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THE EFFECTIVENESS OF GEOSPATIAL TECHNOLOGY-INTEGRATED PROJECT-BASED LEARNING MODEL ON STUDENTS' SPATIAL THINKING SKILLS ACROSS DIFFERENT LEARNING STYLES

Zahrofi Alifarhan Adipranata[1*], Ifan Deffinika[2], Evi Fitriana[3]

[1*,2,3] Universitas Negeri Malang, Malang, Indonesia.
*Zahrofi.alifarhan.2207216@students.um.ac.id

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Spatial thinking is essential in geography learning for understanding human-space relationships, yet conventional instruction often fails to develop higher-order spatial reasoning. This study examines the effectiveness of a geospatially integrated Project-Based Learning (PjBL) model on students' spatial thinking skills, while accounting for learning styles as a moderating variable. A quasi-experimental pretest-posttest control-group design was employed, involving 425 tenth-grade students from SMAN 1 Batu. Two purposively selected classes served as the experimental (geospatial PjBL using Google Earth) and control (lecture-based instruction) groups. Results showed that the geospatially integrated PjBL model significantly improved students' spatial thinking abilities ($p < 0.001$). The most substantial improvement occurred in the Tools of Representation dimension, followed by the Concepts of Space and the Cognitive Processes to Evaluate Spatiality dimensions. Moreover, students with kinesthetic and audiovisual learning styles showed greater improvement than those with purely auditory or visual preferences. These findings suggest that integrating geospatial technology into PjBL strengthens spatial visualization and cognitive processes through active, contextual experiences. This study contributes by integrating learning styles as a moderating variable into geospatial PjBL, an underexplored area.

Corresponding Author:
Zahrofi Alifarhan Adipranata
Zahrofi.alifarhan.2207216@Students.um.ac.id

INTRODUCTION

Geography is a discipline that examines the reciprocal relationship between humans and space; therefore, its instruction demands strong spatial thinking skills (Oktaviani et al., 2017). Spatial thinking skills enable students to critically comprehend the concepts of location, distance, pattern, and the distribution of geographical phenomena (Hidayati et al., 2021). However, various studies indicate that this capability has not developed optimally because geography instruction in schools remains dominated by conventional, teacher-centered methods (Buana & Putra, 2023). Such learning models tend to restrict students' active participation in interpreting spatial data and applying spatial concepts within real-world contexts. Consequently, students often cannot connect theoretical knowledge with the geographical phenomena in their surroundings. These limitations underscore the imperative for interactive, contextual, and project-based learning approaches to foster spatial reasoning.

Project-Based Learning (PjBL) is a learning model proven effective in enhancing student engagement and higher-order thinking skills (Alexandersen et al., 2025). PjBL requires students to design, implement, and present real-world projects related to the subject matter. In the context of geography, this model provides learners with opportunities to solve spatial problems using empirical data and geospatial technologies (Putra et al., 2021; Mu'ayyadah & Fatmawati, 2021; Nadifa, Wahyudi, and Sumariyani, 2025). Activities such as map delineation, satellite image interpretation, and land-use change analysis facilitate experiential learning. This approach fosters cognitive and affective competencies aligned with 21st-century skills.

The PjBL model has been extensively researched and proven to enhance learning outcomes compared to conventional methods by facilitating collaboration, problem-solving, and reflection (Zhang et al., 2022). In geography learning, integrating PjBL with Geographic Information Systems (GIS) has been empirically proven to bolster students' spatial thinking skills (Sofias & Pierrakeas, 2021). For instance, Sofias and Pierrakeas (2020) demonstrated that WebGIS-based projects significantly improved high school students' spatial ability scores compared to those in a control group. Incorporating empirical data, digital maps, and geospatial applications into project-based frameworks enables students not only to grasp theoretical concepts but also to apply them directly to authentic environments. This pedagogical advantage facilitates multimodal learning and effectively accommodates diverse learning styles.

Geospatial technologies, such as Google Earth and Geographic Information Systems (GIS), have been proven effective as visual and contextual learning media (Lee & Bednarz, 2012). Using spatial data and high-resolution imagery, students can more concretely understand the interrelationships among spatial phenomena (Fatimatuzzahro et al., 2023). A study by Oktavianto (2017) demonstrated that Google Earth-assisted geography instruction significantly enhanced high school students' spatial thinking skills. Furthermore, integrating geospatial technologies aligns with constructivist principles, in which learners construct their own knowledge through the exploration of spatial data. Employing these geospatial tools within a Project-Based Learning (PjBL) framework facilitates an active, multimodal educational experience that is highly relevant to authentic, real-world contexts.

Beyond learning approaches, individual differences in learning styles also impact the effective mastery of spatial concepts. Students possess distinct learning preferences, visual, auditory, audiovisual, or kinesthetic, which dictate how they assimilate and process information (Abidoye et al., 2023). Research by Hasna Hidayanti et al. (2019)

showed that learning styles significantly influence spatial thinking skills when integrated with active learning models such as REACT (Relating, Experiencing, Applying, Cooperating, Transferring). Students with a kinesthetic learning style showed the greatest improvement through direct, hands-on learning experiences, whereas auditory learners showed the least improvement due to limited involvement in physical activities (Wu & Wang, 2025).

Integrating learning styles into the design of Project-Based Learning (PjBL) can significantly enhance learning outcomes. Wu et al. (2025) found that grouping students according to the Felder-Silverman model within a PjBL framework effectively improved STEM learning attitudes among secondary school students. These findings reinforce the argument that the success of PjBL is highly contingent upon the alignment between learning syntax and students' dominant learning styles. Within the context of geography education, visual learners benefit from maps and imagery, audiovisual learners from verbal explanations and interactive media, while kinesthetic learners thrive through practical field delineation activities (Gusriani et al., 2022).

Figure 1. Learning Mode Poll Results Chart

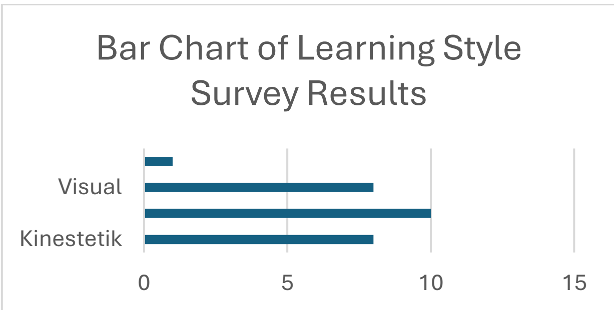

Figure 2. Bar Chart of Learning Style Survey Results.

A preliminary survey conducted among tenth-grade students at State Senior High School (SMAN) 1 Batu found that Project-Based Learning (PjBL) was the most preferred learning model (37%), followed by Problem-Based Learning (26%), Game-Based Learning (21%), and Think-Pair-Share (16%). Concurrently, the dominant learning styles identified within this cohort were kinesthetic and audiovisual. These findings indicate that the majority of students exhibit active and visual learning inclinations, which align seamlessly with the inherent characteristics of the PjBL syntax.

This premise solidifies the rationale for selecting PjBL, integrated with geospatial technologies, as the most viable pedagogical model for cultivating spatial thinking skills. Nevertheless, its actual efficacy necessitates empirical validation through rigorously measured experimentation.

Based on previous research findings, few studies have simultaneously integrated the PjBL model, geospatial technology, and learning styles within a single research framework. Most of the existing literature predominantly isolates pairs of variables such as PjBL and spatial thinking (Fadjarajani et al., 2024) or learning styles and educational outcomes (Hasna Hidayanti et al., 2019) without examining their complex interactions within the context of digital geography. To date, no empirical research has investigated the simultaneous interaction among the PjBL model, geospatial technologies, and learning styles, acting as a moderating variable, in enhancing spatial thinking skills. This omission is particularly significant given that spatial thinking is a multidimensional competency that is inherently influenced by learning experiences, the media used, and students' cognitive preferences (Silviariza & Handoyo, 2020). This study fills this gap by analyzing the effectiveness of the PjBL model, integrated with geospatial technology, on spatial thinking skills, while considering learning styles as a moderating factor.

This study aims to examine the impact of a geospatial technology-integrated Project-Based Learning (PjBL) model on students' spatial thinking skills while accounting for their diverse learning styles. The selection of the PjBL model is underpinned not only by student preference surveys but also by its intrinsic merits in fostering contextual, collaborative, and real-world-oriented learning. PjBL facilitates active student engagement through systematic phases, from project planning and execution to evaluation, that promote the integration of conceptual knowledge with practical application. Within the geospatial instruction context, students do more than merely comprehend theories of geographic distribution; they actively participate in tasks such as strategic location mapping and spatial pattern analysis utilizing empirical data. The inherent flexibility of this model further accommodates diverse learning preferences: visual learners benefit from graphical representations, verbal instructions, and interactive student worksheets; audiovisual learners benefit from a combination of visual and auditory stimuli; and kinesthetic learners deepen their understanding through direct, hands-on practice. Consequently, integrating the PjBL model with learning style differentiation is posited to significantly enhance student engagement and strengthen spatial thinking skills in meaningful ways.

The selection of remote sensing materials in this study was intended to ensure alignment between the project's characteristics and students' learning styles. This material is multidimensional because it combines visual, technical, and applicative aspects through the use of geospatial technologies such as Google Earth, which allows students to delineate the area around their residence and hone their image interpretation skills (Li et al., 2020). Based on this foundation, this study aims to analyze the differences in the influence of the PjBL model integrated with geospatial technology and students' learning styles on spatial thinking skills, compared to conventional lecture-based learning. The results of this study are expected to make theoretical contributions to the development of technology-based geography learning models and practical contributions to teachers in designing contextual, adaptive learning activities that align with students' learning styles. Thus, combining learning models and learning styles can be an effective strategy for improving students' spatial thinking in the digital learning era.

RESEARCH METHODS

This study employed a quantitative quasi-experimental approach, using a pretest-posttest control-group design, to analyze the effectiveness of a geospatial technology-integrated Project-Based Learning (PjBL) model on students' spatial thinking skills, with learning styles as a moderating variable. This design enables researchers to compare learning outcomes between two distinct learning settings while preserving the authenticity of the natural classroom context (Creswell & Creswell, 2018) The experimental group (Class X-4) received a treatment comprising the implementation of the geospatial technology-integrated PjBL model utilizing Google Earth and Project-Based Worksheets (LKPD). In contrast, the control group (Class X-6) engaged in conventional lecture-based instruction. The research procedure encompassed three primary phases: (1) preparation involving instrument development and pretest administration; (2) treatment consisting of PjBL implementation in the experimental group and conventional instruction in the control group; and (3) evaluation and analysis comprising posttest data collection, data processing, and interpretation of statistical results, as delineated in the following research design.

Table 1. Research Design

Groups	Pretest (O_1)	Treatment (X)	Posttest (O_2)
Experimental	O_1	PjBL integrated geospatial technology	O_2
Control	O_2	Conventional Learning	O_2

Data source: Pre-test and post-test research design test (Dimitrov & Rumrill, 2003)

The study population comprised all tenth-grade students at SMAN 1 Batu during the 2024/2025 academic year, totaling 425 students distributed across 12 intact classes. A purposive sampling technique was employed, specifically predicated on the equivalence of average academic performance across the classes. Based on this criterion, Class X-4 (n = 35) was designated as the experimental group, while Class X-6 (n = 36) was established as the control group.

This study involves two primary variable categories: (a) Independent variables of project-based learning models integrated with geospatial technology and learning styles; and (b) Dependent variables: spatial thinking skills. The research instruments consist of: (1) Spatial thinking ability tests developed based on the indicators of Concepts of Space, Tools of Representation, and Cognitive Processes (Jo & Bednarz, 2009). (2) A learning style questionnaire to identify visual, auditory, audiovisual, and kinesthetic preferences;

and (3) Observation sheets and interview protocols to substantiate quantitative findings with qualitative data. The content validity of the instruments was established through expert judgment, while reliability was verified using the Cronbach's Alpha coefficient, yielding values ranging from 0.755 to 0.817.

Research data were collected through pre- and posttests to assess changes in students' spatial thinking skills before and after the implementation of the learning model. Quantitative data analysis was conducted using SPSS version 25. The initial phase of the analysis included validity and reliability testing to ensure the instruments' reliability, as well as normality (Shapiro-Wilk) and homogeneity (Levene's test) evaluations to verify compliance with parametric statistical assumptions. The validity test results showed that most items demonstrated a significant correlation with the total score ($r > 0.349$; $p < 0.05$), while the Cronbach's Alpha coefficient of 0.817 indicated high internal consistency. Additionally, the Kolmogorov–Smirnov test yielded a significance value of 0.184 ($p > 0.05$), indicating that the data were non-normally distributed and homogeneous across all groups.

After the data were declared valid, a paired-samples t-test was conducted to determine significant differences between pretest and posttest scores within each group, and an independent-samples t-test was conducted to compare learning outcomes between the experimental and control groups. In addition, gain scores were calculated to assess the relative increase in spatial thinking skills. The results of this analysis serve as the basis for assessing the effectiveness of the Project-Based Learning (PjBL) model integrated with geospatial technology on students' spatial thinking skills, while accounting for variations in learning styles (visual, audiovisual, kinesthetic).

RESULT AND DISCUSSION

1. Result

   Data Validity, Reliability, and Prerequisites Test

   Before analyzing differences in learning outcomes, researchers conducted validity, reliability, and prerequisite data tests to ensure the instruments used were appropriate for measuring students' spatial thinking abilities.

   Validity testing was conducted utilizing a Pearson Product-Moment correlation analysis on 13 test items. The test results showed that most instrument items had positive correlations with the total score, with a significance level of 0.01. The highest correlation coefficients were observed in items P6 ($r = 0.840$), P5 ($r = 0.759$), and P1 ($r = 0.753$), indicating that these specific items possess excellent discriminating power. Conversely, item P3 yielded the lowest correlation coefficient ($r = 0.044$) and was consequently recommended for revision. Based on these findings, 10 of the 13 items were deemed valid, as their correlation values exceeded the critical r-table threshold ($r = 0.349$; $N = 35$; $p < 0.05$). Therefore, the instrument was deemed appropriate and viable for assessing students' spatial thinking skills.

   A reliability test was conducted to assess internal consistency using

Cronbach's Alpha. The SPSS analysis yielded α=0.817, which falls within the high-reliability category. This result signifies that the test items collectively exhibit a robust level of consistency in measuring the construct of spatial thinking skills. Furthermore, the“Cronbach's Alpha if Item Deleted” metrics indicated that the exclusion of any single item would not substantially diminish the overall reliability; consequently, all items were retained in the final instrument.

Item-Total Statistics

	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
P1	67.4571	47.667	.753	.778
P2	67.2857	50.445	.387	.794
P3	67.5714	52.605	.044	.807
P4	67.4857	49.610	.463	.790
P5	67.6571	44.820	.759	.766
P6	64.9429	42.820	.840	.755
P7	64.7714	46.005	.565	.777
P8	64.6571	47.585	.274	.801
P9	65.7143	42.739	.461	.785
P10	67.0286	42.205	.595	.769
P11	67.7429	41.550	.547	.775
P12	67.2000	42.929	.394	.796
P13	64.4857	47.904	.176	.817

Figure 3. Results of the Instrument Validity and Reliability Test (Source: Data processing using SPSS.)

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest_eksperimen	.125	35	.184	.922	35	.016
Pretest_Kontrol	.127	35	.167	.942	35	.063
PostTest_Eksperimen	.222	35	.000	.881	35	.001
Posttest_Control	.159	35	.025	.931	35	.031

a. Lilliefors Significance Correction

Figure 4. Results of Normality Test (Source: SPSS Data Processing Results)

The normality test in this study used the Shapiro-Wilk test, as the sample sizes for each group were less than 50 respondents ($N < 50$). Based on the Shapiro-Wilk test results, the experimental and control groups had p-values below the normality significance level ($p < 0.05$), indicating that the data were not normally distributed. Therefore, the analysis of learning outcome improvement for the control group continued using nonparametric tests, namely the Wilcoxon Signed-Rank test and the Mann-Whitney test.

Comparative Analysis of Pretest and Posttest Scores

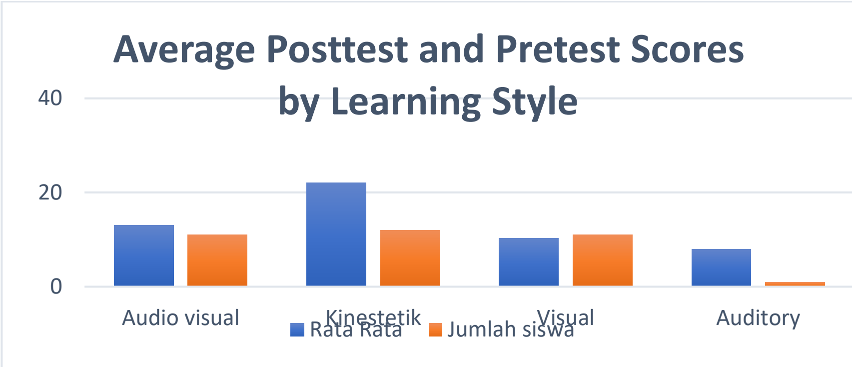

Figure 5. Results: Average Posttest and Pretest scores by Learning Style (Source: Data processing using Excel.)

A comparative analysis of pretest and posttest scores was conducted to determine the improvement in students' spatial thinking abilities within each group following the intervention. Figure 4 presents the average posttest-pretest gain scores by learning style in the experimental class. The initial data show that the kinesthetic and audiovisual learning styles had very high average gain scores. However, this data must be revalidated using inferential statistical tests. Because the data were non-normal, the analysis of learning outcome improvements was conducted using two nonparametric tests: the Paired Samples Test (Wilcoxon Signed-Rank Test), the Mann-Whitney Test, and the Kruskal-Wallis Test.

Result of Two Related Samples Test (Wilcoxon Signed-Rank Test)

Because the results of the normality test indicated that the data in the control class were not normally distributed (Shapiro–Wilk p = 0.0000 < 0.05), the analysis of improvement in learning outcomes in the control class was conducted using the nonparametric Wilcoxon Signed-Rank Test.

Ranks

		N	Mean Rank	Sum of Ranks
PosttestC - PretestC	Negative Ranks	11[a]	18.45	203.00
	Positive Ranks	20[b]	14.65	293.00
	Ties	5[c]		
	Total	36		
PosttestE - PretestE	Negative Ranks	0[d]	,00	,00
	Positive Ranks	35[e]	18.00	630.00
	Ties	0[f]		
	Total	35		

a. PosttestC < PretestC
b. PosttestC > PretestC
c. PosttestC = PretestC
d. PosttestE < PretestE
e. PosttestE > PretestE
f. PosttestE = PretestE

Figure 6. Results of the Two Related Sample Test analysis (Source: SPSS data processing results)

Table 2. Wilcoxon Signed-Rank Test (Two Related Sample Test) Test Results: Control and Experimental Classes.

Variable	Negative Ranks	Positive Ranks	Ties	Total	Remarks
PosttestC – PretestC	11 students	20 students	5 students	36	Insignificant increase
PosttestE – PretestE	0 students	35 students	0 students	35	Significant improvement (p < 0,001)

Source: SPSS data processing results

Based on the test results presented in Table 2, the control group included 20 students with increased posttest scores, 11 with decreased scores, and 5 with scores remaining unchanged (Positive Ranks = 20, Negative Ranks = 11, Ties = 5). This indicates that conventional instruction yielded inconsistent and non-significant improvements.

Conversely, all 35 students in the experimental group demonstrated an increase in their posttest scores relative to their pretest scores (Positive Ranks = 35, Negative Ranks = 0, Ties = 0), yielding a *p*-value of < 0.001. These results substantiate that implementing the geospatial technology-integrated PjBL model resulted in a significant and consistent enhancement in students' spatial thinking skills.

The Wilcoxon test results reveal that the experimental group experienced a significant increase in spatial reasoning following project-based instruction integrated with geospatial technologies. In contrast, the control group showed only marginal, non-significant gains. The significant improvement observed in the experimental group indicates that project-based activities, bolstered by interactive spatial media (e.g., Google Earth and project-based worksheets), effectively empower students to think critically and understand spatial concepts concretely.

Results of the Mann-Whitney U Test for Two Groups

Test Statistics[a]

	N_Gain
Mann-Whitney U	6.000
Wilcoxon W	672.000
Z	-7.179
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: Kelompok_Kelas

Figure 7. Results of the Mann-Whitney U Test
(Source: SPSS data processing results)

Based on the results of the Mann-Whitney U test of the Normalized Gain (N-Gain) scores for students' spatial thinking abilities, the Mann-Whitney test yielded U = 6.000 and a Z score of -7.179, with an Asymp. Sig. (2-tailed) of 0.000.

Since the obtained significance value is much smaller than the specified significance level (*P* = 0.05), the null hypothesis (*H0*) is rejected, and the alternative hypothesis (*Ha*) is accepted. This indicates that there is a statistically significant difference in the improvement in spatial thinking skills between students taught using a project-based learning (PBL) model integrated with geospatial technology and those taught using the lecture method. Thus, it can be concluded that the application of a project-based learning model integrated with geospatial technology is significantly more effective in improving students' spatial thinking skills compared to conventional learning methods.

Intergroup Comparative Analysis (Experimental vs. Control)

After a significant increase in the experimental class was found in the paired-sample t-test, the analysis continued by comparing the average posttest difference between the experimental and control classes using an independent-samples t-test. The objective of this analysis was to test the hypothesis that the geospatial technology-integrated Project-Based Learning (PjBL) model yields superior outcomes relative to conventional learning.

The calculation revealed a posttest average of 76.0 for the experimental class and 69.4 for the control class, with a difference of 6.6 points. The independent-samples t-test yielded a t-value of 3.72 ($p < 0.001$), indicating a significant difference between the two groups. The average gain score also supported this finding, with the experimental class achieving an improvement of 10.8 points, significantly greater than the control class's 4.7 points.

These findings demonstrate that the geospatial technology-integrated PjBL model is significantly more effective at enhancing students' spatial thinking skills than conventional lecture-based instruction. This substantial improvement is attributed to the fact that project-based activities, supported by geospatial applications such as Google Earth, afford students direct, hands-on opportunities to practice spatial representation, spatial pattern analysis, and image interpretation, experiential elements notably absent in conventional learning paradigms.

Analysis Based on Learning Style.

Beyond comparing inter-group learning outcomes, this study investigated the influence of students' learning styles on the enhancement of spatial thinking skills following the implementation of the geospatial technology-integrated Project-Based Learning (PjBL) model. This analysis was conducted to determine which learning style category achieved the most optimal improvement. Data were collected using a learning style questionnaire, which classified students into four distinct typologies: visual, auditory, audiovisual, and kinesthetic. The measured enhancements in spatial thinking skills within each category were analyzed descriptively using gain scores (the difference between pretest and posttest scores).

Data analysis revealed that students with a kinesthetic learning style showed the greatest improvement, achieving a gain score of 22. This was subsequently followed by audiovisual learners (a score of 13), visual learners (a score of 10), and auditory learners (a score of 8). These findings indicate that the kinesthetic learning preference is most congruent with the characteristics of the geospatial technology-integrated PjBL model. This pedagogical approach allows students to engage in direct, hands-on physical activities, such as map delineation, image interpretation, and spatial exploration utilizing Google Earth. Conversely, auditory learners tended to show lower improvement, as individuals with this typology rely predominantly on verbal instruction rather than visual stimuli or direct experiential practice.

Table 3. Improvement of Spatial Thinking Skills Based on Learning Style

Learning Style	Number of Students	Average Gain Score	Remarks
Kinesthetic	11	22	Highest improvement
Audiovisual	10	13	High improvement
Visual	8	10	Moderate improvement
Auditory	6	8	Low improvement

Source: Data processing results using the Gainscore method

Geospatially integrated PjBL accommodates all learning styles (Widiawati et al., 2023). However, it is most effective for kinesthetic and audiovisual students because both gain hands-on experience manipulating spatial data and visually seeing the relationships between geographic objects in context.

Analysis Based on Spatial Thinking Ability Indicators

Additional analysis was conducted on three indicators of spatial thinking ability: Concepts of Space, Tools of Representation, and Cognitive Processes to Evaluate Spatiality (Jo & Bednarz, 2009). This analysis aims to determine which specific aspect of spatial thinking showed the most pronounced improvement following the implementation of the geospatial technology-integrated Project-Based Learning (PjBL) model within the experimental group.

Table 4. Average Spatial Thinking Ability Score Based on Indicators

Spatial Thinking Ability Indicators	Average of Pretest	Average of Posttest	Gain	Improvement categories
Concepts of Space	64,5	75,3	10,8	High
Tools of Representation	63,2	77,1	13,9	Very high
Cognitive Processes to Evaluate Spatiality	65,7	73,4	7,7	Medium

Source: Pretest Posttest Results with Indicators (Jo & Bednarz, 2009)

As presented in Table 6, the *Tools of Representation* indicator exhibited the most substantial improvement, achieving a gain score of 13.9. This was followed by *Concepts of Space* (10.8) and *Cognitive Processes to Evaluate Spatiality* (7.7). The significant enhancement in the *Tools of Representation* dimension indicates that using geospatial media, such as Google Earth and digital maps, effectively helps students understand spatial representations both visually and practically. Furthermore, the advancement in the *Concepts of Space* indicator suggests that students are better equipped to grasp spatial relationships, including location, direction, distance, and geographic distribution patterns through geospatial-based projects (Lee & Bednarz, 2012). Conversely, the comparatively lower gain observed in the *Cognitive Processes to Evaluate Spatiality* indicator can be attributed to the fact that spatial analysis and evaluation necessitate higher-order thinking skills, which typically develop at a slower trajectory than the preceding two competencies.

Results of the Kruskal-Wallis test in determining effective learning styles for spatial thinking ability.

Test Statistics[a,b]

	N_Gain_eksperimen
Chi-Square	9.724
df	3
Asymp. Sig.	.021

a. Kruskal Wallis Test

b. Grouping Variable: Gaya_Belajar

Figure 8. Results of the Kruskal-Wallis Test
(Source: SPSS data processing results)

Based on the results of the Kruskal-Wallis test, a significance value (Asymp. Sig.) of 0.021 was obtained, which is smaller than the standard significance level of 0.05 ($p < 0.05$). This indicates that there is a significant difference in the improvement in students' spatial thinking ability (N-Gain) through the application of the PjBL model integrated with geospatial technology, depending on their learning styles.

Ranks

	Gaya_Belajar	N	Mean Rank
N_Gain_eksperimen	AudioVisual	11	16.23
	Auditori	1	13.50
	Visual	11	12.36
	Kinestetik	12	25.17
	Total	35	

Figure 9. Detail Learning Style from Results of the Kruskal-Wallis Test
(Source: SPSS data processing results)

Detailed results of the Kruskal-Wallis test are shown in Figure 7; the Kinesthetic group had the highest mean rank (25.17), followed by the Audiovisual (16.23), Auditory (13.50), and Visual (12.36) groups. Thus, it can be concluded that this geospatial-based PjBL learning model statistically yields varying degrees of improvement depending on students' learning styles, with the model proving most effective in facilitating improvements in spatial thinking skills among students with a kinesthetic learning style.

2. Discussion

The findings of this study indicate that implementing the Project-Based Learning (PjBL) model integrated with geospatial technology significantly improved students' spatial thinking skills compared to conventional learning. Paired-sample t-test and Wilcoxon Signed-Rank Test analyses revealed a significant improvement in the experimental class *($p < 0.001$)*, while the improvement in the control class was not significant *($p > 0.05$)*. Furthermore, the independent-sample t-test results confirmed a significant difference in student learning outcomes between the experimental and control groups ($t = 3.72$; $p < 0.001$).

The improvement of spatial thinking skills in the experimental group was reflected by a mean posttest score increase of 10.8 points relative to the pretest. An indicator-based analysis indicated that the most substantial improvement occurred in the *Tools of Representation* dimension, followed by *the Concepts of Space and Cognitive Processes to Evaluate Spatiality dimensions*. This suggests that using geospatial media, such as Google Earth and digital maps, effectively facilitates students' comprehension of spatial interrelationships in a more concrete, contextual manner.

The research findings also highlight the influence of learning styles on the effectiveness of the PjBL model. Students with kinesthetic and audiovisual learning styles demonstrated greater gains in learning outcomes than those with visual and auditory learning styles. These findings strengthen the premise that the success of geospatial-integrated PjBL is heavily contingent upon the alignment among the learning approach, technological media, and students' cognitive characteristics (Oktaviano, 2020). Ultimately, these results confirm that integrating geospatial technologies into PjBL not only quantitatively elevates learning outcomes but also enriches students' cognitive processes in grasping the spatial concepts that constitute the core of geographic inquiry.

The effectiveness of the Project-Based Learning (PjBL) model integrated with geospatial technology in improving spatial thinking skills

The alignment between learning styles and the geospatially integrated PjBL model aligns with the principles of social constructivism, where students actively construct knowledge through meaningful, hands-on experiences (Vygotsky et al., 1978). Through project-based activities, students no longer merely receive information passively; rather, they are required to connect theoretical knowledge with the spatial realities of their surroundings in an explorative and collaborative manner (Thomas, 2000). This inquiry process, which entails analyzing geospatial data and resolving spatial problems, directly bolsters students' higher-order thinking skills, encompassing the concrete analysis, synthesis, and evaluation of spatial information.

The integration of geospatial technologies, such as Google Earth, provides a more contextual, interactive, and visually enriched learning experience. This medium enables students to realistically visualize spatial relationships among geographic objects, comprehend scale, and analyze patterns and distributions of spatial phenomena (Jo & Bednarz, 2009). The use of geospatial technology strengthens the interconnection among the three core dimensions of spatial thinking: *concepts of space* (understanding of space and location), *tools of representation* (the ability to utilize symbols and digital maps), and *cognitive processes* (the analysis and evaluation of spatial phenomena).

Project-Based Learning (PjBL) integrated with geospatial media fosters meaningful learning, as students are not merely required to memorize concepts but are actively engaged in applying them to real-world problem-solving contexts, such as land-use analysis and the identification of disaster-prone areas. These project-based activities require students to collaborate, analyze spatial data, and produce geospatial outputs that can be communicated effectively. This inquiry-driven process enhances higher-order thinking skills (HOTS), encompassing analysis, synthesis, and evaluation of spatial information, as articulated by Lorin W. Anderson and David R. Krathwohl (2001).

The findings of this study are consistent with previous research highlighting the positive contribution of Project-Based Learning (PjBL) to the development of spatial thinking skills and student engagement. Purwanto and Mellyana (2024) found that implementing digital technology-based PjBL significantly improves spatial visualization and problem-solving skills. Similarly, Fadjarajani et al. (2024) found that integrating PjBL with Geographic Information Systems (GIS) enhances students' spatial analysis abilities and map representation skills at the secondary school level.

These results also align with the findings of Sofias & Pierrakeas (2021), which demonstrated that the use of Google Earth in geography instruction strengthens spatial representation skills and improves students' understanding of spatial concepts. Similarly, Fatimatuzzahro et al. (2023) stated that geography learning utilizing high-resolution satellite imagery can help students connect spatial concepts with real-world phenomena.

Although the findings of this study align with prior research, it offers a novel contribution by incorporating students' learning styles as a moderating variable to examine the effectiveness of geospatially integrated PjBL. Previous studies have predominantly focused on technological integration in learning without accounting for differences in students' cognitive characteristics. Therefore, this study extends the existing body of knowledge by demonstrating how geospatially integrated PjBL can be tailored to students' learning preferences to optimize learning outcomes.

Furthermore, the findings of this study reinforce the theoretical framework proposed by Jo & Bednarz (2009), which posits that spatial thinking skills develop through the integration of concepts of space, tools of representation, and cognitive processes to evaluate spatiality. In the current study, the most substantial improvement observed in the *Tools of Representation* indicator indicates that integrating PjBL and geospatial technology is highly effective in stimulating the representational dimension of spatial thinking, thereby laying the groundwork for the development of more complex cognitive dimensions.

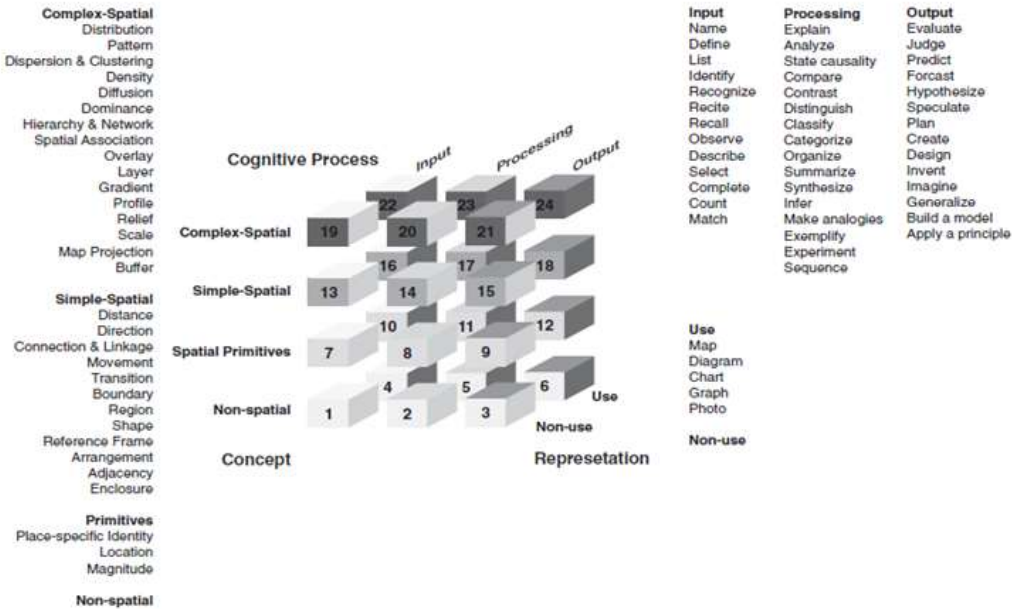

Figure 5 Spatial Thinking Indicators (Jo & Bednarz, 2009)

The improvement in spatial thinking skills can be explained through the framework proposed by Jo & Bednarz (2009), which integrates the dimensions of *Concepts of Space*, *Tools of Representation*, and *Cognitive Processes*, as illustrated in Figure 5. In this study, the *Tools of Representation* dimension emerged as the most dominant factor, as students were directly engaged in data processing (input) and in manipulating spatial information through Google Earth (processing) to produce accurate regional interpretations (output). This active interaction with geospatial technology enables students not only to understand spatial concepts theoretically but also to visualize them concretely. As a result, the spatial information processing cycle is more effective than conventional learning approaches that predominantly rely on lectures and presentations.

The pattern of improvement across indicators is mixed. The highest increase was observed in *Tools of Representation*, as applications such as Google Earth directly facilitate the visualization of spatial patterns. Improvements follow this in *Concepts of Space*, where students were able to relate abstract spatial theories to real-world environmental contexts. Meanwhile, *Cognitive Processes to Evaluate Spatiality* showed a moderate increase, as the ability to evaluate and infer spatial relationships requires higher-order thinking skills that tend to develop more gradually through repeated practice and reflection (NRC, 2006).

Overall, these findings reinforce the assumption that the three indicators of spatial thinking do not develop independently but rather form an interconnected system of thinking. *Tools of Representation* function as a bridge linking *Concepts of Space* (conceptual understanding) with *Cognitive Processes* (analytical and evaluative thinking). Therefore, the effectiveness of the geospatial technology-integrated Project-Based Learning (PjBL) model lies not only in its capacity to support spatial visualization but also in its ability to facilitate the integration of conceptual understanding and cognitive processes in students’ analysis of geographical phenomena.

Variations in Learning Styles and Responses to the Project-Based Learning (PjBL) Model

Each student exhibits distinct learning style preferences in receiving and processing information, and these variations significantly influence the effectiveness of learning models. The findings of this study indicate that kinesthetic and audiovisual learning styles were dominant in the experimental class. At the same time, purely auditory and purely visual learners demonstrated relatively lower levels of improvement. These results suggest that the effectiveness of the Project-Based Learning (PjBL) model integrated with geospatial technology is strongly influenced by the alignment between learning syntax and students’ cognitive characteristics and learning preferences.

Students with kinesthetic learning styles demonstrated the greatest improvement in spatial thinking, as the characteristics of PjBL afford opportunities for direct, hands-on activities and field-based experiences. Through activities such as regional mapping, digital map delineation, and field observation using satellite imagery, kinesthetically oriented students were able to construct an understanding of spatial concepts through concrete action. This finding is consistent with Abidoye et al. (2023), who affirmed that project-based learning is particularly effective for students with kinesthetic learning tendencies, given its emphasis on physical and collaborative activities that enhance the retention of spatial information.

Concurrently, audiovisual learners also showed significant improvement, benefiting from the combined use of verbal instruction and digital visualization. The implementation of PjBL utilizing Google Earth strengthened their spatial understanding by integrating map imagery with contextual explanations. Wu & Wang (2025) demonstrated that integrating multimodal media into project-based STEM learning enhances student engagement and academic achievement, particularly among audiovisual learners, by activating multiple cognitive pathways simultaneously.

Conversely, students with auditory and purely visual learning styles demonstrated comparatively lower levels of improvement. This outcome may be attributed to the PjBL model's demand for active engagement and collaborative participation in project work. In contrast, auditory learners tend toward a more passive orientation and rely predominantly on verbal instruction (Fernanda et al., 2024). Meanwhile, visually oriented students who lacked kinesthetic tendencies encountered difficulties when required to participate in practical activities, despite demonstrating competence in interpreting spatial representations.

The findings of this study underscore the critical importance of aligning learning models with students' learning styles. The integration of geospatial technology within PjBL is most effective when the learning syntax combines kinesthetic and audiovisual styles, encouraging students to learn through concrete experiences, digital visualization, and collaborative reflection.

The findings about learning style variation carry important implications for the development of geography learning strategies in the twenty-first century (Widiawati et al., 2023). Teachers are encouraged to adapt the PjBL syntax to support multimodal learning by providing learning experiences that integrate visual, kinesthetic, and auditory elements in a balanced manner. Within this context, geospatial technology functions as a bridging medium between concrete experience and conceptual representation, thereby accommodating diverse learning styles. For instance, teachers can direct students to engage in digital map exploration, spatial data-driven group discussions, and project presentations using interactive geospatial imagery. Such activities not only accommodate diverse learning styles but also foster scientific communication and collaboration among students. Consequently, the implementation of a geospatial technology-integrated PjBL model has the potential to be an inclusive, adaptive, and relevant pedagogical approach to meet the demands of technology-based and spatial data-driven learning in the modern era.

CONCLUSION

This study demonstrates that the geospatial technology-integrated Project-Based Learning (PjBL) model is highly effective in enhancing students' spatial thinking skills within secondary school geography education. Statistical analysis revealed a significant difference between the experimental and control groups ($p < 0.001$), with the highest mean improvement observed in the *Tools of Representation* indicator, followed by *Concepts of Space* and *Cognitive Processes to Evaluate Spatiality*. These findings indicate that the use of geospatial technologies, such as Google Earth and WebGIS, strengthens students’ ability to visualize, interpret, and analyze spatial phenomena in more concrete, context-specific ways. Furthermore, learning styles were found to play a significant role in the model’s effectiveness, with kinesthetic and audiovisual learners demonstrating greater improvements in spatial thinking skills compared to those with purely auditory or visual learning preferences.

The findings of this study reinforce the theoretical framework of spatial thinking (Jo & Bednarz, 2009) and social constructivism (Vygotsky et al., 1978), both of which emphasize that spatial competence develops through the integration of spatial concepts, representational tools, and higher-order cognitive processes. From a practical standpoint, the geospatial-integrated PjBL model can be implemented as an innovative, adaptive, and inclusive learning strategy to foster students' spatial literacy and enhance the quality of 21st-century geography learning (Widiawati et al., 2023). The application of this model also provides new directions for developing project-based learning designs that are more contextually grounded and responsive to diverse learning styles, thereby facilitating the accommodation of varied learner characteristics in contemporary geography classrooms.

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