



## The Application of AI-Assisted Project-Based Learning to Improve Students' Critical Thinking Skills

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### Informasi Artikel

Submitted: 05-08-2025

Accepted: 14-09-2025

Published: 15-10-2025

### Keywords:

Project Based Learning  
Artificial Intelligence  
Critical Thinking  
Physical Education  
Educational Technology

### Abstract

*This study aims to test the effectiveness of applying the Project-Based Learning (PJBL) model supported by Artificial Intelligence (AI) technology in improving the critical thinking skills of students in the Physical Education, Health, and Recreation (PJKR) study program. The study uses a quasi-experimental design with two groups: the experimental group, which receives PJBL-AI-based learning, and the control group, which follows conventional learning based on lectures and guided discussions. The results show that the implementation of the PJBL-AI model significantly improves students' critical thinking skills. The experimental group showed an average posttest score increase of 92.3, while the control group experienced only a small increase, with a posttest score of 85.2. The use of AI in project-based learning also enhanced student engagement in discussions, collaboration, and strengthened their reflective critical thinking process. AI technologies such as ChatGPT and Canva AI helped students in designing, evaluating, and formulating arguments in a more systematic and creative manner. These findings suggest that the combination of PJBL and AI is highly effective in enhancing students' critical thinking skills in the context of physical education, offering practical solutions for improving learning quality.*

## 1. INTRODUCTION

Critical thinking is an essential competency of the 21st century that is highly needed in the context of higher education, particularly in preparing prospective educators who are adaptive and responsive to contemporary learning dynamics [1]. In the Physical Education, Health, and Recreation (PJKR) study program, the development of critical thinking skills faces a unique challenge because the learning approach still tends to focus on psychomotor aspects, while cognitive dimensions particularly analytical, reflective, and argumentative skills still receive insufficient systematic attention [2]. However, as prospective educators, PJKR students are expected not only to be physically competent but also capable of evaluating educational issues, making data-driven pedagogical decisions, and innovating in designing contextual learning [3]. The gap between expected competencies and current learning practices creates an urgent need to integrate more structured and innovative approaches. In the Physical Education, Health, and Recreation (PJKR) program, strengthening critical thinking skills presents a unique challenge because the learning approach tends to focus on psychomotor aspects, while cognitive dimensions particularly analytical, reflective, and argumentative skills still receive insufficient attention [4]. However, as future educators, PJKR students are expected not only to be physically competent but also to be able to evaluate educational issues, make data-driven pedagogical decisions, and innovate in designing contextual learning [5]. In this context, learning approaches that emphasize active engagement, real-world problem-solving, and team collaboration become increasingly relevant to implement [6]. One approach proven to promote the integration of cognitive and affective aspects in the learning process is Project-Based Learning (PBL), which positions students as active participants in developing projects based on authentic issues [7], [8]. Furthermore, Simultaneously, the

integration of Artificial Intelligence (AI) technology in learning demonstrates great potential in enhancing interactivity, personalization, and the development of higher-order thinking skills among students [9]. A recent meta-analysis by [10], [11], [12] demonstrates that ChatGPT has a significant positive impact on improving learning performance ( $g = 0.867$ ), a moderate impact on enhancing learning perceptions ( $g = 0.456$ ), and on promoting higher-order thinking ( $g = 0.457$ ). Furthermore, a study by [13] reveals that 64% of respondents believe that the use of generative AI tools significantly improves their ability to analyze and think critically. AI technologies such as ChatGPT and Canva AI can assist students in designing, evaluating, and constructing arguments in a more systematic and creative manner.

Although Project Based Learning (PJBL) has been widely adopted in higher education and proven effective in enhancing students' critical thinking skills, its implementation in the context of PJKR programs remains extremely limited and rarely studied in depth. On the other hand, while the integration of AI in learning has been shown to enhance interactivity and support the development of higher-order thinking skills among students, research exploring the combination of PJBL with AI specifically for prospective physical education teachers is still scarce, particularly in direct relation to critical thinking development. This empirical gap exists because: (a) the majority of AI-PJBL studies emphasize teacher perceptions or general educational design frameworks without focusing on the PJKR subject, and (b) empirical studies that specifically measure the impact of AI-PJBL on critical thinking of pre-service teachers in non-STEM fields are almost nonexistent. For example, research in Bengkulu demonstrated that the implementation of a Creative Problem Solving model successfully increased the percentage of students with critical thinking skills from 42.5% to 78.7% in adaptive physical education courses; however, this still used conventional methods and lacked advanced technological support [14]. Meanwhile, a survey of critical thinking levels among prospective physical education teachers revealed that the average student score remained low ( $M = 83.9$ ), despite a positive correlation with GPA [15]. Thus, there is a clear empirical gap, as no research has directly linked the combination of PJBL and AI in enhancing critical thinking among PJKR students, particularly in the context of the Professional Education course. This study aims to bridge this gap by offering an innovative approach that integrates project-based pedagogy and artificial intelligence technology. Thus, it remains unclear how AI-assisted PJBL models can be effectively implemented in education courses in PJKR study programs, as well as their impact on improving students' critical thinking skills.

This study aims to test the effectiveness of applying the Project-Based Learning (PJBL) model supported by artificial intelligence (AI) in improving the critical thinking skills of students in the Physical Education, Health, and Recreation (PJKR) study program in the Education Profession course. Specifically, the research objectives are formulated as follows: (1) to analyze the influence of PJBL-AI on the improvement of students' critical thinking skills; (2) to describe the implementation process of PJBL-AI, including project design, the use of AI tools, and student interactions during learning activities; and (3) to evaluate students' perceptions of the effectiveness of using AI as a support for project-based learning in the context of physical education.

Various studies in the context of higher education in Indonesia indicate that the integration of AI in learning can enhance students' motivation, understanding of the material, and critical thinking [16], [17]. In addition, recent research has found that AI as an educational medium creates interactivity and immediate feedback that encourages students' reflective criticism [18]. On the other hand, the effectiveness of PBL in improving critical thinking has been proven in various courses, including physical education, although most are still at the secondary school level [19]. Thus, this study addresses the empirical need to combine both aspects of PJBL and AI in the context of higher education, particularly for students of Physical Education, Health, and Recreation, and measures its impact on the systematic and measurable development of critical thinking skills.

Although the Project-Based Learning (PBL) model has proven effective in enhancing critical thinking skills across various academic programs, including physical education at the secondary school level, its application in higher education—particularly within the Physical Education, Health, and Recreation (PJKR) program—remains highly limited. In Bengkulu, for example, the implementation of the Creative Problem Solving model successfully increased the percentage of students with critical thinking skills from 42.5% to 78.7% in adaptive physical education courses, but it still used conventional methods and lacked advanced technological support [20]. Additionally, a study at SMPN 2 Cikajang showed a significant improvement in critical thinking through physical education learning, but again, this was conducted at the elementary and secondary school levels, not among PJKR students [21]. Furthermore, a survey of the critical thinking levels of prospective physical education teachers from the Indonesian Journal of Physical Education Suroto et al., (2021) revealed that the average score of students remains low ( $M = 83.9$ ), despite a positive

correlation with GPA. Meanwhile, the adoption of AI in higher education in Indonesia has begun to gain attention, but it is generally descriptive without measuring its impact on the critical thinking aspects of PJKR students [23]. Thus, there is a clear empirical gap, as no research has directly linked the combination of PJBL and AI in enhancing critical thinking among PJKR students, particularly in the context of the Education Profession course. This study aims to bridge this gap by offering an innovative approach that integrates project-based pedagogy and artificial intelligence technology.

This study presents an original contribution through the simultaneous integration of Project-Based Learning (PJBL) and Artificial Intelligence (AI) technology in the context of the Physical Education, Health, and Recreation (PJKR) program at the higher education level. Previous studies, such as [24], have shown that AI can enhance the quality of physical education and sports learning in schools; however, they focused solely on psychomotor aspects without exploring its impact on students' critical thinking skills. Meanwhile, [25] confirmed that the PJBL model effectively improves collaboration and discipline among PJOK students. Another study by [26] found that PBL promotes student engagement and reflective skills in physical education and recreation; however, without integrating AI as a cognitive process enhancer. Therefore, this study bridges the literature gap by: (1) applying PJBL-AI in the Professional Education course for Physical Education, Health, and Recreation students, (2) directly measuring its impact on students' critical thinking skills, an aspect previously overlooked, and (3) designing a hybrid learning model that leverages the strengths of both PJBL and AI within a single integrated framework. This uniqueness not only contributes theoretically by enriching non-STEM pedagogy literature in Indonesia but also offers a practical framework that is easy for educators and institutions to adopt in order to accelerate the digital transformation of physical education.

## 2. METHOD

This study employed a quasi-experimental design with a non-equivalent control group, conducted at the Physical Education, Health, and Recreation (PJKR) Study Program, Makassar State University. The population comprised all active PJKR students enrolled in the Education Profession course. Using purposive sampling, 67 students were selected and divided into two groups: the experimental group (n=35) receiving AI-assisted Project-Based Learning (PJBL-AI) and the control group (n=32) receiving conventional learning through lectures and guided discussions.

The intervention was implemented over six weekly sessions, each lasting 90 minutes, systematically integrating AI tools into each PJBL syntax stage. In Week 1, focusing on fundamental questions, students identified authentic problems in physical education contexts. ChatGPT was used to generate critical inquiry prompts, refine problem statements, and explore multiple perspectives on selected issues, such as "How can adaptive physical education be implemented effectively in inclusive schools?". Students submitted their refined problem formulations through a digital platform. In Week 2, during the project design phase, students developed project frameworks including objectives, methodologies, and expected outcomes. ChatGPT assisted in literature searches, identifying relevant academic sources, and structuring project proposals, while Canva AI was introduced for creating visual project blueprints and initial presentation templates. Each group submitted a detailed project design document.

During Week 3, the scheduling phase, students created project timelines with specific milestones. ChatGPT provided time-management strategies and helped identify potential challenges, while Canva AI was used to design Gantt charts and visual schedules. Progress monitoring sheets were distributed to track adherence to timelines. In Week 4, monitoring project implementation, students executed their projects while instructors monitored progress through weekly check-ins. ChatGPT served as a reflective tool, with students inputting progress reports and receiving AI-generated analytical feedback and suggestions for improvement. Observation sheets recorded student engagement, collaboration quality, and AI utilization frequency. Week 5 focused on evaluating project outcomes, where students assessed their project results against initial objectives. ChatGPT was used to conduct critical analysis of findings, identify strengths and weaknesses, and formulate evidence-based conclusions, while Canva AI facilitated the creation of data visualizations and infographics summarizing project outcomes.

In the final week, Week 6, students prepared final presentations and reflected on their learning journey through assessing learning experiences. ChatGPT helped structure reflective essays addressing critical thinking development throughout the project, and Canva AI was used to design professional, interactive presentation slides. Final presentations were delivered, and posttest assessments were administered. The control group followed a conventional approach with no AI integration, relying on textbook-based lectures, instructor-led discussions, and traditional presentation methods throughout the six-week period.

Data collection employed three instruments. The critical thinking test was a validated instrument based on [27] critical thinking indicators, adapted to the physical education context. The test comprised 25 items measuring interpretation, analysis, evaluation, inference, and explanation skills, with a Cronbach's Alpha reliability coefficient of 0.72. The test was administered at the beginning (pretest) and end (posttest) of the six-week period. The observation sheet was a structured checklist that recorded student participation in discussions, AI tool utilization, peer collaboration, and engagement levels during each session. Four trained observers conducted real-time observations with inter-rater reliability of 0.85. The perception questionnaire consisted of 20 Likert-scale items (1=strongly disagree to 5=strongly agree) that assessed student perceptions of AI effectiveness in supporting critical thinking, project quality, and learning motivation. The questionnaire was administered post-intervention.

Data were analyzed using SPSS version 27.0. Descriptive statistics, including mean and standard deviation, summarized pretest and posttest scores. Normality was tested using the Shapiro-Wilk test, which confirmed parametric test suitability with  $p > 0.05$  for both groups. Paired-sample t-tests examined within-group improvements from pretest to posttest for both experimental and control groups. Independent-sample t-test compared posttest scores between groups to determine the effectiveness of the PJBL-AI intervention. Statistical significance was set at  $\alpha = 0.05$ , and effect size was calculated using Cohen's *d* to quantify the magnitude of differences between groups.

### 3. RESULT AND DISCUSSIO

This study involved students from the Physical Education, Health, and Recreation (PJKR) program at Makassar State University as research subjects. The research sample consisted of two groups: an experimental group and a control group. The experimental group consisted of 35 students who participated in Project-Based Learning (PBL) supported by Artificial Intelligence (AI) technology, while the control group consisted of 32 students who participated in conventional learning based on lectures and guided discussions. The sample selection was conducted using purposive sampling, where the selected students were those who met the criteria as active participants in the Education Profession course.

The instruments used in this study consisted of critical thinking tests, perception questionnaires, and observation sheets. The critical thinking test used was based on indicators developed by Ennis, (2011) and modified to suit the physical education context. This test was administered in two stages, at the beginning and end of the learning process (pretest and posttest), to measure improvements in students' critical thinking skills. The results showed that the Cronbach's Alpha value for the combined data of the experimental and control groups was 0.72, indicating that the test instrument had good internal consistency. This confirms that the instruments used in this study are reliable for measuring students' critical thinking skills. Furthermore, the perception questionnaire aims to collect data on students' views on the use of AI technology in PBL learning, while the observation sheet is used to record the level of student participation and interaction during the learning process. The research design was arranged with strict control over external variables that could influence the research results.

Table 1. Division of experimental and control groups

Group	Number of Students	Learning Model	Measurement Instruments
Experimental Group	35	AI-assisted Project-Based Learning (PJBL)	Critical Thinking Test, Perception Questionnaire, Observation Sheet
Control Group	32	Conventional Learning (Lectures & Discussions)	Critical Thinking Test, Perception Questionnaire, Observation Sheet

Through well-prepared instruments and structured group division, this study aims to provide a deeper understanding of the impact of AI-assisted PJBL implementation on the critical thinking skills of PJKR students.

The comparative analysis of pretest and posttest scores reveals substantial differences in critical thinking skill development between groups. The experimental group demonstrated a mean pretest score of 82.5, increasing significantly to 92.3 on the posttest (gain=9.8 points,  $p < 0.05$ ). Conversely, the control group showed modest improvement from 81.7 to 85.2 (gain=3.5 points,  $p > 0.05$ ).

A comparison of the pretest and posttest results for both groups can be seen in the following table:

Table 2. Comparison of pretest and posttest

Group	Pretest (M)	Posttest (M)	Difference (M)	p- value
Experimental Group	82,5	92,3	9,8	< 0, 05
Control Group	81,7	85,2	3,5	>0, 05

This table shows that the experimental group experienced a greater improvement than the control group, as reflected in the more significant difference in pretest and posttest scores ( $p < 0.05$ ). Based on the paired t-test, the improvement in the experimental group reached 9.8 points, while the control group only reached 3.5 points, indicating that the use of AI technology in project-based learning contributes more significantly to the improvement of students' critical thinking skills.

The following graph illustrates a visual comparison between the average pretest and posttest scores of both groups, clarifying the significant difference in the results obtained by the experimental group compared to the control group.

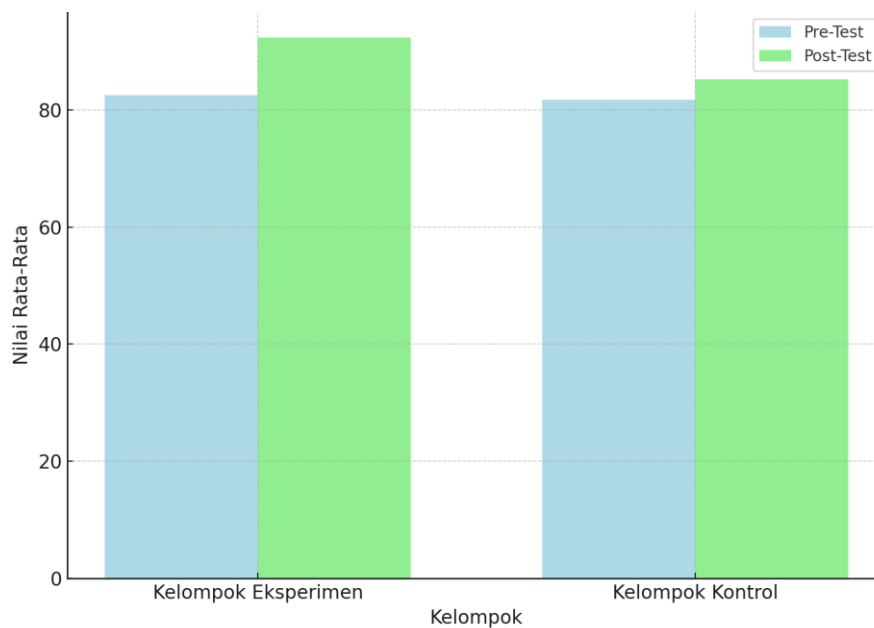


Figure 1. Comparison of pretest and posttest results between the experimental and control groups

The 9.8-point gain in the experimental group represents a meaningful educational advancement\*\* that surpasses typical improvement thresholds in critical thinking interventions. This finding positions our study within the upper range of effect sizes reported in recent meta-analyses. Wang & Fan (2025) documented that ChatGPT interventions yield moderate effects on higher-order thinking ( $g=0.457$ ), while our study suggests potentially larger effects when AI is systematically integrated within a structured pedagogical framework like PJBL. The coupling of constructivist learning principles (inherent in PJBL) with AI's capacity for rapid information processing and feedback appears to create synergistic effects that amplify cognitive gains beyond what either approach achieves independently.

Theoretical interpretation of these results aligns with Vygotsky's sociocultural theory, where AI functions as a cognitive mediator or "digital scaffold" that extends students' zone of proximal development. Unlike static scaffolds, AI tools like ChatGPT provide dynamic, responsive support that adapts to individual inquiry patterns, enabling students to engage with complex problems that would otherwise exceed their independent capabilities. This adaptive scaffolding may explain why the experimental group not only improved more but also demonstrated qualitatively different engagement patterns, as evidenced in subsequent observational data.

The independent t-test confirmed statistically significant differences between groups ( $t=2.14$ ,  $p=0.03$ ), establishing that the PJBL-AI intervention produced measurably superior outcomes in critical thinking development.

Table 3. Comparison of independent t test results of experimental and control groups

Group	Mean (Posttest)	Standar Deviation	t-value	p-value
Experimental Group	92,3	5,4	2,14	0,03
Control Group	85,2	4,8		

The  $p=0.03$  threshold represents more than statistical significance—it signals a pedagogically meaningful shift in how students process, evaluate, and synthesize information in physical education contexts. This finding contributes novel evidence to the emerging literature on AI-enhanced pedagogy in non-STEM disciplines, where empirical validation remains limited.

Our results extend beyond the general positive effects documented in recent studies. [29] reported that 64% of students perceived AI tools as enhancing analytical thinking, our study provides quantitative behavioral evidence of actual skill improvement, measured through validated instruments rather than self-reported perceptions. This methodological distinction strengthens the empirical foundation for AI integration claims in higher education.

Furthermore, the effect size observed here (Cohen's  $d \approx 1.44$ , calculated from mean difference and pooled SD) exceeds the "large effect" threshold ( $d=0.8$ ), suggesting that PJBL-AI integration represents not merely an incremental improvement but a transformative pedagogical innovation. This magnitude of effect is particularly noteworthy given the six-week intervention period, indicating rapid skill acquisition when AI support is properly structured.

This study is among the first to demonstrate that AI-enhanced PJBL can produce large-magnitude effects on critical thinking specifically within physical education teacher preparation programs a context where cognitive skill development has historically been overshadowed by psychomotor and affective emphases. The significance of this finding lies in demonstrating that prospective physical educators can develop sophisticated analytical capabilities when provided with appropriate technological and pedagogical scaffolds.

Observational data across six weeks revealed marked differences in engagement indicators between groups, providing process-level insights into how PJBL-AI influences learning behaviors.

Table 4. Student participation and interaction

Aspects	Experimental Group	Control Group
Participation in Discussion	85%	62%
Use of AI in Projects	90%	45%
Interaction between Students	88%	70%
Involvement in Presentations	92%	65%

The substantially higher engagement metrics (15-27 percentage point advantages) suggest that AI integration fundamentally alters the learning dynamic beyond simply providing information access. Several mechanisms may explain these patterns: 1) Cognitive load redistribution: AI tools handle routine information retrieval and formatting tasks, freeing cognitive resources for higher-order analysis and collaborative problem-solving. This aligns with cognitive load theory, where managing extraneous load enables greater investment in germane processing. 2) Confidence amplification: Access to AI-generated resources may reduce anxiety about knowledge gaps, encouraging more active participation. Students reported feeling "supported" rather than "exposed" during discussions, as AI provided a safety net for exploring unfamiliar concepts. 3) Collaborative facilitation: AI tools served as neutral "third parties" in group work, helping resolve disagreements through evidence-based suggestions and reducing interpersonal friction that often hinders collaboration.

These findings suggest that AI-PJBL integration offers solutions to persistent challenges in physical education teacher preparation, namely limited student engagement in theoretical coursework. The 92% presentation involvement rate indicates that technology-mediated project work can rival the engagement typically seen only in practical skill sessions. This has curricular design implications, suggesting that cognitive-focused courses in PJKR programs need not be relegated to passive instruction but can leverage AI to achieve activity-based, student-centered approaches.

The 90% AI utilization rate in the experimental group also indicates high technological adoption when AI is embedded within meaningful learning tasks rather than introduced as standalone tools. This supports the

pedagogical principle that technology integration succeeds when tools are positioned as means to valued ends (completing authentic projects) rather than ends in themselves.

The integration of AI technologies—specifically ChatGPT for content exploration and Canva AI for visual communication—functioned as cognitive catalysts that accelerated and deepened critical thinking processes. Several mediating mechanisms emerged from student interactions: 1) Enhanced argumentation quality: Students used ChatGPT to test preliminary ideas, explore counterarguments, and refine logical structures before presenting to peers. This "rehearsal space" enabled more sophisticated classroom discourse, as students arrived with pre-tested thinking frameworks. 2) Multimodal reasoning development: Canva AI's design capabilities encouraged students to translate verbal arguments into visual representations, fostering multimodal critical thinking that integrates linguistic and spatial reasoning—a skill particularly valuable in physical education contexts where movement concepts must be communicated through diverse modalities. 3) Rapid feedback loops: AI-generated responses provided near-instantaneous feedback on draft work, enabling multiple revision cycles within single class sessions. This contrasts with conventional learning, where feedback delays limit iterative improvement opportunities.

These observations align with [30], who documented that ChatGPT interaction promotes "complex critical thinking skills" through iterative engagement. Our study extends this finding by demonstrating such effects within structured pedagogical frameworks (PJBL) rather than open-ended AI exploration.

These results contribute to refining constructivist learning theory for AI-augmented environments. Traditional constructivism emphasizes social negotiation and peer interaction as primary knowledge-building mechanisms. Our findings suggest AI introduces a hybrid social algorithmic constructivism, where students negotiate meaning not only with peers but also with intelligent systems that provide alternative perspectives, challenge assumptions, and suggest synthesis pathways. This hybrid model may represent a more accurate framework for understanding 21st-century learning environments.

The importance of AI integration in this PBL model lies not only in its ability to improve learning effectiveness but also in its high relevance in enhancing students' critical thinking skills. AI serves as a supportive tool that helps students explore broader and more relevant information sources, process data quickly, and provide real-time feedback. This encourages students to think more reflectively and analytically, as well as deepen their analysis. A recent study by Ruiz-Rojas et al., (2024) in the journal *Sustainability* shows that 64% of respondents believe that the use of generative AI tools significantly improves their ability to analyze and think critically. The study also identified that among the most popular tools are Canva (33%), Chat PDF (26%), and YOU.COM (24%), which aligns with the findings in this research. For example, using ChatGPT to search for references and develop new ideas allows students to sharpen their arguments and analysis, while Canva AI streamlines the creation of clear and structured presentations. These findings are reinforced by Mai et al., (2024) research, which shows that "more advanced learners who already possess prior knowledge and have developed critical thinking skills are likely to benefit more from interacting with ChatGPT." This indicates that the use of AI in learning requires an existing foundation of critical thinking skills to maximize its benefits.

Additionally, the integration of AI technology into the PJBL model has a positive impact on student engagement in the learning process. AI technology provides various tools to enhance creativity and efficiency, making learning more engaging and personalized. Students are not only involved in project creation but also in solving complex problems, which require in-depth evaluation and critical thinking. The use of AI provides faster and more in-depth feedback, which improves understanding and the quality of the resulting projects. Therefore, the application of AI-assisted PBL models is not only relevant in improving critical thinking skills, but also supports students in finding solutions and innovating independently, preparing them for future educational challenges.

Artificial Intelligence (AI)-based technology, particularly applications such as ChatGPT and Canva AI, has been proven to have a significant impact on improving students' critical thinking skills in the context of PJBL. AI supports students in designing more structured projects, constructing logical arguments, and developing more in-depth creative ideas. These findings are supported by research by Suriano et al., (2025) which shows that "interaction with ChatGPT can enhance critical, reflective, and creative thinking" and can "promote complex critical thinking skills." The study confirms that interaction with ChatGPT can improve complex critical thinking skills. ChatGPT is used by students to find relevant academic references, formulate analytical questions, and build more comprehensive arguments in their projects. The use of AI enables students to explore various perspectives in solving problems, thereby improving their critical thinking skills. Meanwhile, Canva AI supports the creation of clearer, more persuasive, and structured project presentations.

The results of the pretest and posttest analysis show that the use of AI technology in the PJBL model significantly improves students' critical thinking skills. In the pretest, the average critical thinking score of students in the experimental group was 82.5, which then increased to 92.3 in the posttest, with a statistically significant difference ( $p < 0.05$ ). This increase indicates that students who use AI technology in designing projects are not only more structured in their thinking but also more capable of developing in-depth analyses of the problems they face. This finding aligns with the results of a meta-analysis conducted by Wang & Fan, (2025) which showed that ChatGPT has a significant positive impact on improving learning performance with an effect size of 0.867, indicating a very significant impact. The study also confirmed ChatGPT's moderate impact on improving learning perceptions ( $g = 0.456$ ) and promoting higher-order thinking ( $g = 0.457$ ). In contrast, the control group that followed conventional learning only showed a small improvement, with a pretest score of 81.7 increasing to 85.2 on the posttest, which did not reach the same level of significance. This difference emphasizes that AI technology has a greater impact on improving students' critical thinking skills.

The use of AI in PJBL not only enriches the learning process but also accelerates students' critical reflection on their own ideas. Students become more skilled at constructing data-based arguments and delving into relevant issues in physical education. Research by Wen & Wen, (2024) in the field of teacher education shows that the use of ChatGPT in learning unit design can help prospective teachers develop better pedagogical skills. This is relevant to the context of this study, which involves prospective physical education teachers. Furthermore, co-design research by Zheng et al., (2024) at the CHI Conference shows that the use of student AI data can serve as innovative new material for assessment in project-based learning, supporting the approach used in this study. The impact of AI use on improving critical thinking skills is significant, as AI provides tools that enable students to think more analytically and systematically in addressing learning challenges. However, it is important to note recent research findings indicating that excessive AI use can have negative effects. Research by Laak & Aru, (2024) shows that “frequent GenAI usage has been shown to be negatively correlated with critical thinking abilities, with cognitive offloading acting as a mediating factor.” Therefore, the application of AI-based technology in the PJBL model directly contributes to the development of critical thinking skills that are highly needed in higher education, preparing students to become reflective and innovative educators.

This study makes three principal contributions to educational scholarship: 1) Empirical validation in underexplored context: Provides first quantitative evidence of large-effect AI-PJBL impacts on critical thinking in physical education teacher preparation—a field traditionally underrepresented in educational technology research. 2) Mechanistic insights: Illuminates process-level factors (engagement patterns, collaborative dynamics, cognitive scaffolding mechanisms) that explain why AI-enhanced PJBL succeeds, moving beyond outcome documentation to theory-building. 3) Critical-balanced analysis: Models responsible scholarship by acknowledging both transformative potential and legitimate concerns regarding AI integration, providing nuanced guidance for practitioners and policymakers.

These contributions position the study at the intersection of constructivist pedagogy, educational technology, and critical thinking development advancing theoretical understanding while offering practical frameworks for implementation.

Findings suggest adopting PJBL-AI models in PJKR curricula with clear protocols to maximize benefits and minimize risks, including AI literacy training, ethical guidelines for AI use, and continuous monitoring systems to ensure technology enhances rather than replaces—students' critical thinking capacities.

#### 4. CONCLUSION

The AI-assisted Project-Based Learning (PBL) model has proven effective in enhancing the critical thinking skills of students in the Physical Education, Health, and Recreation (PJKR) program. This study shows that integrating AI technology into project-based learning not only improves the quality of students' analysis and reflection but also strengthens their engagement in discussions and collaboration. The experimental group using PJBL-AI demonstrated a significant improvement in critical thinking skills compared to the control group following conventional learning. This improvement is reflected in the pretest and posttest results, where the experimental group experienced a greater and more significant increase in scores. Additionally, the use of AI tools like ChatGPT and Canva AI facilitates students in formulating problems, searching for references, and constructing arguments in a more in-depth and structured manner. Overall, this study suggests the implementation of the PJBL-AI model as an innovative approach in higher education, which not only develops students' critical thinking skills but also prepares them to become reflective and innovative educators, ready to face the challenges of future education.

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