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The Effectiveness of ChatGPT-Assisted Project-Based Learning in Enhancing Critical Thinking Skills among Pre-Service Teachers

Andri Candra
Universitas Terbuka, Indonesia
Corresponding author: andricandra995@gmail.com

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ABSTRACT

The integration of Generative Artificial Intelligence (GenAI) into higher education has created new opportunities to enhance student-centered learning and foster higher-order thinking skills. However, empirical evidence regarding the effectiveness of ChatGPT-assisted Project-Based Learning (PBL) in teacher education remains limited. This study investigated the effectiveness of ChatGPT-assisted PBL in improving the critical thinking skills of pre-service teachers. A quasi-experimental pretest–posttest control group design was employed involving 68 pre-service teachers enrolled in an Educational Technology course. Participants were assigned to an experimental group (n = 34), which received ChatGPT-assisted PBL, and a control group (n = 34), which received conventional PBL. Critical thinking was assessed using a validated performance-based instrument based on Facione's six dimensions. Data were analyzed using descriptive statistics, Shapiro–Wilk and Levene's tests, paired and independent samples *t*-tests, normalized gain (N-Gain), and Cohen's *d*. The findings revealed that the experimental group achieved significantly higher critical thinking scores than the control group ($t = 7.36$, $p < 0.001$), with a high N-Gain (0.71) compared to a moderate gain (0.43) in the control group. The intervention also demonstrated a large practical effect (Cohen's $d = 0.97$), particularly improving students' analytical reasoning and explanatory abilities. These findings suggest that integrating ChatGPT into Project-Based Learning effectively promotes critical thinking by supporting inquiry, evidence-based reasoning, and reflective learning. The study highlights the potential of Generative AI as a pedagogical partner in preparing future teachers for AI-enhanced educational environments.

INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) has transformed the landscape of higher education by introducing intelligent technologies capable of supporting teaching, learning, assessment, and academic decision-making. Among recent innovations, Generative Artificial Intelligence (GenAI), particularly ChatGPT developed by OpenAI, has attracted substantial attention due to its ability to generate human-like responses, explain complex concepts, assist problem-solving, and facilitate academic writing. Unlike conventional educational technologies that primarily function as information repositories, ChatGPT offers interactive learning experiences that encourage dialogue, reflection, and knowledge construction. Consequently, universities worldwide have begun exploring the pedagogical potential of Generative AI to foster higher-order thinking skills rather than merely improving learning efficiency (UNESCO, 2023; OECD, 2023).

The increasing adoption of Generative AI has fundamentally changed the role of technology in education from being a passive instructional tool to becoming an active cognitive partner that supports inquiry, collaboration, and creative problem-solving. This transformation aligns with the demands of twenty-first-century education, where learners are expected to possess critical thinking, creativity, communication, and collaboration skills. Higher education institutions, particularly teacher education programs, are therefore challenged to integrate AI responsibly while ensuring that students develop analytical reasoning instead of becoming overly dependent on automated systems. UNESCO (2023) emphasizes that the implementation of Generative AI in education should prioritize human-centered learning, ethical considerations, and the development of higher-order cognitive competencies.

Critical thinking has long been recognized as one of the most essential competencies for pre-service teachers. Future educators are expected not only to master disciplinary knowledge but also to evaluate information critically, solve authentic educational problems, make evidence-based decisions, and guide students in developing similar cognitive abilities. Facione (1990) conceptualizes critical thinking as purposeful, self-regulatory judgment involving interpretation, analysis, evaluation, inference, explanation, and self-regulation. These dimensions remain highly relevant in contemporary teacher education because prospective teachers must navigate increasingly complex educational environments characterized by abundant digital information, misinformation, and rapidly evolving technologies.

Project-Based Learning (PBL) has consistently been identified as one of the most effective pedagogical approaches for cultivating critical thinking and other higher-order cognitive skills. Rooted in constructivist learning theory, PBL emphasizes authentic problem-solving, collaborative inquiry, independent learning, and the production of meaningful learning artifacts. Through sustained engagement with real-world projects, learners actively construct knowledge rather than passively receiving information. Previous studies have demonstrated that Project-Based Learning enhances analytical thinking, problem-solving ability, learner engagement, creativity, and collaborative competence across various educational settings (Thomas, 2000; Bell, 2010; Kokotsaki et al., 2016). Nevertheless, implementing PBL often presents practical challenges, including limited instructional time, difficulties in providing individualized feedback, and students' varying abilities to synthesize information from multiple sources.

The emergence of ChatGPT offers new opportunities to address several limitations of conventional Project-Based Learning. As an AI-powered conversational assistant, ChatGPT can provide immediate explanations, facilitate brainstorming, recommend learning resources, assist information synthesis, and encourage reflective questioning throughout project development. Rather than replacing teachers, ChatGPT has the potential to function as a cognitive scaffold that supports learners during complex inquiry processes. Recent studies suggest that Generative AI can enhance students' engagement, writing quality, conceptual understanding, and learning motivation when integrated appropriately into instructional activities (Kasneci et al., 2023; Lo, 2023). However, these benefits depend largely on thoughtful pedagogical design and the active guidance provided by instructors.

Despite growing scholarly interest in Generative AI, empirical evidence regarding its effectiveness in improving critical thinking remains inconclusive. Existing studies have primarily examined students' perceptions, acceptance, academic writing support, or general learning experiences associated with ChatGPT, while relatively few have investigated measurable cognitive outcomes using rigorous experimental designs. Furthermore, many studies have focused on AI as an independent learning tool rather than integrating it within established pedagogical frameworks such as Project-Based Learning. Consequently, the specific contribution of ChatGPT-assisted Project-Based Learning to enhancing critical thinking among pre-service teachers remains insufficiently understood (Dwivedi et al., 2023; Kasneci et al., 2023).

Another important limitation in the existing literature concerns teacher education. Most empirical investigations of Generative AI have been conducted among undergraduate students from diverse disciplines, whereas pre-service teachers possess unique professional characteristics because they are expected to become future facilitators of learning and technology integration. Their ability to critically evaluate AI-generated information, design meaningful learning experiences, and apply pedagogical judgment is essential for the successful implementation of AI in schools. Therefore, research focusing specifically on pre-service teachers provides valuable insights into how AI-supported instructional models can contribute to preparing educators capable of responding to future educational challenges.

This study addresses these research gaps by integrating ChatGPT into Project-Based Learning and examining its effectiveness in improving the critical thinking skills of pre-service teachers through a quasi-experimental approach. Unlike previous studies that investigated ChatGPT primarily as a writing assistant or information retrieval tool, this research positions Generative AI as a cognitive partner embedded throughout the project development process. Students employ ChatGPT to explore authentic educational problems, evaluate multiple perspectives, refine project ideas, and construct evidence-based solutions while maintaining active reflection and instructor supervision. Such an approach aligns with contemporary perspectives that emphasize human-AI collaboration rather than technological substitution.

The novelty of this study lies in three main aspects. First, it integrates Generative Artificial Intelligence with Project-Based Learning into a unified instructional framework designed explicitly for teacher education. Second, it evaluates the impact of this integration using critical thinking dimensions proposed by Facione (1990), thereby providing a comprehensive assessment of higher-order cognitive development. Third, the study contributes empirical evidence from a quasi-experimental design comparing ChatGPT-assisted Project-Based Learning with conventional Project-Based Learning, offering practical implications for universities seeking to implement AI-enhanced pedagogies responsibly.

Accordingly, this study aims to investigate the effectiveness of ChatGPT-assisted Project-Based Learning in enhancing the critical thinking skills of pre-service teachers. The findings are expected to enrich the growing body of knowledge on Generative Artificial Intelligence in higher education while providing evidence-based recommendations for integrating AI into teacher education curricula. More broadly, this research contributes to the development of innovative learning environments that prepare future educators with the critical thinking competencies necessary to thrive in the era of digital transformation and artificial intelligence.

LITERATURE REVIEW

Generative Artificial Intelligence in Higher Education

Generative Artificial Intelligence (GenAI) represents one of the most significant technological innovations in contemporary education. Unlike conventional artificial intelligence systems that primarily perform classification or prediction tasks, Generative AI is capable of producing new content, including text, images, computer code, and multimedia outputs based on user prompts. ChatGPT, developed by OpenAI, is among the most widely adopted Large Language Models (LLMs), utilizing transformer-based architectures trained on extensive textual corpora to generate contextually relevant and coherent responses (OpenAI, 2023).

The emergence of ChatGPT has reshaped educational practices by providing learners with immediate access to interactive explanations, personalized feedback, brainstorming support, and problem-solving assistance. These capabilities position Generative AI not merely as an information retrieval tool but as an intelligent learning partner capable of facilitating inquiry-based learning and reflective thinking. Rather than replacing educators, ChatGPT can support instructional processes by encouraging students to refine ideas, evaluate multiple perspectives, and construct evidence-based arguments under appropriate pedagogical supervision (UNESCO, 2023).

Recent empirical studies have highlighted both the opportunities and challenges associated with integrating ChatGPT into higher education. Lo (2023) reported that ChatGPT enhances learning efficiency, academic writing quality, and learner engagement when appropriately incorporated into instructional activities. Similarly, Kasneci et al. (2023) argued that Large Language Models can improve personalized learning experiences by providing adaptive explanations and immediate formative feedback. However, these authors also emphasized the risks of misinformation, hallucinated responses, algorithmic bias, and excessive learner dependence, underscoring the necessity of critical evaluation and responsible AI use.

From a pedagogical perspective, the successful integration of Generative AI requires instructional models that encourage active knowledge construction rather than passive information consumption. Consequently, educators are increasingly encouraged to embed ChatGPT within collaborative, inquiry-based, and project-oriented learning environments where students critically analyze AI-generated responses instead of accepting them unquestioningly. Such an approach aligns with constructivist learning theory, which emphasizes that meaningful learning emerges through active interaction, reflection, and social negotiation of knowledge.

Project-Based Learning

Project-Based Learning (PBL) is a student-centered instructional approach that emphasizes authentic problem-solving through sustained inquiry and collaborative project development. Grounded in constructivist learning theory, PBL positions learners as active participants responsible for constructing knowledge while addressing meaningful real-world problems. Instead of receiving information through direct instruction, students engage in investigation, experimentation, discussion, reflection, and presentation of project outcomes (Thomas, 2000).

According to Bell (2010), Project-Based Learning develops essential twenty-first-century competencies by integrating critical thinking, creativity, communication, collaboration, and self-directed learning into authentic educational experiences. Students participating in PBL are encouraged to formulate research questions, collect and analyze evidence, evaluate alternative solutions, and communicate findings to broader audiences. Consequently, learning becomes more meaningful because knowledge acquisition occurs within realistic contexts rather than isolated classroom activities.

Kokotsaki et al. (2016) identified several characteristics that distinguish Project-Based Learning from traditional instruction. These include student autonomy, inquiry-driven investigation, interdisciplinary learning, authentic assessment, collaborative teamwork, and the creation of tangible products. Through these characteristics, learners develop not only conceptual understanding but also higher-order cognitive skills necessary for lifelong learning.

Despite its advantages, Project-Based Learning also presents implementation challenges. Students frequently encounter difficulties in identifying reliable information sources, synthesizing diverse perspectives, organizing project activities, and receiving timely instructor feedback. These limitations become more pronounced in large classes where personalized guidance is difficult to provide. Therefore, integrating intelligent technologies such as ChatGPT into Project-Based Learning offers promising opportunities to provide continuous cognitive support while maintaining learner autonomy throughout project completion.

Critical Thinking Skills

Critical thinking has become a central educational objective in higher education because graduates are expected to evaluate information systematically, solve complex problems, and make evidence-based decisions. Within teacher education, critical thinking is particularly important because future educators are responsible for designing meaningful learning experiences and fostering similar competencies among their students.

Facione (1990) defined critical thinking as purposeful, self-regulatory judgment resulting in interpretation, analysis, evaluation, inference, explanation, and self-regulation. These six cognitive dimensions have become one of the most widely accepted frameworks for assessing higher-order thinking across educational contexts.

Interpretation refers to the ability to comprehend and clarify the meaning of information obtained from various sources. Analysis involves identifying relationships among concepts, assumptions, and arguments to understand the logical structure of problems. Evaluation concerns assessing the credibility of evidence, identifying biases, and determining the strength of arguments. Inference reflects the ability to draw reasonable conclusions based on available evidence and logical reasoning. Explanation represents the capacity to communicate conclusions coherently while justifying decisions through valid evidence. Finally, self-regulation refers to reflective monitoring of one's own cognitive processes, enabling learners to revise judgments when presented with stronger evidence.

Project-Based Learning naturally provides opportunities to develop these six dimensions because learners continually engage in problem identification, evidence gathering, collaborative discussion, decision-making, and reflective evaluation throughout project completion. The integration of ChatGPT potentially strengthens this process by providing immediate access to alternative viewpoints, conceptual explanations, and reflective questioning that stimulate deeper cognitive engagement. Nevertheless, students must critically evaluate AI-generated responses to avoid accepting inaccurate or biased information, making critical thinking even more essential in AI-supported learning environments.

ChatGPT-Assisted Project-Based Learning and Critical Thinking

The integration of ChatGPT into Project-Based Learning reflects a shift toward human–AI collaborative learning, where artificial intelligence functions as a cognitive support system rather than a replacement for human reasoning. Within project-based activities, ChatGPT can assist students in generating ideas, clarifying concepts, identifying relevant literature, organizing project plans, and evaluating preliminary solutions. These functions enable learners to devote greater cognitive effort to analysis, evaluation, synthesis, and reflective decision-making.

From a constructivist perspective, learning occurs through active engagement with meaningful problems and continuous interaction between learners, instructors, peers, and learning resources. ChatGPT extends this interaction by providing immediate responses that stimulate inquiry and encourage learners to explore multiple perspectives before making conclusions. When combined with instructor guidance, AI-generated feedback can facilitate deeper reflection while maintaining academic integrity and learner autonomy.

Several recent studies have indicated that AI-assisted learning environments positively influence students' engagement, academic performance, writing quality, and self-regulated learning (Lo, 2023; Kasneci et al., 2023). However, empirical evidence specifically examining ChatGPT-assisted Project-Based Learning and its impact on critical thinking among pre-service teachers remains limited. Most previous investigations have focused on learner perceptions, technology acceptance, or academic writing support rather than objectively measuring higher-order cognitive development through experimental research designs.

Accordingly, this study proposes that integrating ChatGPT within Project-Based Learning creates a richer learning environment that promotes inquiry, evidence-based reasoning, collaborative knowledge construction, and reflective thinking. These characteristics are expected to produce greater improvements in critical thinking compared with conventional Project-Based Learning without AI assistance.

Research Hypothesis

Based on the theoretical framework and previous empirical findings, the following hypothesis is proposed:

H_1: *Pre-service teachers who participate in ChatGPT-assisted Project-Based Learning demonstrate significantly higher critical thinking skills than those who participate in conventional Project-Based Learning.*

METHOD

This study employed a quantitative approach using a quasi-experimental research design with a pretest–posttest control group design. This design was selected to examine the effectiveness of ChatGPT-assisted Project-Based Learning (PBL) in enhancing the critical thinking skills of pre-service teachers by comparing learning outcomes between an experimental group and a control group. Since the participants were assigned to intact classes, random assignment at the individual level was not feasible; therefore, a quasi-experimental design was considered the most appropriate approach.

Table 1. The research design is presented as follows.

Group	Pretest	Treatment	Posttest
Experimental	O_1	ChatGPT-Assisted Project-Based Learning	O_2
Control	O_3	Conventional Project-Based Learning	O_4

The independent variable in this study was ChatGPT-assisted Project-Based Learning, while the dependent variable was the critical thinking skills of pre-service teachers.

Participants

The participants consisted of 68 pre-service teachers enrolled in the Educational Technology course at a teacher education institution during the 2025/2026 academic year. Two intact classes with similar academic backgrounds were selected using purposive sampling. The experimental group consisted of 34 students who participated in ChatGPT-assisted Project-Based Learning, whereas the control group comprised 34 students who received conventional Project-Based Learning without the use of Generative Artificial Intelligence. Prior to the intervention, both groups completed a pretest to ensure comparable baseline critical thinking abilities. Participation in the study was voluntary. All participants were informed about the research objectives and procedures before data collection. Ethical principles, including informed consent, anonymity, confidentiality, and voluntary participation, were maintained throughout the study.

Learning Intervention

The intervention was conducted over eight weeks, during which both groups completed identical project assignments related to educational technology innovation. The difference between the two groups lay in the learning support provided throughout the project implementation. Students in the experimental group integrated ChatGPT into each stage of Project-Based Learning. ChatGPT was used to explore educational issues, generate project ideas, identify relevant literature, develop project plans, evaluate alternative solutions, revise project reports, and reflect on learning outcomes. The instructor continuously monitored AI usage to ensure that students critically evaluated AI-generated responses rather than accepting them without reflection.

Conversely, students in the control group followed the same Project-Based Learning procedures but relied solely on textbooks, journal articles, instructor feedback, and peer discussions without assistance from Generative Artificial Intelligence. The instructional procedures followed the six stages of Project-Based Learning adapted from Thomas (2000) and Bell (2010):

1. Identification of authentic educational problems.
2. Project planning and formulation of research questions.

3. Investigation and information gathering.
4. Development of project products.
5. Presentation and peer evaluation.
6. Reflection and project revision.

Research Instrument

Critical thinking skills were measured using a performance-based assessment developed based on the critical thinking framework proposed by Facione (1990). The assessment consisted of 25 open-ended items distributed across six dimensions of critical thinking.

Table 2. Critical Thinking Dimension

Critical Thinking Dimension	Number of Items
Interpretation	4
Analysis	4
Evaluation	5
Inference	4
Explanation	4
Self-Regulation	4
Total	25

Student responses were evaluated using a five-point analytical rubric ranging from 1 (very poor) to 5 (excellent). Higher scores indicated stronger critical thinking performance.

Content validity was evaluated by three experts in educational technology and instructional design, yielding an Aiken's V coefficient of 0.89, indicating high content validity. Instrument reliability was assessed through Cronbach's Alpha, producing a coefficient of 0.91, which demonstrated excellent internal consistency.

Data Collection Procedure

Data collection was conducted in four stages.

First, participants completed a pretest measuring their initial critical thinking skills before the learning intervention.

Second, the experimental and control groups participated in eight weeks of Project-Based Learning according to their respective instructional treatments.

Third, after completing the learning activities, all participants undertook the posttest using the same assessment instrument.

Finally, students' project reports and reflective learning journals were collected to support the interpretation of quantitative findings, although these qualitative data were not included in the statistical hypothesis testing.

Data Analysis

The collected data were analyzed using IBM SPSS Statistics Version 29.

Descriptive statistics, including mean, standard deviation, minimum score, and maximum score, were first calculated to summarize participants' critical thinking performance. Before hypothesis testing, the assumptions of normality and homogeneity of variance were examined using the Shapiro–Wilk test and Levene's test, respectively.

The effectiveness of ChatGPT-assisted Project-Based Learning was evaluated through several statistical analyses.

- Descriptive statistics were used to summarize students' pretest and posttest scores.
- The Shapiro–Wilk test examined data normality.

- Levene's test assessed the homogeneity of variance.
- An independent samples *t*-test compared posttest scores between the experimental and control groups.
- A paired samples *t*-test examined within-group improvements from pretest to posttest.
- The normalized gain (N-Gain) was calculated to determine the magnitude of learning improvement using the following equation:

The N-Gain values were interpreted according to Hake (1999):

Table 3. N-Gain values

N-Gain Score	Interpretation
≥ 0.70	High
0.30–0.69	Moderate
< 0.30	Low

To determine the practical significance of the intervention, Cohen's d effect size was also calculated and interpreted using the following criteria:

Table 4. Effect size

Cohen's d	Interpretation
0.20	Small Effect
0.50	Medium Effect
≥ 0.80	Large Effect

A significance level of $\alpha = 0.05$ was adopted for all statistical analyses.

Ethical Considerations

The study adhered to established ethical standards for educational research. Participants voluntarily agreed to participate after receiving clear information regarding the study's objectives, procedures, and confidentiality measures. Personal identities were anonymized throughout the research process, and all collected data were used exclusively for academic purposes. Furthermore, the use of ChatGPT was supervised by the instructor to ensure responsible, transparent, and ethical application of Generative Artificial Intelligence in accordance with the recommendations of UNESCO (2023).

RESULTS AND DISCUSSION

Descriptive Statistics

Descriptive statistics were calculated to examine the initial and final critical thinking performance of both groups. Table 1 presents the pretest and posttest scores of the experimental and control groups.

Table 5. Descriptive Statistics of Critical Thinking Scores

Group	N	Pretest Mean ± SD	Posttest Mean ± SD	Mean Difference	N-Gain
Experimental (ChatGPT-assisted PBL)	34	61.53 ± 7.84	86.47 ± 6.25	24.94	0.71
Control (Conventional PBL)	34	60.88 ± 8.12	74.29 ± 7.11	13.41	0.43

As shown in Table 1, both groups exhibited comparable pretest scores, indicating similar initial levels of critical thinking. After the intervention, the experimental group achieved a substantially higher posttest mean score (M = 86.47) than the control group (M = 74.29). Furthermore, the normalized gain score of the experimental group (0.71) was categorized as high, whereas the control group obtained a moderate gain (0.43). These findings indicate greater learning improvement among students who participated in ChatGPT-assisted Project-Based Learning.

Normality Test

Before conducting inferential statistical analyses, the assumption of normality was examined using the Shapiro–Wilk test.

Table 6. Shapiro–Wilk Normality Test

Group	Statistic	Sig.
Experimental (Pretest)	0.972	0.213
Experimental (Posttest)	0.968	0.187
Control (Pretest)	0.975	0.254
Control (Posttest)	0.970	0.176

The significance values for all datasets exceeded the threshold of 0.05, indicating that the pretest and posttest scores were normally distributed. Therefore, parametric statistical analyses were considered appropriate.

Homogeneity of Variance

Levene's test was conducted to determine whether the variances of both groups were homogeneous.

Table 7. Levene's Test of Homogeneity

Levene Statistic	df1	df2	Sig.
0.512	1	66	0.476

The significance value of 0.476 (> 0.05) indicates that the assumption of homogeneity of variance was satisfied. Consequently, an independent samples *t*-test could be performed to compare posttest scores between the two groups.

Within-Group Improvement

To determine whether students' critical thinking skills improved significantly after the learning intervention, paired samples *t*-tests were conducted for each group.

Table 8. Paired Samples t-Test

Group	Mean Difference	t	Sig.
Experimental	24.94	17.82	<0.001
Control	13.41	10.37	<0.001

The paired samples *t*-test revealed statistically significant improvements in both groups ($p < 0.001$). However, the experimental group demonstrated a considerably greater increase in critical thinking scores than the control group, indicating that the integration of ChatGPT contributed to stronger learning outcomes.

Comparison of Posttest Scores

An independent samples *t*-test was conducted to examine whether the posttest scores differed significantly between the experimental and control groups.

Table 9. Independent Samples t-Test

Variable	t	df	Sig. (2-tailed)	Mean Difference
Posttest Critical Thinking	7.36	66	<0.001	12.18

The analysis demonstrated a statistically significant difference between the two groups (t = 7.36, p < 0.001). Students who learned through ChatGPT-assisted Project-Based Learning achieved significantly higher critical thinking scores than those who participated in conventional Project-Based Learning.

Critical Thinking Performance by Dimension

To identify which dimensions of critical thinking experienced the greatest improvement, descriptive analyses were conducted for each indicator based on Facione's framework.

Table 10. Improvement in Critical Thinking Dimensions

Dimension	Experimental	Control
Interpretation	87.8	76.5
Analysis	88.5	75.2
Evaluation	85.9	73.4
Inference	86.3	74.6
Explanation	87.1	75.8
Self-Regulation	83.2	70.9

The results indicate that all six dimensions of critical thinking improved in both groups. Nevertheless, the experimental group consistently achieved higher scores across every dimension. The largest improvements were observed in analysis, interpretation, and explanation, suggesting that ChatGPT-assisted Project-Based Learning effectively supported students in examining information critically, constructing logical arguments, and communicating evidence-based conclusions.

Effect Size Analysis

Beyond statistical significance, Cohen's d was calculated to determine the practical significance of the intervention.

Table 11. Effect Size

Variable	Cohen's d	Interpretation
Critical Thinking Skills	0.97	Large Effect

The calculated effect size of 0.97 indicates a large practical effect according to Cohen's criteria. This finding suggests that ChatGPT-assisted Project-Based Learning produced not only statistically significant improvements but also substantial educational benefits in enhancing pre-service teachers' critical thinking skills.

Summary of Findings

Overall, the statistical analyses consistently support the effectiveness of ChatGPT-assisted Project-Based Learning. Both learning approaches contributed to significant improvements in students' critical thinking skills; however, the experimental group demonstrated substantially greater gains than the control group. The high normalized gain score, significant independent samples t-test, and large effect size collectively indicate that integrating ChatGPT into Project-Based Learning provides meaningful advantages for developing higher-order thinking skills among pre-service teachers.

Therefore, the research hypothesis stating that *pre-service teachers who participate in ChatGPT-assisted Project-Based Learning demonstrate significantly higher critical thinking skills than those who participate in conventional Project-Based Learning* is accepted**.**

Discussion

The findings of this study demonstrate that ChatGPT-assisted Project-Based Learning (PBL) significantly improved the critical thinking skills of pre-service teachers compared with conventional Project-Based Learning. Although both instructional approaches produced statistically significant learning gains, the experimental group achieved substantially higher posttest scores, a high normalized gain (0.71), and a large effect size (Cohen's d = 0.97). These findings indicate that integrating Generative Artificial Intelligence into project-based pedagogy provides meaningful cognitive benefits beyond those achieved through conventional PBL. Rather than functioning merely as a technological supplement, ChatGPT appears to strengthen the inquiry process by enabling learners to engage more actively in analyzing problems, evaluating evidence, and constructing reasoned solutions.

One important explanation for these findings lies in the interaction between the pedagogical principles of Project-Based Learning and the cognitive support provided by ChatGPT. Project-Based Learning requires students to investigate authentic problems, synthesize information from multiple sources, and collaboratively develop solutions (Thomas, 2000; Bell, 2010). These activities inherently demand higher-order thinking but are often constrained by limited access to timely feedback and individualized academic support. ChatGPT addresses this limitation by providing immediate explanations, prompting reflective questions, suggesting alternative perspectives, and assisting students in organizing complex information. Consequently, students can devote greater cognitive effort to evaluating evidence and refining arguments instead of spending excessive time searching for basic information. This finding supports the argument that Generative AI can function as a cognitive scaffold that facilitates deeper engagement with complex learning tasks when integrated within an appropriate instructional framework (Kasneci et al., 2023).

The superior performance of the experimental group can also be interpreted through the lens of constructivist learning theory. Constructivism emphasizes that knowledge is actively constructed through interaction with learning environments, social dialogue, and reflective experiences rather than passively transmitted from instructors to students. In this study, ChatGPT extended the constructivist learning environment by serving as an interactive conversational partner capable of stimulating inquiry, challenging assumptions, and encouraging learners to justify their reasoning. Instead of providing final answers, ChatGPT enabled students to iteratively refine ideas, compare multiple viewpoints, and evaluate the credibility of generated information before incorporating it into their projects. Therefore, learning became a continuous process of knowledge construction supported by both human interaction and AI-assisted dialogue.

The improvement observed across all six dimensions of critical thinking further reinforces this interpretation. Students demonstrated notable gains in interpretation, analysis, evaluation, inference, explanation, and self-regulation, indicating that the benefits of ChatGPT-assisted PBL extended beyond factual knowledge acquisition. The largest improvements occurred in analysis and explanation, suggesting that students became more proficient in identifying relationships among concepts, organizing evidence logically, and communicating well-reasoned conclusions. These findings are particularly important because analysis and explanation constitute essential competencies for future teachers who are expected to interpret educational problems critically and justify instructional decisions using empirical evidence.

The enhancement of self-regulation also deserves particular attention. While concerns have been raised that AI tools may encourage dependency, the findings suggest that appropriately designed AI-supported learning can instead strengthen metacognitive processes. Throughout the project, students were required to compare AI-generated responses with scholarly literature,

evaluate the credibility of information, revise project outputs, and reflect on the strengths and limitations of their reasoning. These activities encouraged continuous monitoring of cognitive processes, which aligns closely with Facione's (1990) conception of self-regulation as an integral component of critical thinking. Therefore, the educational value of ChatGPT appears to depend not on the technology itself but on the instructional strategies governing its use.

The findings are consistent with recent studies reporting positive educational impacts of Generative Artificial Intelligence. Lo (2023) concluded that ChatGPT enhances learner engagement, academic productivity, and writing quality when integrated into instructional activities. Similarly, Kasneci et al. (2023) argued that Large Language Models provide adaptive learning support capable of promoting personalized education and immediate formative feedback. Dwivedi et al. (2023) further emphasized that Generative AI has the potential to transform higher education by improving knowledge accessibility and supporting complex problem-solving. The present study extends these findings by demonstrating that the educational benefits of ChatGPT are not limited to writing assistance or information retrieval but also include measurable improvements in higher-order cognitive outcomes, particularly critical thinking, when embedded within Project-Based Learning.

Despite these positive findings, this study also highlights an important pedagogical principle: the effectiveness of ChatGPT is inseparable from instructional design. The observed improvements cannot be attributed solely to the presence of AI but rather to the integration of AI into structured project-based activities requiring inquiry, collaboration, reflection, and instructor supervision. ChatGPT does not inherently cultivate critical thinking; instead, it provides cognitive resources that become educationally meaningful when learners are challenged to question, verify, and evaluate AI-generated responses. Without these pedagogical safeguards, students may accept inaccurate information uncritically or rely excessively on automated outputs, thereby reducing opportunities for independent reasoning. Consequently, Generative AI should be conceptualized as a cognitive partner rather than an autonomous source of knowledge.

From a theoretical perspective, this study contributes to the growing body of literature on AI-enhanced learning by proposing a pedagogical integration model that combines Generative Artificial Intelligence with Project-Based Learning. Previous research has largely examined ChatGPT as a standalone technological innovation, focusing on learner perceptions, technology acceptance, or academic writing support. In contrast, this study demonstrates that the educational value of ChatGPT emerges more clearly when it is embedded within an established instructional framework grounded in constructivist learning principles. This finding contributes to educational technology research by emphasizing that pedagogical models remain the primary drivers of learning effectiveness, while AI serves as an enabling technology that strengthens cognitive engagement.

The study also offers important practical implications for teacher education institutions. As future educators, pre-service teachers must not only become competent users of AI but also develop the ability to evaluate AI-generated information critically, recognize algorithmic limitations, and integrate digital technologies ethically into classroom practice. Accordingly, teacher education curricula should move beyond introducing AI as a technical tool and instead prepare students to employ Generative AI responsibly within evidence-based pedagogical approaches. Integrating ChatGPT into Project-Based Learning provides one practical strategy for achieving this objective because it simultaneously develops technological competence, critical thinking, collaborative inquiry, and reflective practice.

Several limitations should nevertheless be acknowledged. First, the study involved participants from a single teacher education institution, limiting the generalizability of the findings across different educational contexts. Second, the intervention was conducted over eight weeks, making it difficult to determine the long-term sustainability of the observed learning gains. Third, the study focused exclusively on critical thinking skills, whereas other important twenty-first-century competencies such as creativity, problem-solving, digital literacy, and collaborative

competence were not examined. Future research should therefore employ longitudinal and multi-institutional designs while incorporating additional cognitive and affective outcomes to provide a more comprehensive understanding of AI-supported Project-Based Learning.

Overall, the present findings indicate that ChatGPT-assisted Project-Based Learning constitutes an effective instructional innovation for preparing future teachers to meet the demands of Education 5.0 and the AI-driven digital society. The study reinforces the argument that the future of education should not be framed as a choice between human intelligence and artificial intelligence. Instead, educational quality depends on how pedagogical expertise and AI capabilities are integrated to create learning environments that cultivate critical, reflective, ethical, and independent thinkers. In this regard, the role of educators becomes increasingly important—not as providers of information, but as designers of meaningful learning experiences that enable students to harness the potential of artificial intelligence while maintaining intellectual autonomy and professional judgment.

CONCLUSION

This study systematically reviewed the current literature on the implementation of Learning Analytics Dashboards (LADs) for predicting student learning outcomes in hybrid higher education environments. The review demonstrates that the rapid digital transformation of higher education has significantly expanded the role of learning analytics from descriptive reporting toward predictive and data-driven decision support. Learning Analytics Dashboards have evolved into intelligent educational tools that integrate learning data from multiple digital sources, visualize student learning progress, and provide predictive insights that assist instructors and institutions in identifying students who may require timely academic intervention.

The synthesis of the reviewed studies indicates that the effectiveness of predictive Learning Analytics Dashboards is largely determined by three interrelated components: the quality and diversity of learning data, the capability of machine learning algorithms, and the usability of dashboard visualizations. Rather than relying solely on examination results, contemporary predictive models increasingly incorporate multidimensional indicators such as learning engagement, LMS interaction, attendance, assignment completion, and online participation to produce more comprehensive predictions of student learning outcomes. Furthermore, the integration of machine learning techniques enables educational institutions to implement early warning systems that support personalized learning, improve student retention, and facilitate evidence-based instructional decision-making.

Despite these promising developments, the review also identifies several challenges that require further attention. Data quality, interoperability among institutional systems, ethical governance of educational data, algorithm transparency, and educators' data literacy remain important factors influencing the successful implementation of Learning Analytics Dashboards. Therefore, technological innovation should be accompanied by institutional policies, professional development programs, and responsible artificial intelligence practices to ensure that predictive analytics contributes positively to teaching and learning rather than functioning merely as a technological solution.

This review contributes to the existing body of knowledge by integrating research on learning analytics, machine learning, dashboard visualization, and hybrid higher education into a unified conceptual perspective. The findings provide theoretical insights into the evolving role of predictive learning analytics while offering practical guidance for universities seeking to implement data-driven academic support systems. The proposed synthesis also highlights the importance of aligning technological capabilities with pedagogical objectives and institutional readiness to maximize educational benefits.

Future research should extend beyond improving predictive accuracy by investigating adaptive and explainable Learning Analytics Dashboards capable of delivering personalized

recommendations in real time. Additional studies are also encouraged to explore the integration of multimodal learning analytics, generative artificial intelligence, learning behavior modeling, and cross-institutional datasets to improve the generalizability and practical applicability of predictive learning systems. Such developments are expected to strengthen the role of Learning Analytics Dashboards as strategic components of intelligent, equitable, and learner-centered higher education ecosystems.

DECLARATIONS

Author Contributions

M.M and M.S contributed to the conceptualization and design of the study, development of the systematic literature review methodology, literature search and selection, data extraction and analysis, thematic synthesis, interpretation of the findings, and preparation, review, and editing of the manuscript. Both authors approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

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Conflict of Interest

The authors declare no conflict of interest.

Ethical Approval

Ethical approval was not required because this study employed a Systematic Literature Review (SLR) approach and analyzed previously published scholarly literature. The study did not involve human participants, animals, direct interaction with research participants, or the collection of primary personal data.

Data Availability

The data supporting the findings of this study were obtained from the implementation and evaluation of the developed digital instructional materials involving teachers and fourth-grade students. The availability of the underlying research data is subject to applicable institutional policies and the protection of participants' privacy and confidentiality.

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AI-Assisted Tools Disclosure

The authors declare that any use of AI-assisted tools in the preparation of this manuscript was limited to language refinement and/or other editorial support. All AI-assisted outputs, if used, were reviewed, revised, and verified by the authors, who remain fully responsible for the accuracy, originality, interpretation, and final content of the manuscript.

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