



Development of ZEP Quiz-Assisted Interactive Learning Media to Enhance Elementary Students' Spatial Literacy in Learning Cubes and Cuboids

Anisah Raniyah Mumtazah

Muhammadiyah Prof. Dr.
Hamka University, Indonesia

Nurafni

Muhammadiyah Prof. Dr.
Hamka University, Indonesia

Article Info

Article history:

Received: May, 23, 2026

Revised: June, 29, 2026

Accepted: July, 31 2026

Keywords:

3D Geometry;
Elementary Mathematics;
Interactive Learning Media;
Spatial Literacy;
ZEP Quiz.

Abstract

Spatial literacy is a fundamental competency that enables students to visualize, interpret, and communicate three-dimensional objects in mathematics learning. However, elementary geometry instruction continues to rely heavily on conventional teaching approaches, limiting students' opportunities to develop these essential skills through meaningful interaction. This study aimed to develop and evaluate ZEP Quiz-assisted interactive learning media to enhance elementary students' spatial literacy in learning cubes and cuboids. A Research and Development approach employing the ADDIE model was adopted to design, validate, implement, and evaluate the learning media. The study involved 57 fifth-grade students from an elementary school in East Jakarta, Indonesia, who participated in sequential small-group ($n = 28$) and large-group ($n = 29$) trials. Data were collected using a spatial literacy achievement test administered before and after the intervention and analyzed through descriptive statistics, Shapiro-Wilk and Levene's tests, paired-samples t-tests, and normalized gain (N-Gain) analysis using IBM SPSS Statistics. The findings revealed significant improvements in students' spatial literacy following the implementation of the developed media ($p < 0.001$). The average N-Gain scores reached 0.64 in the small-group trial and 0.70 in the large-group trial, indicating a moderate level of learning improvement. These findings demonstrate that ZEP Quiz-assisted interactive learning media provides an effective and engaging strategy for strengthening spatial literacy in elementary geometry learning while supporting the implementation of student-centered digital instruction.

To cite this article: Mumtazah, A.R., Nurafni, N., (2026). Development of ZEP Quiz-Assisted Interactive Learning Media to Enhance Elementary Students' Spatial Literacy in Learning Cubes and Cuboids. *Al Qodiri: Jurnal Pendidikan, Sosial dan Keagamaan*, 24(2), 1.172-1.184.

INTRODUCTION

Education systems worldwide are increasingly expected to cultivate learners who possess higher-order thinking skills that enable them to solve complex problems in rapidly changing environments. Among these competencies, spatial literacy has received growing attention because it supports learners in interpreting, representing, and manipulating spatial information across academic and everyday contexts. Spatial literacy is particularly important in mathematics education, where students are required to understand geometric relationships, visualize three-dimensional objects, and communicate spatial ideas accurately (del Cerro Velázquez & Morales Méndez, 2021; Supli & Yan, 2024). Nevertheless, international assessments and classroom-based studies continue to report that many elementary school students experience persistent difficulties in mastering geometry concepts that require strong spatial reasoning (Musa et al., 2025). These challenges become more pronounced in educational settings where instruction remains predominantly teacher-centered and emphasizes procedural knowledge over conceptual understanding. Consequently, strengthening students' spatial literacy has become an important educational priority that aligns with the development of twenty-first-century competencies, including critical thinking, communication, creativity, and problem solving (Kennedy & Sundberg, 2025). Addressing this issue

* Corresponding author:

Mumtazah et al, Muhammadiyah Prof. Dr. Hamka University, Indonesia
anisahraniyahmumtazah13@gmail.com

requires learning environments that actively engage students in constructing spatial knowledge rather than merely receiving information passively.

The challenge of developing spatial literacy is evident in many elementary mathematics classrooms, particularly during geometry instruction involving cubes and cuboids. Although these topics form the foundation for more advanced geometric reasoning, many students continue to struggle with visualizing three-dimensional structures, identifying relationships among faces and edges, and mentally transforming objects from different perspectives (Kyaw & Vidákovich, 2025; Taylor et al., 2023). Classroom observations in Indonesian primary schools further indicate that mathematics lessons frequently rely on lectures, textbook explanations, and routine exercises, providing limited opportunities for students to explore geometric concepts through meaningful interaction. Such instructional practices often reduce students' motivation and restrict their ability to connect abstract mathematical concepts with authentic spatial experiences. Moreover, limited classroom interaction makes it difficult for teachers to diagnose misconceptions related to spatial visualization and reasoning at an early stage (Hsieh, 2023; Rahmawati et al., 2021). As a result, students frequently memorize geometric formulas without developing the conceptual understanding required to apply them in unfamiliar situations. These conditions demonstrate that improving spatial literacy requires not only curriculum reform but also innovative instructional media capable of supporting active and experiential learning.

Recent advances in educational technology have created new opportunities to redesign mathematics instruction through interactive digital environments (Stahl, 2021). Digital learning media provide multimodal representations that combine visual, textual, and interactive elements, enabling students to explore abstract mathematical concepts more effectively than conventional instructional materials (Borba et al., 2022). Interactive technologies also facilitate immediate feedback, adaptive learning experiences, and collaborative engagement that encourage students to participate actively throughout the learning process. Previous research has consistently shown that technology-enhanced learning environments can improve students' conceptual understanding, learning motivation, and engagement in mathematics classrooms (Georgiou & Ioannou, 2021; Uwineza et al., 2023; Q.-F. Yang et al., 2021). Nevertheless, the educational value of digital media depends not only on technological sophistication but also on instructional design that aligns with students' cognitive characteristics and learning objectives. Consequently, developing digital media that intentionally supports spatial thinking has become increasingly important for strengthening elementary geometry learning. Such innovations are expected to transform students from passive recipients of information into active constructors of spatial knowledge.

Among the various forms of digital learning innovation, educational games have emerged as promising tools for promoting meaningful and student-centered learning experiences. Game-based learning integrates instructional content with elements such as challenges, exploration, rewards, and immediate feedback that enhance learner engagement while maintaining educational objectives (Ahmad & Khan, 2024; Nadeem, 2024). These characteristics are particularly relevant for geometry instruction because spatial reasoning develops more effectively when learners actively manipulate objects, navigate environments, and receive continuous feedback during problem solving. One platform that has recently attracted attention is ZEP Quiz, a gamified learning environment that allows students to interact with virtual spaces using avatars while completing subject-specific learning activities. Unlike conventional quiz platforms that primarily present isolated questions, ZEP Quiz combines virtual exploration with assessment tasks, thereby creating richer opportunities for students to construct spatial representations (Porat & Ceobanu, 2024; Zekeik et al., 2025). This interactive environment has the potential to support spatial visualization, reasoning, and communication simultaneously through authentic learning experiences. Therefore, investigating the educational potential of ZEP Quiz is both timely and relevant for strengthening digital mathematics education in elementary schools.

The growing body of literature demonstrates that digital learning media have contributed positively to mathematics learning across different educational contexts (Zekeik et al., 2025). Studies have reported that augmented reality applications improve students' visualization of geometric objects by presenting three-dimensional representations that are difficult to achieve through traditional instruction (Meister et al., 2022; Overskott et al., 2024). Other investigations have shown that digital gamification platforms increase learner motivation, classroom participation, and

academic achievement through competitive and interactive learning activities (Almufarreh, 2026; Kaya & Ercag, 2023; Lampropoulos & Sidiropoulos, 2024). Research on digital quiz platforms such as Quizizz and Kahoot also indicates positive effects on students' engagement and learning performance because these platforms provide immediate feedback and enjoyable learning experiences (Janković et al., 2024). Furthermore, systematic reviews emphasize that interactive technologies can facilitate the development of spatial reasoning when instructional activities encourage learners to manipulate spatial representations actively (Gittinger & Wiesche, 2024; Y. Yang et al., 2026). Collectively, these studies confirm the educational benefits of technology-enhanced learning while highlighting the increasing integration of gamification into mathematics education (Lee & Lai, 2024). However, the majority of existing evidence focuses on learning motivation, achievement, or conceptual understanding rather than explicitly examining spatial literacy as a multidimensional construct.

Despite these encouraging findings, several important limitations remain unresolved in the existing literature. First, previous studies have concentrated predominantly on widely used gamified platforms such as Quizizz and Kahoot, whereas empirical investigations involving ZEP Quiz remain relatively scarce, particularly in elementary mathematics education (Putra et al., 2025). Second, most studies have evaluated students' general academic achievement without comprehensively measuring spatial visualization, spatial reasoning, and spatial communication as integrated dimensions of spatial literacy (Bintoro et al., 2021; Lewis_Presser et al., 2025). Third, research examining the development of ZEP Quiz through a systematic instructional design framework such as ADDIE is still limited, reducing understanding of how carefully designed educational games influence learning effectiveness (Hidayati et al., 2026). Finally, empirical evidence focusing specifically on elementary students learning cubes and cuboids remains insufficient despite the importance of these topics in developing foundational spatial thinking (Downton & Livy, 2022). These limitations reveal a clear research gap regarding the design, implementation, and evaluation of ZEP Quiz-assisted interactive learning media for improving elementary students' spatial literacy. Addressing this gap is essential for expanding both theoretical understanding and practical applications of game-based learning in mathematics education.

Based on these considerations, this study aims to develop and evaluate ZEP Quiz-assisted interactive learning media to improve elementary school students' spatial literacy in learning cubes and cuboids using the ADDIE research and development model. Specifically, the study investigates the effectiveness of the developed media by examining changes in students' spatial literacy before and after its implementation. The research contributes theoretically by extending current knowledge regarding the integration of gamified virtual learning environments with spatial cognition and multimedia learning principles in elementary mathematics education. Methodologically, it demonstrates the application of a systematic ADDIE framework for designing and evaluating interactive educational media tailored to spatial literacy development. Practically, the findings provide evidence-based guidance for teachers seeking innovative digital strategies that foster active participation, conceptual understanding, and spatial thinking in geometry classrooms. Furthermore, the study offers insights for curriculum developers and educational technology designers regarding the pedagogical potential of immersive quiz-based learning environments. Ultimately, this research is expected to enrich the growing discourse on digital transformation in mathematics education while providing an effective alternative for promoting meaningful and student-centered geometry learning.

METHOD

Research Design

This study employed a Research and Development (R&D) approach using the ADDIE instructional design model, which consists of the sequential phases of Analysis, Design, Development, Implementation, and Evaluation. The R&D approach was selected because the primary objective of the study was not only to evaluate learning outcomes but also to systematically design, develop, validate, and evaluate an interactive learning medium capable of improving elementary school students' spatial literacy. The ADDIE model was adopted because it provides a structured yet flexible

framework for developing educational products while allowing iterative revisions based on expert feedback and field-testing results (Mariani et al., 2026). Unlike conventional experimental studies that merely compare learning outcomes, the present study emphasized product development accompanied by empirical evaluation to ensure that the resulting media met pedagogical, technical, and practical requirements. Consequently, the study integrated instructional design principles with quantitative evaluation to assess the effectiveness of the developed ZEP Quiz interactive media.

Research Setting and Participants

The research was conducted at SDN Susukan 07 Pagi, East Jakarta, Indonesia, during the second semester of the 2025/2026 academic year. The implementation focused on fifth-grade mathematics learning, particularly the topics of cubes and cuboids, because these concepts require students to develop strong spatial visualization and reasoning abilities. The target population consisted of all fifth-grade students enrolled at the school. Participants were selected using purposive sampling, considering the similarity of academic level, curriculum implementation, and classroom characteristics relevant to the objectives of the study. A total of 57 students participated, comprising 28 students in the small-group trial and 29 students in the large-group trial. The small-group trial functioned as a formative evaluation to identify weaknesses in the initial product and gather feedback for improvement, whereas the large-group trial served as a summative evaluation to examine the consistency of the revised media under broader classroom conditions (Ross & Morrison, 2021). Therefore, these two groups were not designed as experimental and control groups but represented consecutive stages within the ADDIE development process. Participation was voluntary, and permission to conduct the research was obtained from the school administration before data collection commenced.

Research Instruments

Data were collected using multiple instruments to evaluate both the quality of the developed media and students' learning outcomes. The primary instrument was a spatial literacy achievement test consisting of 10 multiple-choice items administered as both a pretest and a posttest. The instrument was developed based on three fundamental dimensions of spatial literacy: spatial visualization, spatial reasoning, and spatial communication (Kustiawati et al., 2023; Octaria Dina, 2025). Spatial visualization measured students' ability to mentally manipulate and recognize three-dimensional objects from different perspectives, spatial reasoning assessed their ability to analyze spatial relationships and solve geometry-related problems, and spatial communication evaluated their ability to interpret and communicate spatial information accurately. In addition to the achievement test, expert validation sheets were used to evaluate the instructional quality, media design, language appropriateness, and technical functionality of the ZEP Quiz interactive media. Observation notes and documentation were also collected during classroom implementation to support product refinement throughout the development process.

Instrument Validity and Reliability

Prior to implementation, all research instruments underwent a systematic validation process to ensure their appropriateness for elementary mathematics learning. Content validity was established through expert judgment involving specialists in mathematics education, instructional media, and elementary education. The experts reviewed each test item and media component based on relevance, clarity, language appropriateness, content accuracy, and alignment with the intended learning objectives. Suggestions provided during the validation stage were incorporated into the revised version of the media before classroom implementation. Subsequently, the achievement test was pilot-tested to evaluate item clarity and internal consistency. Instrument reliability was examined using Cronbach's alpha, with coefficients above the commonly accepted threshold of 0.70 indicating satisfactory reliability for educational research. This validation process ensured that both the instructional media and assessment instruments possessed adequate validity and reliability before being used in the field trials.

Research Procedure

The development and evaluation process followed the systematic stages of the ADDIE model, beginning with an analysis of learning problems and ending with the production of a validated interactive learning medium. During the Analysis phase, classroom observations, curriculum

reviews, and needs analyses were conducted to identify instructional problems related to students' spatial literacy. The Design phase involved preparing learning objectives, assessment indicators, storyboard development, and interface planning for the ZEP Quiz interactive media. During the Development phase, the prototype was produced, evaluated through expert validation, and revised according to expert recommendations. The Implementation phase consisted of two consecutive classroom trials. The initial prototype was first implemented in a small-group trial involving 28 students to identify practical limitations and collect formative feedback. After revising the product, a large-group trial involving 29 students was conducted to evaluate the consistency of the revised media's effectiveness. Finally, the Evaluation phase involved analyzing quantitative data and interpreting the findings to determine the effectiveness and feasibility of the developed learning media.

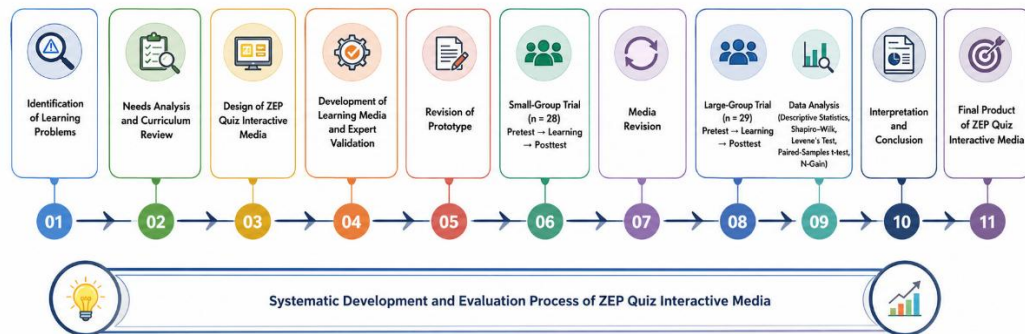


Figure 1. Systematic Development and Evaluation Process of ZEP Quiz Interactive Media

The overall research procedure illustrated in Figure 1 demonstrates that the study employed an iterative development cycle in which each phase informed the subsequent stage. Product revisions were conducted after expert validation and the small-group trial to ensure continuous improvement before broader implementation. This iterative approach is consistent with the fundamental principles of the ADDIE model, which emphasize continuous evaluation and refinement throughout instructional product development.

Data Analysis

Quantitative data were analyzed using IBM SPSS Statistics. Descriptive statistics, including the mean, standard deviation, minimum score, and maximum score, were calculated to summarize students' spatial literacy performance before and after the intervention. Prior to hypothesis testing, the assumptions of parametric statistics were examined using the Shapiro-Wilk test for normality and Levene's test for homogeneity of variance. Data were considered normally distributed and homogeneous when the significance value exceeded 0.05. The effectiveness of the ZEP Quiz interactive media was subsequently evaluated using a paired-samples t-test, comparing students' pretest and posttest scores within each trial group. Statistical significance was determined at $\alpha = 0.05$, with $p < 0.05$ indicating a significant improvement in spatial literacy after the intervention. To complement the significance testing, normalized gain (N-Gain) analysis was performed to determine the magnitude of learning improvement achieved by students. The N-Gain values were interpreted according to Hake's classification, where values below 0.30 were categorized as low, values between 0.30 and 0.70 as moderate, and values above 0.70 as high. The combination of descriptive statistics, inferential analysis, and learning gain evaluation provided a comprehensive assessment of the effectiveness of the developed ZEP Quiz-assisted interactive learning media in improving elementary school students' spatial literacy.

RESULTS AND DISCUSSION

Results

This research focused on the spatial literacy skills of two groups: a small group that served as the baseline before the media was developed, and a larger group that served as the baseline to assess the improvements in the developed media. Descriptive statistics for the research data are presented in the following table:

Table 1. Descriptive Statistics of Pre-test and Post-test

Aspects	N	Average	SD	Min	Max
Small Group Pretest	28	51	6,29	40	60
Small Group Post-test	28	83	5,26	74	92
Large Group Pretest	29	51	5,24	42	60
Large Group Post test	29	85	5,33	76	94

Based on these results, the results of the media development conducted were obtained. The small group obtained an average score of 51 on the pre-test and 83 on the post-test. After product revisions by the researcher, the average score was 51 on the pre-test and 85 on the post-test. Descriptively, there was an increase in the average pre-test and post-test scores in both groups after using the ZEP Quiz learning media. Gamification has been shown to increase student engagement in the learning process (Kristiani et al., 2022). After examining the average scores for each small and large group in grade 5 at SDN Susukan 07 Pagi, a paired sample t-test was conducted to determine whether there was a difference in pretest and posttest scores after using the ZEP Quiz-assisted learning media. This test was conducted to determine whether the developed media successfully achieved its intended objectives, both before and after development.

Table 2. Normality Test

Aspects	Statistics	df	Sig.
Small Group Pretest	0,948	28	0,176
Small Group Posttest	0,960	28	0,351
Large Group Pretest	0,962	29	0,376
Large Group Posttest	0,959	29	0,306

Based on the calculation table for normality test 2 using the Shapiro-Wilk formula, the small group pre-test obtained a sig. value of 0.176 and the post-test obtained a sig. value of 0.351. This indicates that the data is normally distributed because the sig. value is > 0.05 . The large group obtained a sig. value for the pre-test of 0.375 and for the post-test of 0.306. This also indicates that the data is normally distributed in the large group. Based on these results, the researcher then conducted a homogeneity test, as presented in the following table:

Table 3. Homogeneity Test

Data	df1	df2	Sig.
Pretest	1	54	0,182
Posttest	1	55	0,837

From these data, the homogeneity value for the pretest was 0.182, indicating homogeneous results. The posttest also obtained a value of 0.837, also indicating homogeneous results. These data demonstrate significance because they are greater than 0.05, thus concluding that both the pretest and posttest have the same data diversity, or homogeneity. After conducting normality and homogeneity tests, a paired sample t-test was conducted to determine whether there was a difference in pretest and posttest scores after using the learning media, as summarized in the following table:

Table 4. Paired t-test

Group	Mean Difference	t	df	Sig. (2-tailed)
Small Group	-32,500	-18,760	27	0,000
Large Group	-33862	-108,255	28	0,000

The results of the paired sample t-test showed an increase in students' spatial literacy skills after using the ZEP Quiz learning media in both research groups. In the small group, the average pretest score was 50.50, while the average posttest score increased to 83.00. The test results showed

a t-value of -18.760, $df = 27$, and $\text{Sig. (2-tailed)} = 0.000$. Because the significance value is less than 0.05, there is a significant difference between the pretest and posttest scores in the small group.

Meanwhile, in the large group, the average pretest score was 51.38, while the average posttest score increased to 85.24. The test results showed a t-value of -108.255, $df = 28$, and $\text{Sig. (2-tailed)} = 0.000$, thus concluding that there was a significant difference between the pretest and posttest scores in the large group. Overall, the paired sample t-test results indicated that the use of the ZEP Quiz learning media resulted in an increase in students' spatial literacy skills in both study groups.

Table 5. N-Gain

Aspect	Group	Mean	Kategori
N-Gain Score	Small	0,64	Medium
	Large	0,70	Medium
N-Gain Persen	Small	64,73%	Quite Effective
	Large	70,40%	Quite Effective

The N-Gain analysis was conducted to determine the level of improvement in students' spatial literacy skills after using the ZEP Quiz learning media. The analysis showed that the small group obtained an average N-Gain score of 0.64, which is in the moderate category, while the large group obtained an average N-Gain score of 0.70, which is also in the moderate category. These results indicate that the use of ZEP Quiz-assisted learning media can improve students' spatial literacy skills at a moderate level.

Based on the N-Gain percentage, the small group achieved an average score of 64.73%, while the large group achieved an average score of 70.40%. Based on the N-Gain effectiveness category, both groups are classified as moderately effective. These findings indicate that the developed media has the potential to support the improvement of students' spatial literacy skills.

Discussion

The present study demonstrates that the implementation of ZEP Quiz-assisted interactive learning media significantly enhanced elementary students' spatial literacy in learning cubes and cuboids. Rather than merely improving test performance, these findings indicate that integrating immersive gamified learning with a systematically designed instructional framework creates learning conditions that facilitate meaningful spatial knowledge construction. The observed improvement suggests that students were able to move beyond procedural memorization toward deeper conceptual understanding of three-dimensional geometric relationships. From a constructivist perspective, learning becomes more effective when students actively manipulate representations and construct meaning through interaction rather than passively receiving information. The interactive environment provided by ZEP Quiz appears to support this process by allowing learners to explore spatial objects, receive immediate feedback, and continuously refine their mental representations. Consequently, the findings reinforce the argument that technology-enhanced environments become pedagogically valuable when instructional interaction, rather than technological novelty, becomes the central mechanism supporting conceptual development (Borba et al., 2022; Stahl, 2021). This finding contributes to the growing body of evidence suggesting that digital game-based environments can strengthen higher-order mathematical competencies when intentionally aligned with instructional objectives.

The substantial increase in students' posttest scores also supports theoretical perspectives concerning spatial cognition and multimedia learning. Spatial literacy encompasses visualization, spatial reasoning, and spatial communication, all of which require learners to mentally transform and interpret three-dimensional information. According to multimedia learning principles, presenting information through integrated visual, textual, and interactive representations reduces unnecessary cognitive processing while facilitating meaningful schema construction. The ZEP Quiz environment enabled students to engage simultaneously with visual objects, problem-solving activities, and immediate corrective feedback, thereby strengthening cognitive integration across multiple representational forms. This mechanism helps explain why the improvement extended beyond simple factual recall toward broader spatial understanding. Previous studies similarly

reported that interactive digital environments improve spatial reasoning by enabling repeated manipulation of virtual objects and encouraging active cognitive engagement (Supli & Yan, 2024; Taylor et al., 2023; Yang et al., 2026). However, unlike many earlier investigations focusing primarily on augmented or virtual reality, the present findings demonstrate that a gamified quiz platform can achieve comparable pedagogical benefits when carefully embedded within an instructional design process, thereby extending current theoretical understanding regarding the diversity of digital environments capable of fostering spatial cognition.

Another noteworthy finding is the consistency of learning improvement across both the small-group and large-group implementation stages. Although the large-group trial showed slightly higher posttest achievement and N-Gain values, both implementation phases demonstrated statistically significant improvement, indicating that the instructional effectiveness of the developed media remained stable after iterative refinement. This consistency highlights the importance of the ADDIE development model, which emphasizes continuous revision based on expert validation and formative evaluation before broader implementation. Rather than viewing instructional media as a static product, the iterative development process ensured that weaknesses identified during preliminary implementation were systematically addressed before large-scale application. Such findings support instructional design theory, which argues that educational effectiveness emerges through continuous alignment among learner needs, instructional objectives, content organization, and technological implementation. Similar conclusions have been reported by Hidayati et al. (2026) and Shakeel et al. (2023), who emphasized that iterative instructional design substantially improves learning quality and user experience. Therefore, the present study suggests that the effectiveness of digital learning media depends not solely on technological sophistication but equally on systematic pedagogical development grounded in evidence-based instructional design principles.

The moderate N-Gain obtained in both implementation stages provides further insight into the educational value of the developed media. Although the learning gains did not reach the high category, achieving consistent moderate improvement within a relatively short instructional intervention represents meaningful educational progress, particularly considering the inherent complexity of spatial reasoning development. Spatial literacy involves sophisticated cognitive processes that generally require prolonged learning experiences and repeated exposure to diverse spatial tasks. Consequently, expecting dramatic gains from a single instructional intervention may be unrealistic. The present findings therefore indicate that ZEP Quiz functions as an effective catalyst for conceptual growth rather than an instant solution to spatial learning difficulties. This interpretation aligns with previous studies showing that technology-supported mathematics learning frequently produces moderate but educationally meaningful improvements because conceptual restructuring develops gradually through sustained interaction (Georgiou & Ioannou, 2021; Uwineza et al., 2023; Gittinger & Wiesche, 2024). Accordingly, the moderate N-Gain should be interpreted as evidence of sustainable cognitive development rather than limited instructional effectiveness.

The findings also reveal important implications regarding learner engagement as an underlying mechanism influencing spatial literacy development. Gamified learning environments introduce challenge, exploration, feedback, and achievement elements that encourage students to participate more actively throughout the learning process. Increased engagement likely enabled students to devote greater cognitive effort toward understanding geometric structures instead of merely completing routine classroom exercises. This interpretation is consistent with self-determination theory, which suggests that intrinsically motivating learning environments strengthen persistence, cognitive investment, and conceptual understanding. Numerous recent studies have similarly reported positive relationships between gamification, learner motivation, classroom participation, and academic achievement (Ahmad & Khan, 2024; Kaya & Ercag, 2023; Lampropoulos & Sidiropoulos, 2024; Almufarreh, 2026). Nevertheless, the present study extends this literature by demonstrating that gamification contributes not only to motivational outcomes but also to the development of multidimensional spatial literacy, including visualization, reasoning, and communication. This conceptual extension broadens the educational role of gamified learning beyond engagement toward supporting more complex cognitive competencies in mathematics education.

From a broader theoretical perspective, this study contributes to the emerging discourse concerning digital transformation in elementary mathematics education. Existing literature has predominantly examined popular gamified assessment platforms such as Kahoot and Quizizz, with relatively limited empirical attention devoted to ZEP Quiz, particularly within geometry learning contexts. Furthermore, many previous investigations have emphasized general academic achievement rather than explicitly examining spatial literacy as an integrated construct. By combining ADDIE-based instructional development with systematic evaluation of spatial visualization, reasoning, and communication, the present study addresses these gaps while offering a more comprehensive conceptual understanding of how immersive gamified environments support mathematical cognition. These findings therefore extend existing theories by demonstrating that instructional design quality functions as a mediating mechanism through which digital technologies influence learning outcomes. Rather than attributing educational improvement solely to technological innovation, the results suggest that meaningful learning emerges through the interaction between learner-centered pedagogy, cognitive engagement, and well-designed digital environments. Consequently, this research occupies an important position within the contemporary international literature by providing empirical evidence that advances both instructional design theory and the application of game-based learning for developing higher-order spatial competencies in elementary mathematics education.

Another important aspect emerging from this study concerns the pedagogical role of immediate feedback embedded within the ZEP Quiz environment. Unlike conventional classroom assessments, where feedback is often delayed until after instructional activities have concluded, the developed media enabled learners to identify misconceptions and revise their reasoning during the learning process itself. Immediate feedback functions as a cognitive scaffold that supports self-monitoring, error correction, and metacognitive regulation, thereby facilitating deeper conceptual learning rather than superficial task completion. This mechanism is particularly important in geometry because misconceptions regarding spatial relationships frequently accumulate when students receive insufficient opportunities to verify and refine their mental models. The findings therefore align with cognitive feedback theory, which emphasizes that timely feedback enhances learning efficiency by reducing cognitive uncertainty and strengthening conceptual connections. Similar conclusions have been reported by Janković et al. (2024), Lee and Lai (2024), and Yang et al. (2021), who found that interactive digital platforms promoting continuous feedback significantly improve students' mathematical understanding and argumentation. Nevertheless, the present study extends previous research by demonstrating that immediate feedback contributes specifically to the development of spatial literacy, suggesting that formative digital assessment should be viewed not merely as an evaluation strategy but as an integral component of conceptual learning.

The findings should also be interpreted within the broader context of contemporary elementary mathematics education, where digital transformation increasingly shapes classroom practice. Many elementary schools continue to experience difficulties in implementing student-centered learning because instructional activities remain dominated by teacher explanations and procedural exercises. Under such conditions, opportunities for students to explore geometric concepts independently and develop spatial reasoning are often constrained. The positive outcomes observed in this study indicate that integrating immersive gamified media into regular mathematics instruction may help address this long-standing pedagogical challenge by shifting the instructional focus from knowledge transmission to active knowledge construction. However, the effectiveness of such digital innovation is likely influenced by contextual factors including teachers' digital competence, classroom technological infrastructure, curriculum flexibility, and students' prior experience with educational technology. These contextual considerations may explain why learning gains reported across previous digital learning studies vary despite employing similar technological approaches (Zekeik et al., 2025; Porat & Ceobanu, 2024; Gittinger & Wiesche, 2024). Consequently, educational technology should be understood as part of a broader instructional ecosystem in which successful implementation depends upon the alignment between pedagogy, technology, teacher readiness, and learner characteristics rather than technology alone.

Despite the encouraging findings, several considerations deserve critical reflection. The significant improvement observed after the intervention cannot be attributed exclusively to the technological features of ZEP Quiz, as multiple instructional factors likely interacted throughout the

learning process. The structured learning sequence provided by the ADDIE model, teacher facilitation, collaborative classroom interaction, and repeated exposure to geometry problems may all have contributed to students' improved spatial literacy. Therefore, the present findings should be interpreted as evidence supporting the effectiveness of an integrated instructional system rather than the isolated impact of a single digital platform. This interpretation is consistent with current educational technology literature, which increasingly recognizes that learning outcomes emerge from the interaction among instructional design, learner engagement, assessment practices, and classroom context instead of technological innovation in isolation (Borba et al., 2022; Stahl, 2021; Lampropoulos & Sidiropoulos, 2024). Recognizing these interacting factors strengthens the theoretical interpretation of the results while avoiding deterministic assumptions regarding digital technology. It also highlights the importance of adopting holistic perspectives when evaluating educational innovations in mathematics classrooms.

Overall, this study contributes to the international literature by positioning spatial literacy as a multidimensional learning outcome that can be enhanced through carefully designed gamified instruction rather than through technological immersion alone. Previous studies have frequently evaluated digital learning interventions using general indicators such as academic achievement, motivation, or engagement, whereas the present research explicitly integrates spatial visualization, spatial reasoning, and spatial communication into a unified analytical framework. In doing so, the study provides empirical evidence that instructional design grounded in constructivist learning principles and multimedia learning theory can effectively support higher-order spatial cognition in elementary geometry education. Theoretically, the findings enrich current discussions concerning the mechanisms through which digital game-based learning facilitates conceptual development, while practically offering educators a validated instructional model that can be adapted to similar mathematics learning contexts. More importantly, this research fills an important gap in the global literature by providing one of the few empirical investigations examining ZEP Quiz as a systematically developed instructional medium for spatial literacy development in elementary education. Accordingly, the study advances the field beyond demonstrating whether digital media improve learning outcomes toward explaining how pedagogically designed gamified environments contribute to the development of complex mathematical thinking and support the broader digital transformation of mathematics education.

CONCLUSION

This study demonstrated that the development of ZEP Quiz-assisted interactive learning media using the ADDIE model provides an effective approach to enhancing elementary school students' spatial literacy in learning cubes and cuboids. The systematic development process, supported by expert validation and iterative product refinement, produced an interactive learning medium that successfully promoted students' spatial visualization, spatial reasoning, and spatial communication through immersive and engaging learning experiences. The consistent improvement in students' learning outcomes across both the small-group and large-group trials indicates that integrating gamified virtual environments into mathematics instruction can foster more active participation and facilitate deeper conceptual understanding of three-dimensional geometry. These findings extend existing evidence on digital game-based learning by demonstrating the educational potential of ZEP Quiz as a structured instructional medium rather than merely an assessment platform. Practically, the developed media offers teachers an alternative digital learning strategy that aligns with contemporary student characteristics and supports the implementation of student-centered mathematics instruction. Nevertheless, the study was conducted within a single elementary school and involved a relatively limited number of participants, which may restrict the generalizability of the findings. Future studies are therefore encouraged to examine the effectiveness of the developed media across diverse educational settings, larger participant populations, different mathematical topics, and

experimental research designs that include comparison groups to further validate its educational impact.

AUTHOR CONTRIBUTIONS STATEMENT

Anisah Raniyah Mumtazah Conceptualization, methodology, investigation, software, learning media development, formal analysis, data curation, validation, visualization, and writing original draft preparation. Nurafni Conceptualization, supervision, methodology, validation, project administration, writing review and editing, and final manuscript approval. Both authors contributed substantially to the interpretation of the findings, critically reviewed the manuscript for important intellectual content, approved the final version of the manuscript, and agreed to be accountable for all aspects of the work.

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