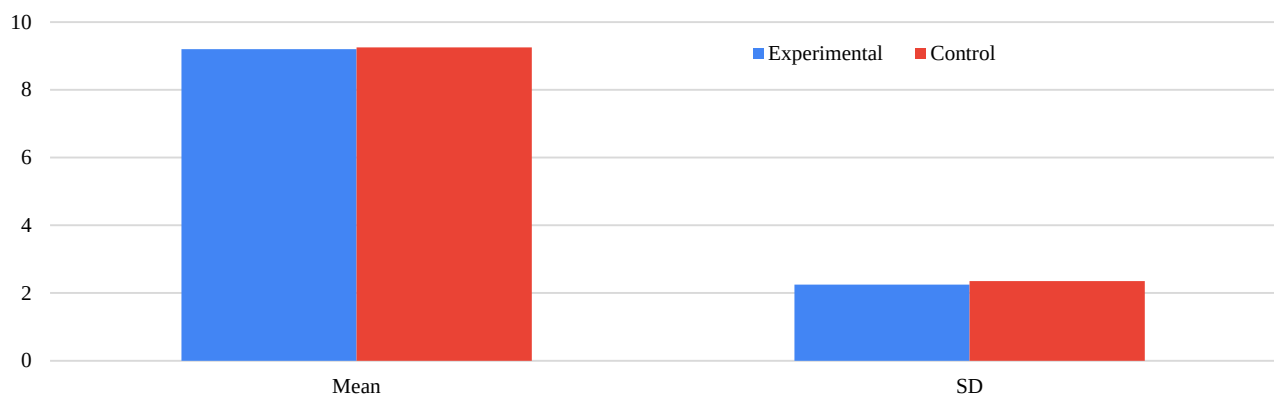


Figure 3. Independent Samples t-test Results for Pre-Test Spatial Thinking Skills Scores between Experimental and Control Groups
(Note: The Y-axis represents spatial thinking skills scores on a 0–100 scale. Values are presented as Mean (M) and Standard Deviation (SD))

Data Analysis

Data were analyzed using SPSS. Means and standard deviations were calculated for pre-test, post-test, and follow-up scores. Analysis of covariance (ANCOVA) was used to compare the performance of the experimental and control groups while controlling for initial differences in students' abilities, allowing for an assessment of the effect of infographic-based instruction compared to the traditional method.

Paired-samples t-tests were also conducted to compare post-test and follow-up scores for the experimental group, evaluating the retention of knowledge and spatial thinking skills three months after instruction.

RESULTS

Results of the First Question

This research question aimed to examine the effectiveness of using infographics in developing spatial thinking skills among primary school students in the experimental and control groups, at a significance level of $p = 0.05$. To address this objective, an Analysis of Covariance (ANCOVA) was conducted, with pre-test spatial thinking scores included as a

covariate in order to control for any pre-existing differences between the two groups. This statistical procedure ensured that any observed differences in post-test performance could be attributed to the instructional intervention, namely the use of infographics in teaching. Table 4 and Figure 4 present the adjusted means and standard errors of the post-test scores for both the experimental and control groups across all domains of spatial thinking skills.

Table 4. Adjusted Means and Standard Errors for Post-Test Spatial Thinking Skills Scores
(Note: Adjusted means were calculated after controlling for pre-test scores. Domain scores were calculated out of 25 points for each spatial thinking skill, whereas the total spatial thinking skills score was calculated out of 100 points)

Test Domain	Group	N	Adjusted Mean	Standard Error
Spatial Perception	Experimental	50	22.41	0.42
	Control	50	18.35	0.45
Orientation & Directions	Experimental	50	21.78	0.40
	Control	50	17.12	0.42
Spatial Relationships	Experimental	50	23.89	0.38
	Control	50	18.76	0.40
Map & Symbol Understanding	Experimental	50	22.64	0.41
	Control	50	17.53	0.43
Total Spatial Thinking Skills	Experimental	50	90.72	1.10
	Control	50	71.76	1.18

Table 4 and Figure 4 present the adjusted means and standard errors of the post-test scores across the various domains of spatial thinking skills, as well as the total spatial thinking score, for both the experimental and control groups. The adjusted means were computed after controlling for pre-test scores to ensure that the observed differences between the two groups were not influenced by any initial disparities prior to the instructional intervention.

The results indicate that the experimental group, which received infographic-based instruction, achieved higher adjusted mean scores across all spatial thinking domains compared to the control group.

For example, in the Spatial Perception domain, the experimental group obtained a mean score of 22.41, whereas the control group scored 18.35. Similarly, in the Orientation and Directions domain, the experimental group achieved a mean score of 21.78 compared to 17.12 for the control group. These differences suggest a marked improvement in students' spatial thinking skills attributable to the use of infographics as an instructional tool.

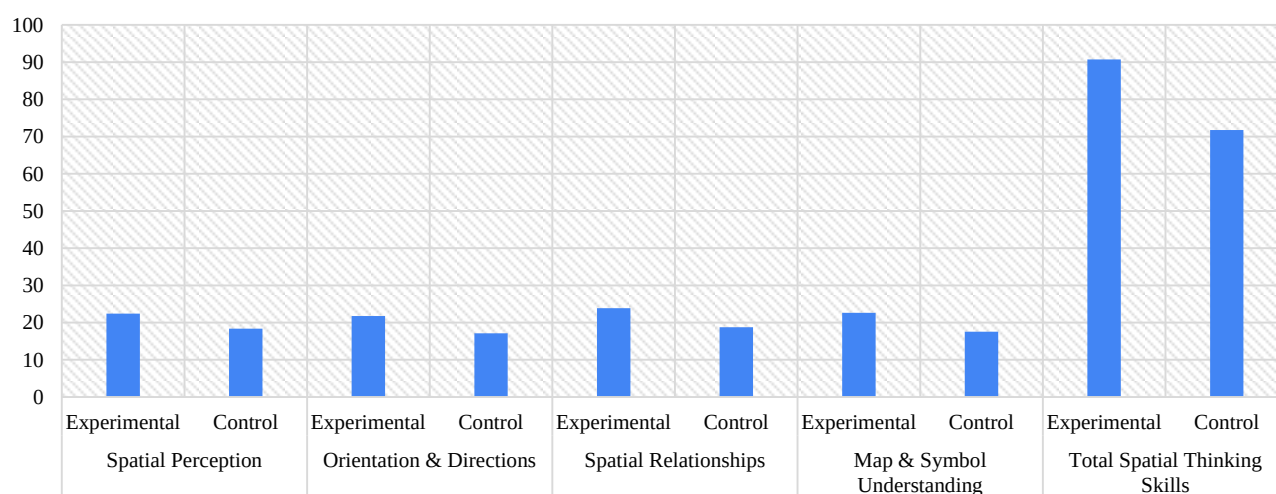


Figure 4. Adjusted Means and Standard Errors for Post-Test Spatial Thinking Skills Scores (Note: The Y-axis represents adjusted mean scores for spatial thinking skills on a 0–100-point scale. Values are presented as adjusted means with standard errors)

In terms of the magnitude of differences across domains, the Spatial Relationships domain exhibited the largest gap between the two groups (23.89 for the experimental group versus 18.76 for the control group), indicating that this domain may be particularly responsive to infographic-based learning. Other domains, including Map and Symbol Understanding (22.64 vs. 17.53) and Spatial Perception, also demonstrated notable differences, suggesting that the impact of the intervention extended across multiple dimensions of spatial thinking rather than being limited to a single skill area.

When considering the total spatial thinking score, the experimental group achieved an adjusted mean of 90.72 out of 100, compared to 71.76 for the control group, representing a substantial overall difference in favor of the experimental group. The relatively small standard error values for both groups indicate precise and reliable statistical estimates, thereby increasing confidence in the results and reducing the likelihood that the observed differences occurred due to random variation. Although these differences are clearly reflected in the adjusted means, determining their statistical significance requires the application of an Analysis of Covariance (ANCOVA). This analysis accounts for pre-test differences and provides a more accurate assessment of the effect of the instructional intervention. The ANCOVA results for the post-test spatial thinking skills scores are presented in Table 5 and Figure 5.

Table 5. ANCOVA Results for Adjusted Means of Spatial Thinking Skills Post-Test Scores
(Note: SS = Sum of Squares; df = Degrees of Freedom; MS = Mean Square; η^2 = Eta Squared; p-values indicate significance of F)

Spatial Thinking Skills	Source	SS	df	MS	F	p	η^2
Spatial Perception	Adjusted Model	498.72	2	249.36	13.16	0.001	0.68
	Error	1839.41	97	18.96			
Orientation & Directions	Adjusted Model	462.81	2	231.41	10.55	0.003	0.64
	Error	2127.59	97	21.93			
Spatial Relationships	Adjusted Model	721.55	2	360.78	23.40	0.001	0.91
	Error	1496.82	97	15.42			
Map & Symbol Understanding	Adjusted Model	690.44	2	345.22	21.91	0.001	0.89
	Error	1528.71	97	15.74			
Total Spatial Thinking Skills	Adjusted Model	4923.58	2	2461.79	30.61	0.001	0.95
	Error	7801.26	97	80.43			

Table 5 and Figure 5 present the results of the Analysis of Covariance (ANCOVA) conducted to compare the adjusted post-test mean scores across the various domains of spatial thinking skills, as well as the overall spatial thinking score, after controlling for pre-test performance. This analysis was employed to isolate the effect of infographic-based learning and to ensure that any observed differences between the experimental and control groups were attributable to the instructional intervention rather than to pre-existing differences among students.

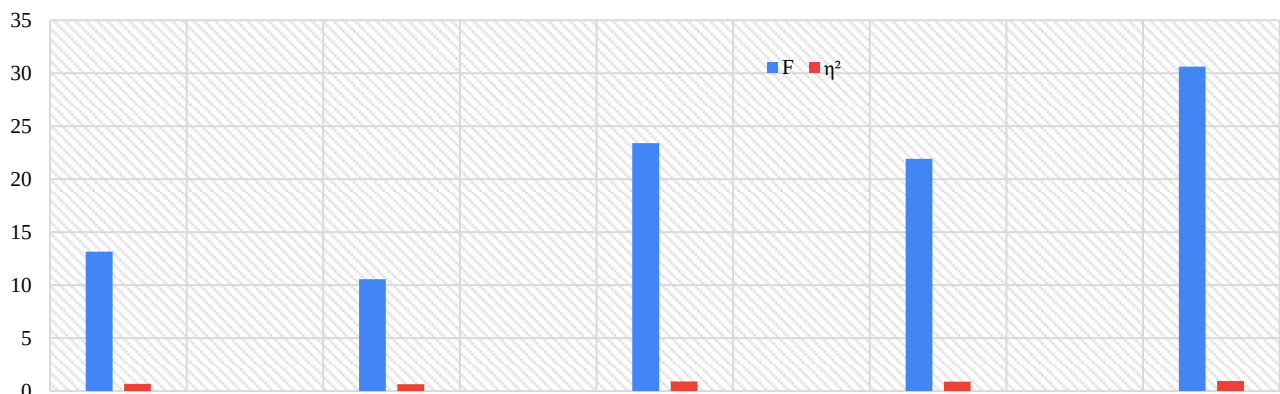


Figure 5. ANCOVA Results for Adjusted Means of Spatial Thinking Skills Post-Test Scores
(Note: The Y-axis presents statistical metric values, including F-values and eta-squared (η^2), across spatial thinking skill domains)

The findings reveal statistically significant differences between the adjusted means of the two groups across all domains of spatial thinking skills. In the domain of **Spatial Perception**, the analysis yielded an F value of 13.16 at a significance level of $p = 0.001$, indicating a statistically significant effect of infographic-based learning on students' spatial perception abilities. Similarly, the results for **Orientation and Directions** showed an F value of 10.55 ($p = 0.003$), further confirming the superiority of the experimental group after adjusting for pre-test scores.

More pronounced effects were observed in the domain of **Spatial Relationships**, which recorded one of the highest F values (23.40) at $p = 0.001$. This finding suggests that spatial relationships were among the skills most strongly influenced by infographic-based learning. In addition, the **Map and Symbol Understanding** domain demonstrated a high level of statistical significance, with an F value of 21.91 ($p = 0.001$), reflecting the effectiveness of visual representations in enhancing students' ability to interpret spatial symbols and comprehend abstract spatial concepts.

This strong impact extended to the **total spatial thinking skills score**, where the ANCOVA results revealed a substantial overall effect of the intervention. The F value reached 30.61 at $p = 0.001$, indicating highly significant differences between the experimental and control groups in overall spatial thinking performance after controlling for pre-test scores. This result confirms that infographic-based learning contributed to a comprehensive and integrated improvement in students' spatial thinking skills, rather than influencing isolated skill domains.

Further evidence supporting these findings is provided by the effect size estimates. The eta squared (η^2) values indicate a very large effect of the intervention across all domains, with values of 0.68 for Spatial Perception, 0.64 for Orientation and Directions, 0.91 for Spatial Relationships, 0.89 for Map and Symbol Understanding, and a peak value of 0.95 for the total spatial thinking skills score. These substantial effect sizes demonstrate that a large proportion of the variance in students' post-test performance can be attributed to infographic-based learning, underscoring both the statistical robustness and the educational significance of the intervention.

Results of the Second Question

The second research question examined the **long-term effectiveness** of infographic-based learning in enhancing spatial thinking skills among primary school students. Specifically, it investigated whether the improvements observed immediately after the intervention were sustained three months later, at a significance level of $p = 0.05$. To address this question, a Paired Samples t-test was conducted for the experimental group, comparing students' performance on the immediate post-test with

their performance on the delayed post-test administered three months after the completion of the intervention. The results, presented in Table 6 and Figure 6, include means, standard deviations, t-values, significance levels, and effect size estimates (η^2), providing a comprehensive assessment of the persistence and stability of learning gains over time.

Table 6. Paired Samples t-test Comparing Immediate and Delayed Post-Test Scores for the Experimental Group
(Note: N = sample size; M = mean; SD = standard deviation; df = degrees of freedom; η^2 = Eta Squared)

Domains	Test Time	N	Mean	SD	df	T-Value	Sig. (p-value)	Eta Squared (η^2)
Spatial Perception	Immediate	50	22.41	2.18	49	1.18	0.24	0.03
	Delayed	50	22.63	2.14				
Orientation & Directions	Immediate	50	21.78	2.05	49	1.05	0.30	0.02
	Delayed	50	21.95	2.01				
Spatial Relationships	Immediate	50	23.89	1.94	49	1.21	0.23	0.03
	Delayed	50	24.07	1.91				
Map & Symbol Understanding	Immediate	50	22.64	2.09	49	1.09	0.28	0.02
	Delayed	50	22.81	2.06				
Total Score	Immediate	50	90.72	6.84	49	1.27	0.21	0.03
Spatial Perception	Delayed	50	91.46	6.71				

Table 6 and Figure 6 indicate that the mean scores of the experimental group in the delayed post-test were slightly higher than those obtained in the immediate post-test across all domains of spatial thinking skills, as well as for the total score. This finding suggests that students were able to retain and recall the acquired spatial skills after a three-month interval. It reflects the sustained impact of the infographic-based instructional program, as its effectiveness was not limited to immediate post-intervention performance but extended over time, thereby confirming its long-term value in reinforcing spatial thinking skills. A closer examination of the **Spatial Perception** domain reveals a slight increase of 0.22 points, indicating that students maintained their ability to distinguish spatial forms and understand the distribution of elements within a given space. This stability represents a foundational skill upon which other spatial abilities are built, as effective processing of spatial visual information directly supports competencies related to orientation and direction. Consistent with this relationship, the **Orientation and Directions** domain exhibited a slight increase of 0.17 points, reflecting students' sustained ability to apply spatial orientation strategies and comprehend directional relationships.

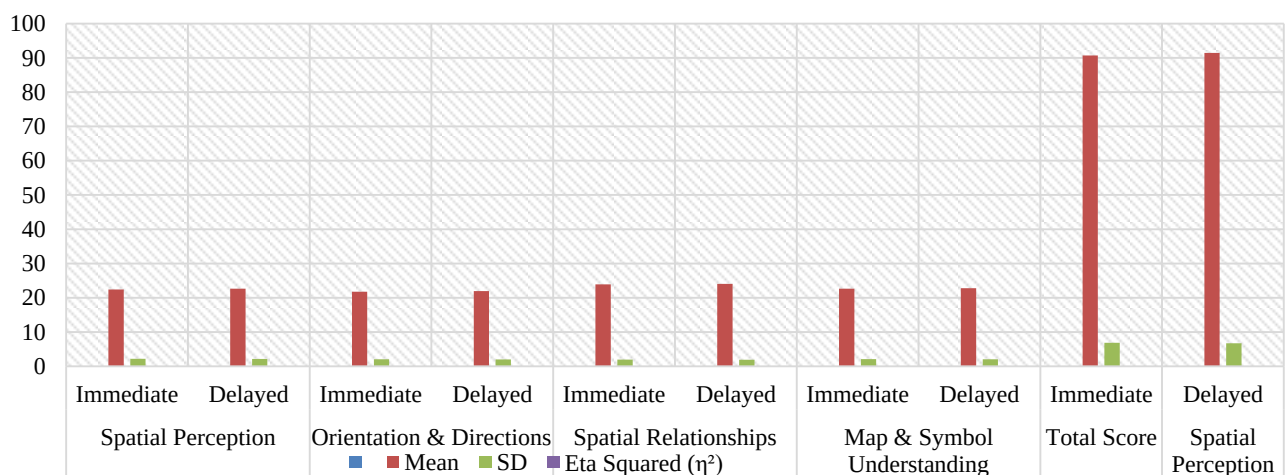


Figure 6. Paired Samples t-test Comparing Immediate and Delayed Post-Test Scores for the Experimental Group
(Note: The Y-axis represents scores/values on a 0–100 scale, while the X-axis represents test domains and time points.)

This interdependence extends to the **Spatial Relationships** domain, which demonstrated an increase of 0.18 points, highlighting students' continued ability to recognize and interpret relationships among spatial elements across different contexts. The stability of perceptual and orientation skills appears to support the development and maintenance of more complex spatial reasoning processes. In turn, this reinforces performance in **Map and Symbol Understanding**, which also showed a slight increase of 0.17 points, indicating that students retained their ability to interpret cartographic symbols and extract spatial meaning from visual representations over an extended period.

With respect to the **total spatial thinking skills score**, the mean increased by 0.74 points, reflecting overall performance stability among students in the experimental group. This result confirms that the acquired skills did not deteriorate over time but remained accessible and coherent. When considering both the individual domains and the total score, it becomes evident that skill retention was comprehensive rather than partial, further underscoring the effectiveness of the infographic-based program in fostering sustained spatial thinking development.

Although the mean scores on the delayed post-test showed a slight increase compared to the immediate post-test, the paired samples t-test revealed that this difference was not statistically significant at the $p \leq 0.05$ level. This outcome suggests performance stability over time rather than substantial gains or declines. Moreover, the effect size values (eta

squared, η^2) were very small, ranging from 0.02 to 0.03, confirming that the observed increases reflect retention of previously acquired skills rather than statistically meaningful improvement.

Based on these findings, it can be concluded that infographic-based learning not only produces immediate improvements in spatial thinking skills but also contributes to their long-term consolidation. The clear coherence between subdomain performance and the total score indicates that the instructional program supports deep learning and ensures sustained retention of spatial skills, thereby establishing infographic-based learning as an effective and robust approach for promoting durable spatial thinking development among primary school students.

DISCUSSION

The results addressing the first research question clearly demonstrate a significant and positive effect of infographic-based learning on the development of spatial thinking skills among primary school students. The experimental group, which received instruction through infographics, achieved higher adjusted mean scores across all spatial thinking domains compared to the control group. These findings were further substantiated by the ANCOVA results, which revealed statistically significant differences across all domains, with high *F* values, significance levels below 0.01, and large effect sizes (η^2). Together, these indicators confirm the strong effectiveness of the instructional intervention and its substantial impact on students' spatial abilities. These results can be attributed to the inherently visual and integrative nature of infographics, which combine images, symbols, maps, and text into a unified representational format. Such integration facilitates students' comprehension of complex spatial information and supports the construction of clear mental representations that can be analyzed and applied in problem-solving contexts. This interpretation aligns with Paivio's Dual Coding Theory, which posits that information processed simultaneously through visual and verbal channels is more effectively encoded, retained, and retrieved. The dual representation of information reduces cognitive loss and enhances both comprehension and recall (AlAli & Al-Barakat, 2024; Liu et al., 2020).

In addition, the findings are consistent with Cognitive Load Theory, which emphasizes that well-organized visual representations reduce extraneous cognitive load on working memory (Khasawneh et al., 2022; Gkintoni et al., 2025). By simplifying complex information and presenting it in a structured visual format, infographics allow learners to allocate cognitive resources to higher-order processes such as analysis, inference, and understanding spatial relationships, rather than expending effort on decoding dense textual information. Consequently, infographic-based instruction enhances learning efficiency, particularly for spatial thinking skills that rely heavily on visual-spatial processing.

When compared with prior research, the results of this study are consistent with findings reported by AlAli & Al-Barakat (2025), which highlighted the effectiveness of visual tools - such as maps and illustrations - in supporting students' understanding of spatial relationships and problem-solving. However, the present study extends existing research in several important ways. First, it employs infographics as a comprehensive instructional tool that integrates text, images, symbols, and maps within a single learning experience, rather than relying on isolated visual aids. Second, it demonstrates significant effects across all spatial thinking domains, indicating a holistic rather than domain-specific impact. Third, the exceptionally large effect sizes observed - reaching up to 0.95 for total spatial thinking skills - suggest a stronger and more far-reaching influence than that reported in much of the previous literature.

Notably, abstract domains such as spatial relationships were particularly responsive to infographic-based instruction. This finding can be interpreted through Piaget's constructivist theory (AlAli & Al-Barakat, 2025), which emphasizes that learning is most effective when learners actively construct knowledge by linking new information to existing cognitive structures. Infographics appear to facilitate this process by transforming abstract spatial concepts into concrete, visually meaningful representations, thereby enhancing students' ability to understand and apply complex spatial relationships.

In addition, the advantage demonstrated by the experimental group can be interpreted through the lens of active learning theory, which emphasizes that learning becomes more meaningful when learners interact with the material and employ it in solving tasks. The use of infographics supports this process by encouraging students to examine visual representations, relate them to existing knowledge, and interpret spatial patterns and relationships. This type of engagement contributes to a more profound understanding of the content and promotes higher-order skills such as critical thinking and problem-solving.

In summary, the use of infographics as an instructional approach contributes not only to improved performance in the short term but also to the broader and longer-lasting development of students' spatial thinking abilities. The findings underscore the importance of integrating modern visual instructional tools into primary education curricula to support higher-order cognitive skills. Moreover, they confirm that infographics constitute a highly effective instructional strategy, yielding significant and enduring improvements that surpass those achievable through traditional text-based or isolated visual approaches.

Regarding the findings related to the second research question, the results indicated that the enhancement in spatial thinking skills gained through infographic-supported instruction remained evident three months after the intervention concluded. The descriptive data indicated that the experimental group obtained slightly higher mean scores on the delayed post-test compared to the immediate post-test, reflecting their ability to retain and retrieve the acquired spatial skills over time. This pattern of results underscores the enduring impact of infographic-based learning, suggesting that the improvements observed were stable rather than short-lived and contributed meaningfully to the continued development of students' spatial competencies. This sustained performance can be attributed to the interactive and visually integrated nature of infographics, which facilitates the encoding of information across both verbal and visual memory systems.

This interpretation is consistent with constructivist learning theory, which posits that presenting information through multiple representational modes enables learners to construct richer and more durable mental representations, thereby enhancing retention and subsequent retrieval. In addition, the instructional design of the program-which systematically

linked foundational skills such as spatial perception and orientation with more complex domains, including spatial relationships and map and symbol understanding-played a critical role in supporting performance stability. The persistence of learning outcomes suggests that the intervention fostered deep and meaningful learning, in which the integration of multiple spatial skills reinforced long-term knowledge retention.

At the subdomain level, the spatial perception domain exhibited a slight increase in mean scores, indicating that students maintained their ability to discriminate spatial forms and understand the distribution of elements within a given space. Similarly, performance in orientation and direction skills remained stable, reflecting students' continued ability to apply spatial orientation strategies and comprehend coordinate relationships.

These foundational competencies form the basis for higher-level spatial thinking, as evidenced by the stable performance observed in the spatial relationships and map and symbol understanding domains, both of which also demonstrated slight increases. Collectively, these results indicate that the program contributed to the consolidation of spatial thinking strategies in a coherent and continuous manner, rather than promoting short-term gains in isolated skills.

Regarding the composite score for spatial thinking skills, the mean showed a slight increase of 0.74 points, indicating that the experimental group maintained a stable level of performance even three months after the instructional program had concluded. This outcome suggests that students were able to retain and retrieve the acquired skills over time, rather than experiencing a decline in proficiency. Although the paired samples t-test revealed that these gains were not statistically significant, the small effect size values ($\eta^2 = 0.02-0.03$) point to a pattern of sustained retention rather than additional improvement. Such results align with cognitive load theory (AlAli & Al-Barakat, 2025; Bani Irshid et al., 2023; Khasawneh et al., 2023; Gkintoni et al., 2025), which posits that well-organized and visually structured learning materials help learners encode information more efficiently and reduce unnecessary cognitive demands, thereby strengthening long-term recall.

In relation to existing scholarship, these findings are consistent with previous work emphasizing the value of visual instructional tools in supporting the retention of spatial understanding (e.g., Mani et al., 2026; Matovu et al., 2023; R  th et al., 2021; Budak & Ceyhan (2024). However, this study contributes an added dimension by demonstrating sustained retention across all components of spatial thinking rather than focusing solely on select skills or immediate post-test results. This broader retention profile marks a significant addition to the literature by offering empirical evidence that learning gains persist over an extended period. The confirmation of stable performance three months after the intervention also highlights the pedagogical value of infographic-based instruction as an effective and enduring teaching strategy. In conclusion, the results related to the second research question confirm that infographic-based learning not only produces immediate improvements in spatial thinking performance but also contributes to the long-term consolidation of these skills. The coherence observed between subdomain performance and the total spatial thinking score indicates that the program supports integrated spatial thinking development and ensures sustained retention of skills. These findings highlight the educational significance of infographic-based instruction as an effective strategy for fostering durable spatial thinking abilities among primary school students.

CONCLUSIONS

The present study yields a set of pedagogically grounded conclusions that highlight the educational significance of infographic-based learning as an effective instructional approach for developing spatial thinking skills among primary school students. This supports the conclusion that infographics facilitate meaningful learning by coherently integrating visual and verbal representations, thereby enabling learners to construct clear and well-organized mental models of spatial concepts. This instructional approach is consistent with dual coding theory, which posits that information processed simultaneously through visual and verbal channels enhances comprehension and long-term retention. By presenting spatial information in a visually structured manner, infographics support learners in understanding complex spatial relationships and patterns, which constitute the core of spatial thinking in geography education.

Another important conclusion is that infographic-based learning contributes to reducing cognitive load by organizing information in a clear and visually accessible format. This design allows learners to allocate their cognitive resources to higher-order thinking processes-such as analysis, interpretation, and spatial reasoning-rather than expending effort on processing fragmented or abstract textual information. This conclusion aligns closely with cognitive load theory, which emphasizes the role of instructional design in optimizing working memory capacity and promoting deep and efficient learning. The structured visual layout of infographics helps learners focus on essential spatial elements and their interrelationships, thereby enhancing conceptual clarity and learning efficiency.

The study further concludes that infographic-based instruction supports the progressive and integrated development of spatial thinking skills. Foundational skills, including spatial perception and orientation, are systematically linked to more advanced domains such as spatial relationships and map and symbol understanding. This integrated progression reflects the principles of Constructivist Learning Theory, which emphasize that learners actively construct new knowledge by building upon existing cognitive structures through meaningful learning experiences. By connecting basic and complex spatial concepts within a unified visual framework, infographics promote coherent learning and reduce fragmentation, enabling students to develop spatial thinking skills in a cumulative and meaningful manner.

Moreover, the stability of students' performance over time indicates that infographic-based learning fosters enduring understanding rather than short-term gains. The interactive and visually rich nature of infographics encourages active engagement with spatial content, supporting the consolidation of learning and the long-term retention of spatial skills. This conclusion is consistent with Active Learning Theory, which highlights the importance of learner engagement and cognitive involvement in achieving meaningful and sustainable learning outcomes.

Based on these conclusions, the study recommends integrating infographic-based learning into primary school curricula, particularly in subjects that rely heavily on spatial reasoning, such as geography. Teacher education and professional development programs should emphasize training educators to design and implement pedagogically sound infographics that align with curricular objectives and learners' cognitive characteristics.

Furthermore, assessment practices should extend beyond traditional achievement tests to incorporate diverse tools capable of capturing students' spatial reasoning processes, including performance-based assessments, visual tasks, and observational measures, in order to obtain a more comprehensive evaluation of learning outcomes.

Limitations, and Future Research Directions

Although the study offers valuable insights, several limitations must be recognized. The participant group consisted solely of male students enrolled in private primary schools in the Al-Ahsa region of Saudi Arabia, which may limit the extent to which the results can be applied to broader populations, including students from other regions, school types, or mixed-gender environments. Furthermore, the study depended exclusively on quantitative instruments to evaluate spatial thinking skills, without integrating qualitative evidence such as classroom observations, teacher feedback, or student interviews that could have enriched the interpretation of how learning unfolded.

Additionally, the instructional intervention was restricted to one unit of the geography curriculum, which constrains the ability to extend the findings to other academic subjects or different grade levels.

Given these limitations, future studies should expand the scope of inquiry by involving more varied participant groups representing different geographical areas, school settings, and genders. Adopting mixed-methods designs that combine quantitative measures with qualitative insights would offer a richer and more comprehensive perspective on the role of infographic-based learning in developing spatial thinking skills. Further research could also explore the influence of infographics on additional higher-order cognitive domains, including critical thinking, problem-solving, creativity, and metacognitive processes. Moreover, comparative investigations examining infographic-based instruction alongside other emerging pedagogical innovations, such as augmented reality, virtual reality, and interactive digital learning platforms, would provide valuable evidence to guide future educational development and support informed instructional decision-making.

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Abbreviations: Not applicable.

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