

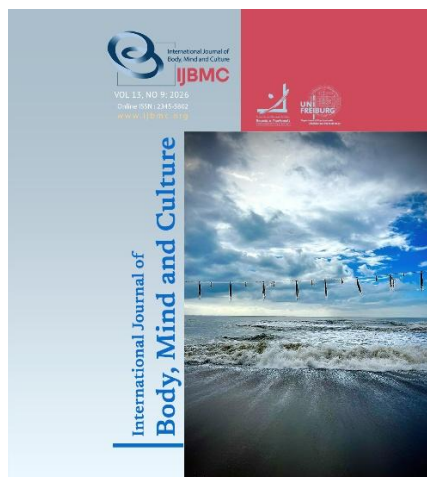
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1 Universitas Negeri Surabaya, Surabaya, Indonesia.

Corresponding author email address:
utaridewi@unesa.ac.id

Peer Tutoring-Based Project-Based Learning and Visual-Spatial Ability among Geography Education Students

Ita Mardiani. Zain¹, Yatim. Riyanto¹, Utari. Dewi^{1*}



ABSTRACT

Objective: This study examined changes in university students' visual-spatial ability following participation in a Peer Tutoring-based Project-Based Learning (PjBL) program.

Methods and Materials: A quantitative quasi-experimental one-group pretest-posttest design was used with 45 undergraduate Geography Education students enrolled in a Basic Geographic Information Systems course. Visual-spatial ability was assessed before and after the intervention. Data were summarized descriptively and analyzed using a paired-samples t-test and normalized gain (N-gain).

Findings: Visual-spatial ability increased significantly from pretest to posttest, $t(44) = -25.07$, $p < .001$, with a mean pretest-posttest difference of -28.58 points (95% CI [-30.88, -26.28]) and a very large within-group effect size (Cohen's $d = 3.74$). The mean N-gain was 0.65 (SD = 0.13), indicating moderate improvement; 68.9% of students were in the moderate-gain category and 31.1% were in the high-gain category.

Conclusion: Peer Tutoring-based PjBL was accompanied by substantial improvement in visual-spatial performance during the instructional period. Because the study lacked a comparison group, the findings should be interpreted as evidence of pretest-posttest change rather than definitive causal evidence of intervention effectiveness.

Keywords: Project-Based Learning, Peer Tutoring, Visual-Spatial Ability, Cognitive Psychology, Geographic Information Systems, Higher Education.

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Introduction

Visual-spatial ability is a cognitive competence that enables individuals to perceive, organize, manipulate, and interpret information represented in visual and three-dimensional forms (Tiwari et al., 2024). As a core component of human cognition, this ability encompasses several mental processes, including recognizing spatial relationships, generating mental images, mentally rotating objects, and interpreting visual representations (Morey, 2018; Zhao et al., 2022). These processes are closely connected to the visuospatial sketchpad within working memory, which temporarily retains and transforms visual information during reasoning, analysis, and problem-solving tasks (Goldsmith et al., 2016). From an educational psychology perspective, visual-spatial ability is fundamental to learning because it facilitates conceptual understanding, visual pattern recognition, creative thinking, and informed decision-making through graphical representations (Liu et al., 2021; Schenck & Nathan, 2024).

The significance of visual-spatial ability is particularly apparent in higher education programs that rely heavily on visual interpretation and spatial analysis. Within Geography Education, especially in Geographic Information Systems (GIS) courses, students are expected to analyze maps, interpret spatial datasets, understand coordinate systems, recognize spatial distributions, integrate multiple thematic layers, and address complex geospatial problems. Successfully completing these tasks requires learners to mentally manipulate spatial information while synthesizing diverse visual representations into coherent conceptual knowledge. Research has shown that students possessing stronger visual-spatial abilities tend to achieve better outcomes in map interpretation, spatial modeling, and geospatial reasoning (Makamure & Jojo, 2021). In contrast, insufficient visual-spatial competence often makes it difficult for learners to organize abstract spatial information, increasing cognitive demands and

limiting the depth of conceptual understanding (Moos & Pitton, 2014). This explanation is consistent with Cognitive Load Theory, which suggests that poorly designed visual instruction can exceed learners' cognitive capacity and reduce learning effectiveness (Castro-Alonso et al., 2019).

The rapid integration of digital technologies, geospatial platforms, and visualization-based instructional media has further increased the importance of developing students' visual-spatial competence. Contemporary higher education emphasizes students' ability to interpret visual information, identify spatial patterns, and construct knowledge through authentic learning experiences rather than relying solely on memorization (Dewi & Primayana, 2019). This perspective aligns with constructivist learning theory, which argues that meaningful learning occurs when learners actively build knowledge through interaction with their environment (Zajda, 2021). Consequently, instructional models that encourage students to engage in authentic inquiry and problem-solving activities are considered more effective for fostering higher-order cognitive abilities than traditional teacher-centered approaches (Dunlosky et al., 2013).

Project-Based Learning (PjBL) represents one instructional approach that reflects constructivist principles. Through project-oriented activities, students are encouraged to investigate authentic problems while applying visualization, spatial planning, interpretation of graphical information, and conceptual reconstruction (Retno et al., 2025; Wang & Zhang, 2025). Developing tangible products or project outcomes requires learners to transform abstract concepts into meaningful visual representations, thereby strengthening mental visualization and spatial reasoning skills (Setyo Retno, 2022). Furthermore, project implementation simultaneously activates multiple cognitive processes—including perception, attention, memory, problem solving, and metacognitive regulation—which collectively

contribute to deeper understanding and more meaningful learning experiences (Sart, 2014; Sulong et al., 2023).

The educational impact of Project-Based Learning may become even greater when combined with peer tutoring. This instructional strategy is supported by Vygotsky's sociocultural theory, which emphasizes that cognitive growth is promoted through social interaction within the Zone of Proximal Development (ZPD) (Kendal, 2011; Lasmawan & Budiarta, 2020). In peer tutoring environments, students collaboratively exchange ideas, clarify concepts, demonstrate procedures, and solve learning tasks together, creating an interactive setting that supports knowledge construction (Budianingsih & Qadriani, 2021; Zain et al., 2026). Previous empirical studies have likewise reported that collaborative learning approaches, including peer tutoring and the Jigsaw strategy, contribute positively to students' academic performance, learning motivation, creativity, and collaborative skills (Ismuningsih & Mawardi, 2022; Setyo Retno, 2022).

Despite the substantial body of research highlighting the benefits of Project-Based Learning and peer tutoring, existing studies have primarily examined broad educational outcomes such as academic achievement, collaborative competence, creativity, and motivation. Comparatively limited attention has been given to investigating whether integrating peer tutoring into Project-Based Learning specifically enhances university students' visual-spatial ability, particularly within Geography Education programs where geospatial visualization plays a central role. As a result, empirical evidence concerning the effectiveness of peer-assisted Project-Based Learning in promoting visual-spatial development among Geography Education students remains relatively scarce. Recent higher-education evidence also indicates that peer-guided PjBL can strengthen learner self-efficacy in a GIS context, reinforcing the

plausibility of combining structured peer support with authentic projects (Zain et al., 2026).

Accordingly, this study investigated changes in university students' visual-spatial ability following the implementation of peer-assisted Project-Based Learning in a Geographic Information Systems (GIS) course. By focusing on undergraduate students in Geography Education, the research provides additional empirical evidence regarding the potential contribution of integrating collaborative learning with project-based instruction to support the development of visual-spatial competence. The findings are expected to offer practical guidance for educators in designing instructional strategies that strengthen spatial reasoning while enriching learning experiences within geospatial education.

Methods and Materials

Research Design

This research adopted a quantitative quasi-experimental approach using a one-group pretest-posttest design to investigate changes in students' visual-spatial ability after the implementation of Peer Tutoring-based Project-Based Learning (PjBL) (Anggreani et al., 2023; Vonny et al., 2023). Participants completed a visual-spatial ability assessment before the instructional program (pretest) and again after completing the intervention (posttest), allowing comparisons of students' performance across the two measurement occasions. The study was conducted in an existing classroom setting, making random assignment and the inclusion of a control group impractical. Consequently, the design is appropriate for identifying changes over the instructional period; however, it does not allow the observed improvements to be attributed solely to the intervention. Other influences, including students' natural academic progression, repeated exposure to the test, previous learning experiences, classroom instruction, and independent learning outside scheduled classes, may also have affected the outcomes.

Participants

The study involved 45 undergraduate students from the Geography Education Study Program who were enrolled in the Basic Geographic Information Systems (GIS) course. Participants were selected through purposive sampling because they fulfilled the characteristics considered necessary for implementing the Peer Tutoring-based PjBL strategy (Mukaromah et al., 2022; Swari et al., 2022). Since all respondents originated from a single academic program at one university, caution should be exercised when extending the findings to different educational institutions, academic disciplines, or student populations.

Intervention

The instructional treatment consisted of applying the Peer Tutoring-based Project-Based Learning model throughout the Basic GIS course. During the intervention, students collaborated in small groups to complete authentic GIS-related projects across several scheduled learning sessions. Each group included a peer tutor whose role was to facilitate discussion, guide collaborative problem solving, encourage active participation, and support fellow students during project completion. Throughout the learning process, the lecturer served primarily as a facilitator by coordinating classroom activities, supervising group collaboration, providing instructional guidance when required, and maintaining consistency in the implementation of the learning procedures across all groups.

Measures

Students' visual-spatial ability was evaluated using a standardized test administered twice: prior to the intervention as a pretest and following the completion of the learning activities as a posttest. The pretest established participants' baseline visual-spatial ability, whereas the posttest assessed changes after exposure to the instructional model. To complement these data, a student perception questionnaire was distributed to obtain feedback regarding the learning experience,

while classroom observations were conducted to monitor the fidelity of the Peer Tutoring-based PjBL implementation during the study (Ismuningsih & Mawardi, 2022). Nevertheless, only the pretest and posttest scores from the visual-spatial ability assessment were included in the statistical analyses presented in this paper.

Data Analysis

The research data were analyzed using both descriptive and inferential statistical techniques. Descriptive analysis summarized students' performance by calculating the mean, standard deviation, minimum score, and maximum score for both the pretest and posttest. Before conducting hypothesis testing, the distribution of the data was examined using the normality test. Because the results indicated that the assumption of normality was satisfied ($p > 0.05$), changes in students' visual-spatial ability were evaluated using a paired-samples t-test. In addition, the magnitude of learning improvement was determined by calculating the normalized gain (N-gain), which was interpreted according to three categories: low ($g < 0.30$), moderate ($0.30 \leq g < 0.70$), and high ($g \geq 0.70$) (Chang et al., 2025; Davis et al., 2023). Owing to the absence of a comparison group, the statistical results should be interpreted as indicating significant changes in students' visual-spatial ability throughout the study period rather than providing definitive evidence that the instructional intervention alone produced those changes.

Findings and Results

Normality Screening

Table 1.

Normality screening of visual-spatial ability scores

Assessment	n	p-value	Decision
Pretest	45	.280	Normal
Posttest	45	.085	Normal

As shown in Table 1, normality screening was satisfactory at both pretest ($p = .280$) and posttest ($p = .085$). The paired-samples t-test was therefore used for the pretest-posttest comparison.

Normalized Gain

Table 2.

Descriptive statistics of N-gain scores for visual-spatial ability

Statistic	Value
Number of participants	45
Minimum N-gain	0.49
Maximum N-gain	0.90
Mean	0.65
Standard deviation	0.13
Moderate ($0.30 \leq g < 0.70$)	31 students (68.9%)
High ($g \geq 0.70$)	14 students (31.1%)
Low ($g < 0.30$)	0 students (0.0%)

Table 2 summarizes the descriptive statistics of students' normalized gain (N-Gain) scores. The mean N-Gain value was 0.65 (SD = 0.13), indicating that students experienced a moderate level of improvement in visual-spatial ability after completing the Peer

Tutoring-based Project-Based Learning intervention. Individual scores ranged from 0.49 to 0.90, reflecting differences in the magnitude of learning gains among participants.

When categorized according to the N-Gain criteria, most students demonstrated improvement within the moderate range. Specifically, 31 students (68.9%) were classified in the moderate category, whereas the remaining 14 students (31.1%) achieved gains in the high category. No participant fell into the low-gain category. Overall, these results indicate that, despite variation in individual learning outcomes, the implementation of the Peer Tutoring-based Project-Based Learning model was accompanied by meaningful improvements in students' visual-spatial ability, with most participants demonstrating gains at least within the moderate classification.

Pretest-Posttest Change in Visual-Spatial Ability

Table 3.

Paired-samples t-test for visual-spatial ability

Outcome	Mean difference (Pre - Post)	SD of difference	95% CI	t	df	p / effect size
Visual-spatial ability	-28.58	7.65	-30.88 to -26.28	-25.07	44	$p < .001$; $d = 3.74$

Table 3 shows a statistically significant pretest-posttest increase in visual-spatial ability, $t(44) = -25.07$, $p < .001$. The mean difference was -28.58 points when calculated as pretest minus posttest, with a 95% confidence interval from -30.88 to -26.28. The standardized within-group effect was very

large (Cohen's $d = 3.74$). These results document substantial change during the intervention period, but the one-group design does not isolate the intervention from testing, maturation, concurrent instruction, or other time-related influences.

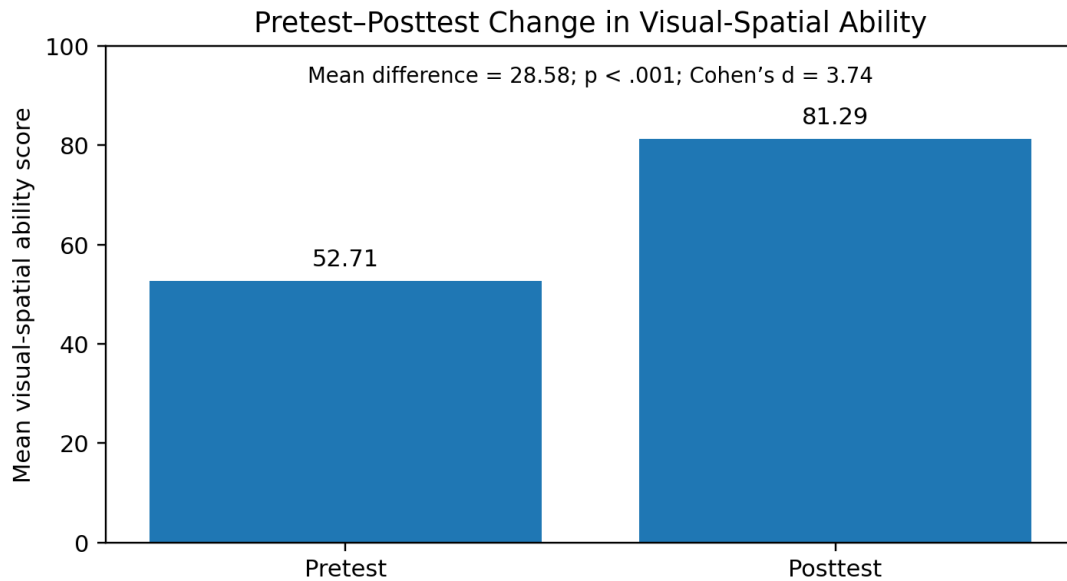


Figure 1. Mean visual-spatial ability scores at pretest and posttest

As illustrated in Figure 1, the mean visual-spatial ability score increased from 52.71 at pretest to 81.29 at posttest, a raw improvement of 28.58 points. This descriptive pattern is consistent with the inferential results in Table 3.

Discussion and Conclusion

The results of this study indicate that students achieved higher levels of visual-spatial ability after completing the Peer Tutoring-based Project-Based Learning (PjBL) program. Statistical analysis demonstrated significant differences between pretest and posttest scores, suggesting that students performed more effectively on visual-spatial tasks following the instructional activities (Hindal, 2014). In addition, the moderate normalized gain (N-Gain) value reflects a meaningful improvement in learning outcomes, although the extent of progress differed among participants (Setyo Retno, 2022). Nevertheless, because the study employed a one-group pretest-posttest design without a comparison group, the observed improvement should not be interpreted as definitive evidence that the instructional intervention alone produced these outcomes. Instead, the findings indicate changes that occurred during the implementation of the Peer Tutoring-based PjBL program and should be

interpreted within the limitations of the research design (Farikah et al., 2022).

Educational psychology describes visual-spatial ability as the cognitive capacity to perceive, organize, interpret, and mentally transform visual and spatial information (Ray-Subramanian, 2021). This competence involves several interconnected processes, including spatial visualization, mental rotation, spatial orientation, and the recognition of relationships among objects in space, all of which contribute to higher-order cognitive functioning. According to information processing theory, these abilities depend substantially on the visuospatial sketchpad component of working memory, which temporarily stores and manipulates visual information while individuals perform reasoning and problem-solving tasks (Wang, 2017). Consequently, instructional environments that repeatedly require learners to interpret visual representations and engage in spatial reasoning may strengthen these cognitive processes over time.

The improvement identified in this study is compatible with the theoretical characteristics of Project-Based Learning. This instructional model encourages learners to investigate authentic problems, develop projects, interpret visual

information, construct representations, and generate solutions to real-world situations (Gobert et al., 2015). Through continuous engagement with these activities, students have repeated opportunities to organize spatial information, refine mental representations, and practice visual reasoning in meaningful contexts. Previous studies likewise suggest that project-oriented learning contributes positively to the development of spatial visualization and mental representation skills (Cohrsen et al., 2017). Therefore, the present findings are consistent with existing evidence indicating that project-based learning environments have the potential to facilitate the growth of visual-spatial competence.

The findings can also be understood through the lens of constructivist learning theory, which views knowledge as something actively constructed through interaction with meaningful experiences rather than transmitted directly from teacher to learner (Bormanaki & Khoshhal, 2017). During project implementation, students are required to connect prior understanding with newly acquired information, reorganize their existing knowledge structures, and apply concepts to authentic situations. These learning experiences may encourage deeper conceptual understanding while simultaneously strengthening students' ability to reason about spatial relationships.

Another aspect that may have supported the observed improvement is the integration of peer tutoring into the project-based learning process. Vygotsky's sociocultural theory emphasizes that cognitive development is enhanced through collaborative interaction within the Zone of Proximal Development (ZPD). By discussing ideas, explaining concepts, demonstrating procedures, and solving problems together, students have opportunities to clarify misunderstandings and exchange strategies for interpreting visual information (Li et al., 2022; Negrea & Gartland, 2025). Although the quality of peer interaction was not directly evaluated in this

investigation, the findings correspond with previous research indicating that collaborative learning environments can promote academic development and cognitive growth. A closely aligned higher-education study also reported that a peer-guided PjBL model in a GIS course was associated with improved student self-efficacy, supporting the broader value of peer-supported project structures for cognitive and motivational outcomes (Zain et al., 2026).

Previous educational psychology literature has identified several learner characteristics-including motivation, sustained attention, self-efficacy, and metacognitive awareness-as important contributors to successful learning in collaborative and project-based instructional settings (Hartelt & Martens, 2024). Likewise, metacognitive activities such as planning, monitoring, and evaluating one's own learning have been associated with stronger spatial reasoning performance. While these factors provide plausible theoretical explanations for the improvement observed in the present study, they were not measured directly. Consequently, their influence cannot be confirmed empirically and should be interpreted only as theoretical mechanisms supported by prior research.

The moderate N-Gain score further suggests that the improvement achieved by participants was not uniform. Variations in learning outcomes may be associated with individual differences in cognitive ability, spatial intelligence, learning motivation, communication skills, previous experience, and cognitive style, all of which have been reported in earlier studies as influencing learning performance (Shareef & Farivarsadri, 2020; Sukmawati et al., 2023). Because these learner characteristics were beyond the scope of the current investigation, their potential contribution remains speculative and requires further empirical examination.

Several alternative explanations should also be considered when interpreting the findings. Without a control group, improvements in posttest performance

cannot be attributed exclusively to the Peer Tutoring-based PjBL intervention. Other factors, including familiarity with the assessment instrument due to repeated testing, students' natural cognitive and academic development during the semester, instructional support provided by the lecturer, previous experience with Geographic Information Systems (GIS), and independent study undertaken outside formal classroom activities, may also have contributed to the observed increase in visual-spatial ability.

In summary, students demonstrated significantly higher visual-spatial ability after participating in the Peer Tutoring-based Project-Based Learning program. Although the research design does not permit causal inference, the results are consistent with existing theoretical perspectives and empirical studies suggesting that collaborative and project-oriented learning environments may promote the development of visual-spatial competence. Future investigations are encouraged to employ experimental or quasi-experimental designs incorporating comparison groups and to include direct measures of motivation, metacognitive regulation, cognitive engagement, and the quality of peer interaction. Such approaches would provide stronger evidence regarding both the effectiveness of Peer Tutoring-based Project-Based Learning and the psychological mechanisms underlying improvements in university students' visual-spatial ability.

Educational Implications

For GIS and geography education, the findings support the use of carefully structured project work in which students must interpret maps, manipulate layers, reason about spatial relationships, and explain procedures to peers. Peer tutors should be prepared to scaffold rather than replace learners' reasoning, while instructors should monitor role distribution, task difficulty, and the quality of peer explanation. Embedding repeated visual-spatial practice within authentic GIS projects may provide a practical way to

integrate cognitive skill development with disciplinary learning.

Limitations

Despite providing valuable insights, this study has several limitations that should be considered when interpreting the findings. First, the use of a one-group pretest–posttest design without a comparison group limits the ability to determine whether the observed improvements resulted exclusively from the Peer Tutoring-based Project-Based Learning intervention. Other factors occurring during the instructional period may also have contributed to the changes in students' visual-spatial ability.

Second, the participants were selected through purposive sampling from a single study program at one university, and the relatively limited sample size may restrict the broader applicability of the findings. Consequently, caution should be exercised when generalizing the results to different educational settings, institutions, or student populations.

Third, administering the same assessment instrument before and after the intervention may have introduced a testing or practice effect, whereby students' familiarity with the test influenced their posttest performance independently of the instructional treatment. In addition, although the visual-spatial ability instrument was employed to evaluate learning outcomes, more comprehensive evidence regarding its validity and reliability should be presented to strengthen confidence in the measurement results.

Another consideration is that contextual variables, including lecturer facilitation, classroom dynamics, and the overall learning environment, were not explicitly controlled and may have affected students' performance during the intervention. These contextual influences should therefore be acknowledged as potential contributors to the observed outcomes.

Finally, this investigation focused exclusively on students' immediate performance following the

completion of the instructional program. It did not examine the long-term retention of visual-spatial ability or investigate the psychological processes that may explain the observed improvement, such as learning motivation, metacognitive regulation, cognitive engagement, or the quality of peer interaction. Future research is therefore recommended to employ more rigorous experimental or quasi-experimental designs with comparison groups, recruit larger and more diverse samples, provide stronger evidence of instrument validity and reliability, and incorporate longitudinal follow-up assessments to evaluate the sustainability of learning outcomes and identify the mechanisms underlying improvements in visual-spatial ability.

Visual-spatial ability increased markedly from pretest to posttest among the 45 Geography Education students who participated in the Peer Tutoring-based PjBL program. The mean N-gain of 0.65 indicated moderate improvement, and the paired-samples analysis showed a statistically significant and very large within-group change. The pattern is theoretically consistent with project-based, constructivist, and peer-assisted learning perspectives. However, because no comparison group was included, the findings should be interpreted as strong evidence of change across the instructional period rather than definitive proof of a causal treatment effect. Future controlled studies should examine whether these gains are replicated, sustained over time, and mediated by variables such as self-efficacy, metacognitive regulation, cognitive engagement, and the quality of peer interaction.

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Declaration of Interest

The authors of this article declared no conflict of interest.

Ethical Considerations

The study protocol adhered to the principles outlined in the Declaration of Helsinki, which provides guidelines for ethical research involving human participants. Ethical considerations in this study were that participation was entirely optional.

Transparency of Data

In accordance with the principles of transparency and open research, we declare that all data and materials used in this study are available upon request.

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Authors' Contributions

All authors equally contributed to this study.

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