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APPLICATION OF PROJECT BASED LEARNING MODEL BASED ON ARTIFICIAL INTELLIGENCE (AI) TO IMPROVE CRITICAL SPATIAL THINKING OF STUDENTS IN SUKOHARJO REGENCY

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ABSTRACT

Project-Based Learning (PjBL) is a learning model that emphasises problem-solving through real-world activities and meaningful projects. The integration of Artificial Intelligence (AI) in PjBL is expected to enhance students' engagement and higher-order thinking skills, particularly critical spatial thinking in geography learning. This study aims to improve students' critical spatial thinking skills by applying an AI-based Project-Based Learning model to the topic of the dynamics of international cooperation. The research employed Classroom Action Research (CAR) conducted in three cycles—planning, action, observation, and reflection—during the even semester of the 2024/2025 academic year at State Senior High School 1 Sukoharjo. The research subjects were 35 students in Phase F+ / Grade XII. Data were collected using observation sheets, written tests (pretest and posttest), questionnaires, and documentation. Data analysis was carried out using descriptive qualitative analysis supported by quantitative data in the form of students' learning achievement percentages based on critical spatial thinking indicators. The results showed a consistent improvement in students' learning outcomes across the three cycles, with mastery learning increasing from 68.57% in cycle I to 77.14% in cycle II and reaching 91.43% in cycle III, exceeding the classical mastery criterion of 85%. The findings indicate that implementing AI-based PjBL effectively enhances students' critical spatial thinking skills, learning motivation, and active participation. Therefore, AI-based Project-Based Learning can be considered a practical instructional approach to support meaningful, technology-integrated geography learning.

Keywords: *project based learning; critical spatial thinking; artificial intelligence*

INTRODUCTION

The advancement of 21st-century education requires strengthening higher-order thinking skills as a fundamental foundation for meaningful and sustainable learning. Among various cognitive competencies, critical thinking and spatial thinking occupy a strategic position, as both play a crucial role in decision-making, complex problem-solving, and the understanding of multidimensional and contextual phenomena. The integration of these two abilities gives rise to the concept of critical spatial thinking, a form of advanced reasoning that combines logical analysis with an understanding of spatial relationships to produce comprehensive interpretations and solutions.

Critical spatial thinking is defined as an individual's ability to use geographic information reflectively and appropriately to understand problems, formulate alternative solutions, and communicate analytical processes and outcomes effectively (Sinton, 2017). This definition is reinforced by Saputro, Rudy, and Liesnoor (2020), who conceptualise critical spatial thinking as a cognitive process involving the processing, creation, and manipulation of visualised objects in analysing phenomena or objects from a spatial perspective. In the context of geography education, this capability is critical, as the concept of space lies at the core of geographical inquiry. This emphasis is reflected in the objectives of geography education, which explicitly aim to habituate students to spatial modes of thinking, as stipulated in the core competencies of the geography curriculum.

Empirical evidence indicates that spatial thinking skills significantly contribute to students' ability to make informed decisions and solve complex, real-life problems in a structured manner (J. Li et al., 2019). Nevertheless, implementing geography learning in secondary education continues to face substantial challenges. Instructional practices often remain insufficiently focused on strengthening spatial concepts, while the availability of learning resources that support the development of spatial thinking, particularly project-based materials, remains limited (Kwon & Iedema, 2022). These constraints reduce students' opportunities to engage in process-oriented learning activities that systematically cultivate higher-order thinking skills.

This situation becomes increasingly problematic when considered alongside the demands of 21st-century learning, which emphasise the mastery of the 6C skills: Critical Thinking, Communication, Creativity, Collaboration, Citizenship, and Character. Critical spatial thinking is closely aligned with these competencies, as it requires observation, spatial imagination, analytical reasoning, and contextual evaluation. Evi Latifatus Sirri et al. (2021) assert that spatial ability necessitates higher-order cognitive skills in observing and mentally visualising geometric forms, thereby requiring strong imaginative and reasoning capacities. Accordingly, critical spatial thinking can be regarded as an integrative competence that bridges conceptual knowledge with students' analytical problem-solving abilities.

At the practical level, low levels of critical spatial thinking remain a persistent issue in schools. This phenomenon was identified among students in class F+3 at SMA Negeri 1 Sukoharjo, where the mastery rate in learning reached only 51.43%. This indicates that merely 18 out of 35 students achieved the Minimum Mastery Criterion (KKM) score above 75. Such low achievement is closely associated with the application of instructional models that insufficiently engage students in active learning, thereby negatively affecting both critical thinking skills and overall learning outcomes (Hidayah et al., 2016). Additionally, students' low enthusiasm for participating in geography lessons further underscores the urgency for more contextual and participatory learning innovations.

One pedagogical approach considered relevant to addressing these challenges is Project-Based Learning (PjBL). PjBL is a problem-oriented instructional model that positions students as active learners in constructing knowledge through authentic learning experiences and real-world activities. Numerous studies have consistently demonstrated the effectiveness of PjBL in enhancing critical thinking skills across diverse educational contexts. Empirical findings indicate that the implementation of PjBL results in statistically significant improvements in students' critical thinking abilities, as evidenced by substantial differences between pretest and posttest scores (Aswan et al., 2024; Huda et al., 2024).

Alongside pedagogical innovation, the rapid advancement of educational technology, particularly Artificial Intelligence (AI), offers new opportunities to enhance learning quality further. The integration of AI into Project-Based Learning not only increases students' motivation and engagement but also fosters adaptive learning environments that support deeper critical thinking processes. A study by Bahrul Alim and Butsiarah (2025) reported that the application of AI-assisted PjBL led to higher posttest scores compared to conventional instruction, while also promoting student engagement in discussion, collaboration, and reflective critical practices.

Despite this growing body of research, existing studies broadly examine Project-Based Learning, Artificial Intelligence, and critical spatial thinking as separate or pairwise constructs. Comprehensive investigations that integrate these three elements within a single pedagogical framework remain scarce, particularly in secondary geography education. Emerging research on AI-integrated PjBL within web-based geographic information systems and adaptive learning environments suggests promising directions (Arqam & Asrifan, 2024; Hayati, 2024); however, these studies have not explicitly focused on systematically developing students' critical spatial thinking skills.

Addressing this research gap, the present study offers a novel contribution by integrating Artificial Intelligence–based Project-Based Learning as a pedagogical approach to enhance students' critical spatial thinking in geography education. Specifically, this study is conducted within the context of international cooperation at SMA Negeri 1 Sukoharjo. This integrative approach is expected not only to enrich geography teaching practices but also to contribute theoretically to the development of innovative instructional models that simultaneously combine Project-Based Learning, Artificial Intelligence, and critical spatial thinking.

MATERIALS AND METHODS

1. Research Design

The research was conducted at State Senior High School 1 Sukoharjo in the even semester of the 2024/2025 academic year. The design of this research is Classroom Action Research (CAR) which consists of 3 (three) cycles including the stages of observation, action, and reflection. The complete research stages are shown in **Figure 1.**

a. Planning Stage

The steps taken in the planning stage are as follows:

1) School permits, namely the principal and class XII teachers of State Senior High School 1, Sukoharjo, Sukoharjo Regency.
2) Assessment of Core Competencies, Basic

Competencies, Indicators, and Learning Objectives

3) Formulating problems faced by students.
4) Designing and compiling teaching modules as guidelines for implementing learning.
5) Preparing learning materials and media according to the material to be delivered.
6) Designing research instruments to analyse teacher activities, student activities, student learning outcomes and student cooperation, namely:
   1) Observation sheet (attached)
   2) Test Sheet: pretest and posttest (attached)
   3) Documentation (attached)

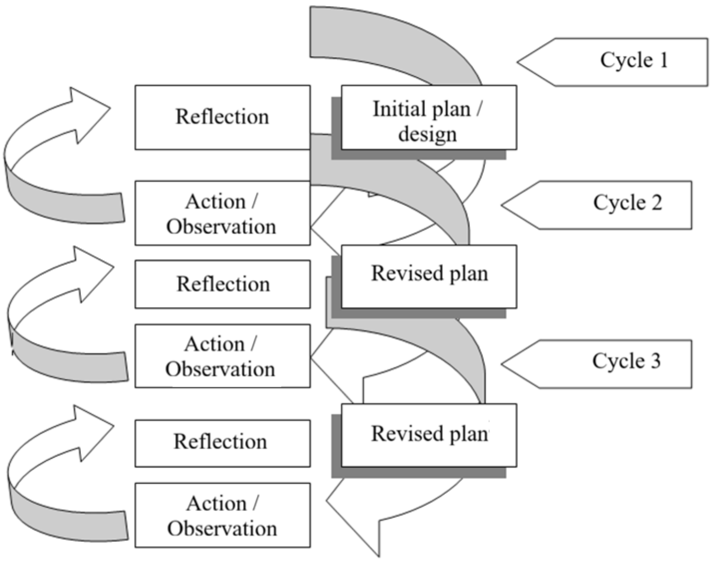

Figure 1. Classroom Action Research Design

b. Action Implementation Stage

This stage involves implementing the learning scenario that has been created using the Project-Based Learning (PjBL) learning model based on Artificial Intelligence (AI).

c. Observation Stage

Observation is the process of observing the implementation of Arikunto's actions (Arikunto Suharsimi, 2013; Iskandar & Narsim, 2015). Observations are carried out by fellow teachers (colleagues) and students.

d. Reflection Stage

Reflection is an activity of contemplating the activities carried out by teachers and students. Researchers, along with observers and students, conduct self-reflection by examining observation data. Any deficiencies found

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in the first cycle will be corrected in subsequent cycles until the desired goals are achieved. If the cycle carried out has not achieved the expected results, the researcher can continue the research activity in the next round.

2. Data Collection Techniques

Two data sets are used in this study: quantitative data on student learning outcomes with indicators of critical spatial thinking, and student satisfaction levels during learning and during collaborative assessments with colleagues. Qualitative data on obstacles, problems, and failures were collected in the study. The data collection techniques and tools used are observation and documentation.

The validity test of the research data was carried out through 3 (three) tests: the instrument validity test, the instrument reliability test, the difficulty level test, the question discrimination power test, and the data validity test.

a. Instrument Validity Test

Validity is the Validity of an instrument that shows the level of Validity of a question item (Arikunto, 2016). The correlation formula used in **equation 1** is the formula proposed by Spearman, as follows:

$$r_{xy} = \frac{(N\sum XY - (\sum X)(\sum Y))}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}} \quad (1)$$

Description:

rxy = Correlation of product moment with raw numbers

N = Number of subjects

X = Number of correct question scores

Y = Total score for each student

The calculation results are then classified according to the following criteria: if rxy count ≥ r table, it is valid; if rxy count ≤ r table, it is invalid. From the results of the data validity test, it can be determined which questions are suitable for research testing and which are not.

b. Instrument Reliability Test

Reliability is one of the instruments that is quite accurate as a data collection tool and refers to the instrument being good (Arikunto, 2016). The SPSS version 25 program is used to calculate the reliability of objective questions using Cronbach's alpha. Reliability testing is carried out for all question items, more than one per variable. Reliability testing is carried out to measure the same object, and if it is repeated, the results will remain the same and not change (Sugiyono, 2015). The calculation of the reliability of the questions using the Cronbach's Alpha formula and the interpretation criteria is shown in **equation 2**.

$$r_{11} = \left(\frac{k}{k-1}\right)\left(1 - \frac{(\sum \sigma^2 b)}{\sigma^2 t}\right) \quad (2)$$

Description:

r11 = Correlation of product moment with raw numbers

k = Number of question items

$\sum \sigma 2b$ = Number of item variants

$\sigma 2t$ = Total variance

Table 1. Reliability Assessment Interpretation Criteria

Correlation Coefficient	Reliability Criteria
Negative – 0,20	Not a Reliability Test
0,21 – 0,40	Low
0,41 – 0,70	Fair
0,71 – 0,90	High
0,91 – 1,00	Very High

Sources: (Pratama et al., 2022; Sudijono, 2009)

c. Difficulty Level

The difficulty index is a number that indicates the difficulty and ease of a question. The difficulty of a question is the proportion of test participants who answered it correctly. To calculate the level of difficulty of a question, it is calculated using **equation 3**:

$$P = B/JS \quad (3)$$

Description:

P = Difficulty index for each question item

B = Number of students who answered correctly

JS = Number of test participants

Interpretation criteria for the level of difficulty are in **Table 2.**

Table 2. Interpretation Criteria for Level of Difficulty

Correlation Coefficient	**Difficulty Level**
$0,71 \leq P \leq 1,00$	Easy
$0,31 \leq P \leq 0,70$	Currently
$0,00 \leq P \leq 0,30$	Difficult

Sources: (Jihad & Hamid, 2013)

d. Discriminating Power of Question Items

The discriminating power of questions is a grouping of questions used to test students with varying abilities. The formula for determining the discriminating power of questions is shown in **Equation 4,** and the discriminating power criteria are shown in **Table 3.**

$$J = \left(\frac{BA}{JA}\right) - \left(\frac{BB}{JB}\right) = PA - PB \quad (4)$$

Description:

J = Number of participants

BA = Number of participants in the upper group who answered correctly

BB = Number of participants in the lower group who answered correctly

JA = Number of participants in the upper group

JB = Number of participants in the lower group

PA = Percentage of participants in the upper group who answered correctly

Table 3. Discriminating Power Criteria

Distinguishing Power	Criteria
Negatif	Very Bad
0,00 – 0,20	Bad
0,20 – 0,40	Fair
0,40 – 0,70	Good
0,70 – 1,00	Very Good

Sources: (Arikunto, 2016)

e. Data Validity

Based on the data obtained, a validity test is continued, including democratic Validity, result Validity, process Validity, catalytic Validity, and dialogic Validity (Prihadi et al., 2024). The following is a description of each validity test used in this study:

- Democratic Validity: namely, researchers collaboratively convey ideas or opinions from colleagues during research.
- Result Validity: namely, the concept of action brings successful results in research (effective results).
- Process Validity: namely, researchers conduct evaluations during research so that improvements can be made.
- Catalytic Validity: namely, researchers understand the inhibiting factors and supporting factors for learning during research.
- Dialogic Validity: namely, carried out in conjunction with democratic Validity, researchers' ideas are subject to criticism through dialogue.

The data analysis technique used in this study employs qualitative descriptive methods, including analysis of obstacles, problems, and failures that occur during the research action stage, and it describes the data on the level of achievement of critical spatial thinking indicators. The achievement of action is seen based on three indicators, namely:

a) Critical spatial thinking achievement indicator
The learning achievement in question is a minimum score of 75% (75), and a class is said to have completed learning if at least 85% of the class has an absorption capacity of 85% or higher.

b) Student satisfaction indicator
Student satisfaction is measured through the student questionnaire, which asks about their involvement in learning and the assessment of the learning process presented by the teacher as a learning experience.

c) Collaboration indicator with colleagues
The observed aspects are all related to the progress of the learning process, so that obstacles or shortcomings in the researcher's actions can be identified.

The achievement levels of the three indicators are presented in **Table 4.**

Table 4. Indicator Success Rate

No	Indicators	Success Rate	
		Minimum score	Percentage (%)
1	Critical Spatial Thinking	75	85%
2	Student Satisfaction	75	85%
3	Peer Collaboration	75	85%

RESULTS AND DISCUSSION

1. Results

The implementation of PjBL in this study was carried out in three cycles, namely the Dynamics of Cooperation Between Countries material, covering three sub-materials: Indonesia's potential and cooperation, Indonesia's cooperation in the international arena, and the influence of cooperation on Indonesia's resilience. The following is an interpretation of achievement in each cycle, based on students' learning outcomes and the critical spatial thinking indicators used by researchers as the basis for assessment. The assessment was conducted via a written multiple-choice test. Before being used as an assessment instrument, the instrument's Validity was assessed as follows.

a. Test Validity Test

The test instrument used in this study was a multiple-choice test with 10 questions. Before being used to measure students' critical spatial thinking abilities, this instrument needs to be tested for question validity. The following are the results of the validity test on each question item listed in **Table 5.**

Table 5. Test of Question Item Validity

No.	Validity Test		
	t Calculate	**t Tabel**	**Criteria**
1	0,650	0,334	Valid
2	0,489	0,334	Valid
3	0,576	0,334	Valid
4	0,576	0,334	Valid
5	0,683	0,334	Valid
6	0,619	0,334	Valid
7	0,619	0,334	Valid
8	0,471	0,334	Valid
9	0,793	0,334	Valid
10	0,377	0,334	Valid

Source: Researcher Analysis, 2025

b. Test Reliability Test

The reliability test of this test instrument uses the Cronbach's Alpha (α) formula. The test items were analysed, and the test reliability was 0.760. According to Pratama (2022), the test item reliability is high, with a value of 0.81, within the 0.71-0.90 interval, as shown in **Table 6.**

Table 6. Test of Question Item Reliability

Cronchbarn Alpha	**Reliability Interval**	**Reliability Criteria**
0,760	0,71-0,90	High

Source: Researcher Analysis, 2025

c. Test Difficulty Level

The level of difficulty is the chance of answering a question correctly at a certain level of ability. After being tested on students, the level of difficulty of each question is calculated. The results of the difficulty level test are shown in **Table 7**.

d. Test Discrimination Power

Table 8 shows that most items have moderate to good discrimination power. Two items exhibit good discrimination, five items are categorised as sufficient, and three items demonstrate poor discrimination and require revision.

Table 7. Level of Difficulty of Question Items

No.	Level of Difficulty of Question Items		
	Score	**Interval**	**Criteria**
1	0,885	0,71 ≤ P ≤ 1,00	Easy
2	0,885	0,71 ≤ P ≤ 1,00	Easy
3	0,914	0,71 ≤ P ≤ 1,00	Easy
4	0,914	0,71 ≤ P ≤ 1,00	Easy
5	0,857	0,71 ≤ P ≤ 1,00	Easy
6	0,514	0,31 ≤ P ≤ 0,70	Currently
7	0,514	0,31 ≤ P ≤ 0,70	Currently
8	0,657	0,31 ≤ P ≤ 0,70	Currently
9	0,857	0,71 ≤ P ≤ 1,00	Easy
10	0,542	0,31 ≤ P ≤ 0,70	Currently

Source: Researcher Analysis, 2025

Table 8. Discrimination Power of Question Items

No.	Item Discrimination Power		
	Score	**Interval**	**Criteria**
1	0,24	0,20-0,40	Enough
2	0,24	0,20-0,40	Enough
3	0,18	0,00-0,20	Bad
4	0,18	0,00-0,20	Bad
5	0,29	0,20-0,40	Enough
6	0,66	0,40-0,70	Good
7	0,66	0,40-0,70	Good
8	0,25	0,20-0,40	Enough
9	0,29	0,20-0,40	Enough
10	0,03	0,00-0,20	Bad

Source: Researcher Analysis, 2025

The following is a comparison of learning outcomes across cycles 1, 2, and 3.

a. Cycle 1

The learning outcomes of students, as measured by the pretest and posttest in cycle 1, increased, as shown in **Figure 2**. In the pretest, 22 students completed the KKM (>75), and 13 did not, for a completion rate of 62.86%. In the posttest, it was found that 24 students completed the KKM (>75), and 11 did not, resulting in a completion rate of 68.57%. This result has not achieved learning success, namely, >85% student completion, so improvements need to be made in the following learning process, namely, cycle 2.

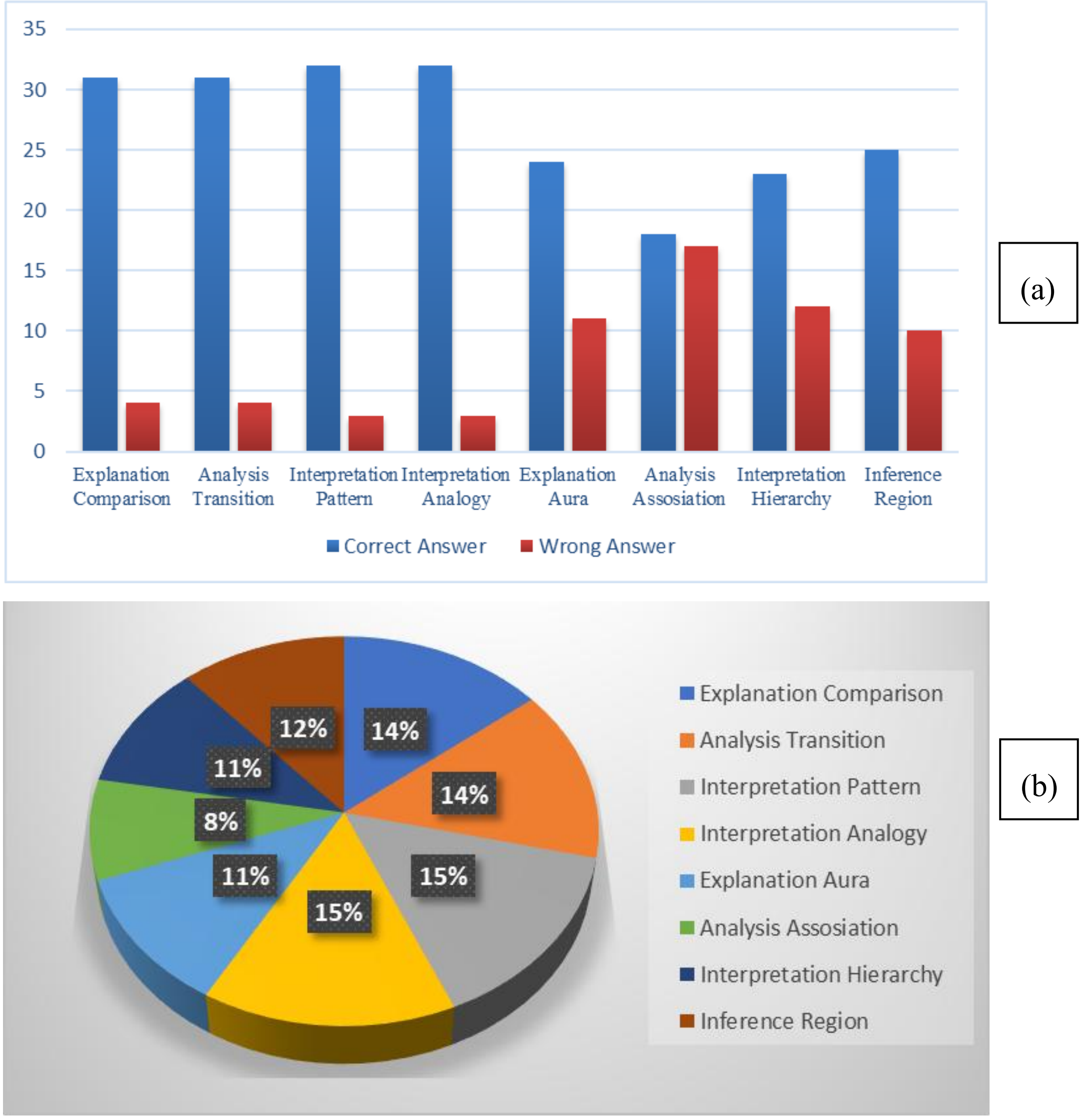

Figure 2. (a) Distribution of Answers Cycle 1; (b) Percentage of Correct Answers Cycle 1

Source: Researcher Analysis, 2025

b. Cycle 2

The learning outcomes of students, as measured through pretests and posttests in cycle 2, increased, as shown in **Figure 3**. In the pretest, 9 participants did not complete the KKM, resulting in a completion rate of 74.29%. Meanwhile, in the posttest, 27 students completed the KKM (>75), and 8 did not, resulting in a completion rate of 77.14%. These results have not achieved learning success (>85%), so improvements are needed in the following learning cycle, namely cycle 3.

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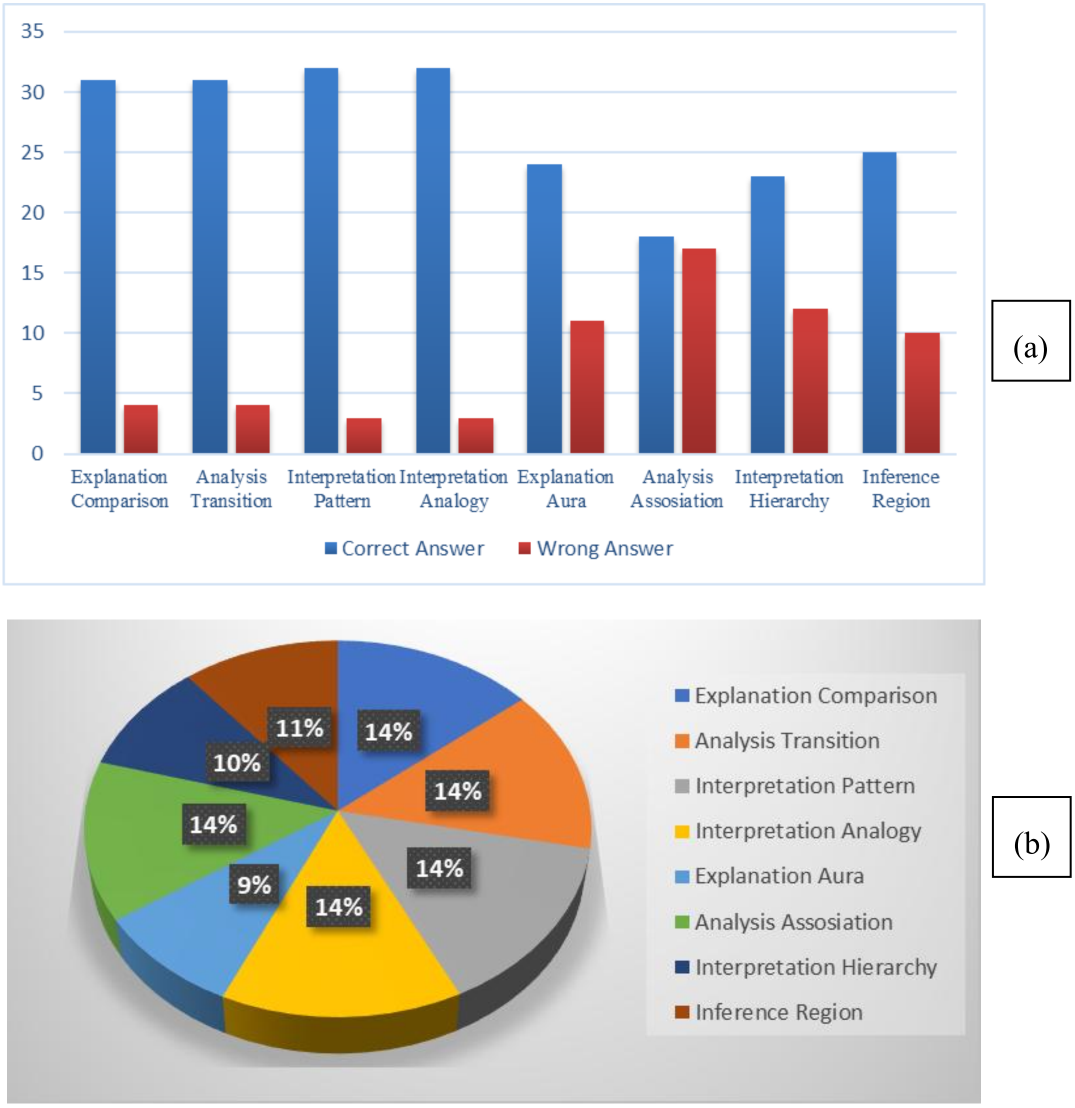
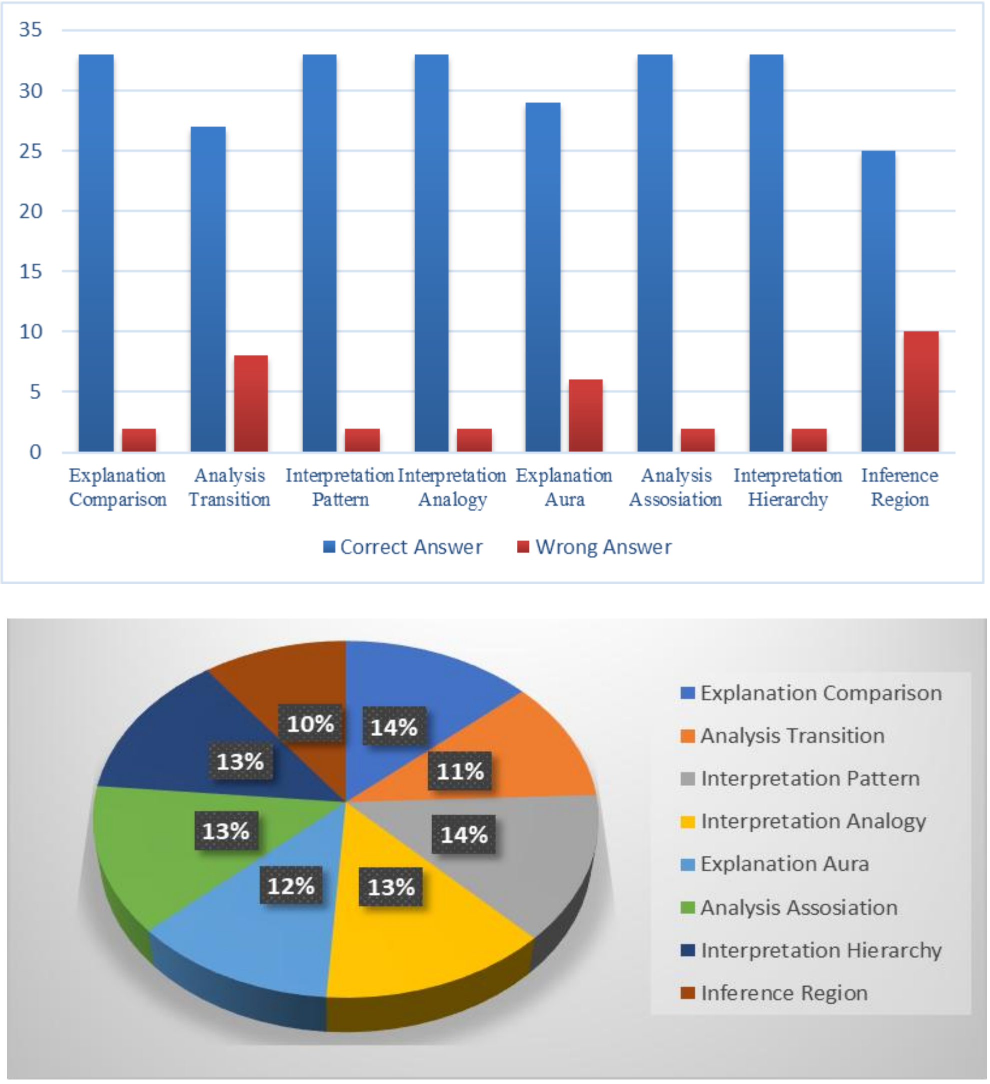


Figure 3. (a) Distribution of Answers Cycle 2; (b) Percentage of Correct Answers Cycle 2

Source: Researcher Analysis, 2025

c. Cycle 3

The learning outcomes of students, measured through pretests and posttests in cycle 1, increased, as shown **in Figure 4**. Based on the graph, in the pretest, 28 students passed the KKM (>75), and 7 did not, for a completion rate of 80%. Meanwhile, in the posttest, 32 students passed the KKM (>75), and 3 did not, resulting in a completion percentage of 91.43%. The completion percentage has reached the classical completion standard of 85% so that learning can be said to have succeeded in achieving the predetermined learning objectives.



(a)

(b)

Figure 4. (a) Distribution of Answers for Cycle 3; (b) Percentage of Correct Answers for Cycle 3

Source: Researcher Analysis, 2025

The achievement of the intended action is seen based on three indicators, namely:

1) Critical spatial thinking achievement indicator

Based on the recapitulation of student test results, a comparison can be seen across the three cycles of actions carried out. The following is a comparison of the percentage of student completion from cycle 1 to cycle 3. Comparison of the percentage of student learning outcomes in cycle 1-cycle 3 is shown in **Figure 5**.

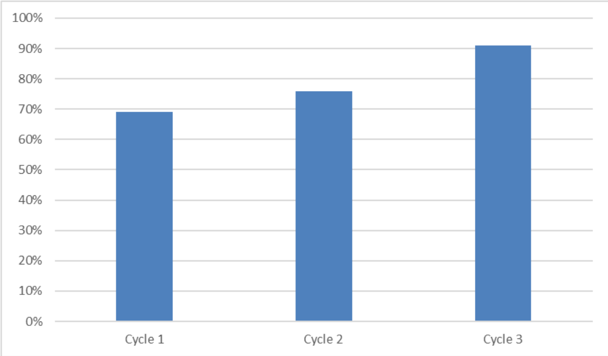


Figure 5. Comparison of the Percentage of Student Learning Outcomes in Cycle 1-Cycle 3

Source: Researcher Analysis, 2025

2) Indicators of student satisfaction

Based on the student satisfaction questionnaire data, the levels of student satisfaction in implementing learning in cycles 1, 2, and 3 are shown in **Table 9**.

Table 9. Level of Student Satisfaction

Cycle	Student Satisfaction Level		
	Score	Interval	Criteria
1	89,66	80 ≤ N ≤ 90	Good
2	90,11	90 ≤ N ≤ 100	Very Good
3	91,40	90 ≤ N ≤ 100	Very Good

Source: Researcher Analysis, 2025

3) Collaboration indicators with peers

The observed aspect is students' level of engagement in the learning process. 2 observers conducted this observation, and the results are presented in **Tables 10**, **11**, **12**, and **13**.

Table 10. Results of Observations of the Level of Student Activity by Observer 1

Cycle	Student Activity Level from Peer to Peer		
	Score	Interval	Criteria
1	88,24	80 ≤ N ≤ 90	Good
2	90,33	90 ≤ N ≤ 100	Very Good
3	92,56	90 ≤ N ≤ 100	Very Good

Source: Researcher Analysis, 2025

Table 11. Results of Observations of the Level of Student Activity by Observer 2

Cycle	Student Activity Level from Peer to Peer		
	Score	Interval	Criteria
1	88,24	80 ≤ N ≤ 90	Good
2	91,52	90 ≤ N ≤ 100	Very Good
3	92,86	90 ≤ N ≤ 100	Very Good

Source: Researcher Analysis, 2025

Table 12. Teacher Observation in Learning by Observer 1

Cycle	Teacher Observation in Learning		
	Score	Interval	Criteria
1	90,91	90 ≤ N ≤ 100	Very Good
2	93,18	90 ≤ N ≤ 100	Very Good
3	93,18	90 ≤ N ≤ 100	Very Good

Source: Researcher Analysis, 2025

Table 13. Teacher Observation in Learning by Observer 2

Cycle	Teacher Observation in Learning		
	Score	Interval	Criteria
1	93,18	90 ≤ N ≤ 100	Very Good
2	93,18	90 ≤ N ≤ 100	Very Good
3	95,45	90 ≤ N ≤ 100	Very Good

Source: Researcher Analysis, 2025

2. Discussion

Based on the research results from applying AI-based PjBL in geography learning, there was an increase in the percentage of student completion from cycle 1 to cycle 3, namely 68.57% in cycle 1, 77.14% in cycle 2, and 91.43% in cycle 3. Referring to the classical minimum learning achievement, namely a percentage of >85%, taking action in cycle 3 indicates that learning has succeeded in achieving the critical spatial thinking indicator. This aligns with the results of Oktavianto's (2017) research, which found that Project-Based Learning can improve students' thinking skills. In the syntax of Project-Based Learning, some activities can train students to think, thereby increasing their thinking skills. In addition, the application of PjBL, combined with AI-based media, can encourage collaborative learning, thereby improving the learning atmosphere and making it more interactive (Nurussalamah et al., 2025; Ruan et al., 2024; Tendrita & Hidayati, 2025). This condition is characterised by students' active involvement in the learning process. A pleasant learning atmosphere makes students more active in carrying out their roles in the classroom (Jejen Tabriji, 2024). In this case, it is actively participating in learning both individually and in groups. The activity of individual students is evident in their interactions with the teacher during the learning process, for example, by responding to or answering the teacher's questions, and in their ability to ask questions related to the learning materials to the teacher. Meanwhile, group activities include discussions in which students work together to create group projects. Current innovations for use in learning activities that are interesting and encourage students to be more active in developing their capacity (Sani et al., 2025; Simanjuntak et al., 2023). The results of peer learning observations show a stable level of student activity in accordance with the good criteria. Meanwhile, in cycles 2 and 3, student activity increased. The results of this observation align with the increase in student test scores across cycles 1, 2, and 3. By using interactive learning media, educators can leverage students' interest in digital activities to boost their learning motivation. This condition aligns with previous research, which indicates that using interactive teaching materials can increase students' learning motivation (Budiarto & Jazuli, 2021; Fadila et al., 2025; Y. Li et al., 2024).

However, this study has several limitations that should be considered for further development. Students' initial digital literacy levels significantly influence the effectiveness of the AI-PjBL model; in Cycle I, most time was still spent on technology adaptation rather than on the material's content. Furthermore, reliance on stable internet infrastructure and device specifications poses a technical obstacle that can lead to disparities in work speed between groups. Finally, this success is limited to the specific geography material covered in this study, so generalisation to geography topics with different data characteristics may require more specific adjustments to instructional strategies.

CONCLUSIONS

This research concludes that integrating Artificial Intelligence (AI) into the Project-Based Learning (PjBL) model significantly enhances the critical spatial thinking skills of grade F+/XII students at SMA Negeri 1 Sukoharjo, as evidenced by a substantial increase in classical mastery from 68.57% in Cycle I to 91.43% in Cycle III. These findings offer significant theoretical implications by strengthening digital constructivism, in which AI serves as a cognitive scaffold that facilitates educators' transition to facilitators within a student-centred ecosystem. The novelty of this study lies in the strategic synergy between AI tools and PjBL syntax to dissect geographic phenomena critically, providing a practical contribution through an innovative instructional model aligned with the demands of the modern curriculum. While the approach effectively boosts motivation and meaningful participation through digital outputs, further research is suggested to explore the influence of students' initial digital literacy levels and a wider range of AI tools to ensure the generalizability of these results across more complex geographical contexts.

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