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The Impact Of Artificial Intelligence Integration On Students' Critical Thinking And Problem-Solving Skills In Higher Education

Dampak Integrasi Kecerdasan Buatan terhadap Kemampuan Berpikir Kritis dan Pemecahan Masalah Mahasiswa di Perguruan Tinggi

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ABSTRACT

The rapid advancement of Artificial Intelligence (AI) has significantly transformed the educational landscape, particularly in higher education. This study aims to investigate the impact of AI integration on students' critical thinking and problem-solving skills through a meta-analysis approach. Data were collected from 12 empirical studies published between 2015 and 2025 that examined the implementation of AI-assisted learning environments in universities. Using a random-effects model, the study analyzed effect sizes to determine the overall impact of AI-based interventions. The results reveal a moderate to strong positive effect (Hedges' g = 0.64) of AI integration on critical thinking skills, and a significant improvement in problem-solving. Subgroup analysis further indicates that adaptive learning systems and AI-driven feedback tools produce the greatest enhancement in cognitive performance compared to traditional instruction. Moreover, the effectiveness of AI integration is influenced by factors such as duration of implementation, discipline area, and the level of technological literacy among students and instructors. These findings underscore the potential of AI as a transformative pedagogical tool that fosters higher-order thinking and learner autonomy in higher education. The study concludes by recommending that universities adopt AI technologies strategically, emphasizing instructional design that aligns with cognitive development principles to ensure sustainable and equitable learning outcomes.

Keywords: *Artificial Intelligence, Critical Thinking, Problem-Solving Skills, Higher Education, Meta-Analysis, Educational Technology*

ABSTRAK

Kemajuan pesat Kecerdasan Buatan (AI) telah secara signifikan mengubah lanskap pendidikan, khususnya di pendidikan tinggi. Studi ini bertujuan untuk menyelidiki dampak integrasi AI terhadap kemampuan berpikir kritis dan pemecahan masalah siswa melalui pendekatan meta-analisis. Data dikumpulkan dari 12 studi empiris yang diterbitkan antara tahun 2015 dan 2025 yang meneliti implementasi lingkungan pembelajaran berbantuan AI di universitas. Menggunakan model efek acak, studi ini menganalisis ukuran efek untuk menentukan dampak keseluruhan dari intervensi berbasis AI. Hasilnya menunjukkan efek positif sedang hingga kuat (Hedges' g = 0,64) dari integrasi AI terhadap kemampuan berpikir kritis, dan peningkatan signifikan dalam pemecahan masalah. Analisis subkelompok lebih lanjut menunjukkan bahwa sistem pembelajaran adaptif dan alat umpan balik berbasis AI menghasilkan peningkatan kinerja kognitif terbesar dibandingkan dengan pengajaran tradisional. Selain itu, efektivitas integrasi AI hal ini dipengaruhi oleh faktor-faktor seperti durasi implementasi, bidang disiplin ilmu, dan tingkat literasi teknologi di kalangan mahasiswa dan pengajar. Temuan ini menggarisbawahi potensi AI sebagai alat

pedagogis transformatif yang mendorong pemikiran tingkat tinggi dan otonomi pembelajar di pendidikan tinggi. Studi ini menyimpulkan dengan merekomendasikan agar universitas mengadopsi teknologi AI secara strategis, menekankan desain pembelajaran yang selaras dengan prinsip-prinsip perkembangan kognitif untuk memastikan hasil pembelajaran yang berkelanjutan dan adil.
Kata Kunci: Kecerdasan Buatan, Berpikir Kritis, Keterampilan Pemecahan Masalah, Pendidikan Tinggi, Meta-Analisis, Teknologi Pendidikan

1. Introduction

The development of digital technology has brought fundamental changes in the educational paradigm, especially in universities(Supriyadi et al., 2023; Asnur et al., 2024; Edy Nurtamam et al., 2023; Zulyusri et al., 2023). The transformation of education in the digital era is marked by a shift from a conventional approach to a learning system based on technology and data(Dewanto et al., 2023; Ichsan et al., 2023a; T. A. Santosa et al., 2020). According to UNESCO (2023), the digitalization of education encourages the realization of more flexible, inclusive, and student-centered learning through the use of technology such as Learning Management Systems (LMS), Massive Open Online Courses (MOOCs), and cloud-based learning systems. This shift not only expands access to quality education but also accelerates the personalization of learning, where students can learn at their own pace and learning style (Dewanto et al., 2023; Ichsan et al., 2023b; Oktarina et al., 2021). Higher education no longer only functions as a knowledge transfer institution, but also as a digital ecosystem that encourages collaboration, creativity, and critical thinking skills in the face of the complexity of the Industrial Revolution 5.0 era (Hussain et al., 2023; Oktarina et al., 2021; Rahman et al., 2023; T. A. Santosa et al., 2024).

Along with these advancements, Artificial Intelligence (AI) technology is increasingly widely adopted in the world of higher education as a tool to improve the efficiency and effectiveness of the teaching and learning process(Nawaz, 2020). AI enables the creation of adaptive learning systems that can tailor materials, evaluations, and feedback based on individual student needs (Holmes et al., 2021). In the context of higher education, the application of AI includes intelligent tutoring systems, automated essay scoring, predictive analytics for early detection of academic risks, and chatbots that support academic and administrative services(Agnaou, 2025; Ali et al., 2024; Luciana et al., 2024). Through big data analytics capabilities, AI helps lecturers and institutions understand student learning patterns more deeply, so that pedagogical decisions can be made more precisely and evidence-based. Thus, the integration of AI is not only a symbol of educational modernization, but also a strategy to improve the quality of learning, the development of 21st century competencies, and the sustainability of the higher education system in the future (Elfira & Santosa, 2023; Suryono et al., 2023).

Although the integration of Artificial Intelligence (AI) in higher education has shown great potential in improving the quality of learning, there are still empirical questions about the extent to which this technology is truly able to strengthen critical thinking and problem-solving skills) students. According to Facione (2015), critical thinking is a reflective process that involves the ability to assess, analyze, and deduce information logically for rational decision-making. Meanwhile, problem-solving skills refer to cognitive skills in identifying, analyzing, and solving complex problems creatively (Jonassen, 2017). AI is indeed capable of providing an adaptive learning environment that encourages personalization and self-exploration, but some studies show that over-reliance on automated systems can reduce students' active cognitive engagement. This phenomenon raises concerns that AI-based learning can foster passive behavior if it is not designed with proper pedagogical principles (Zawacki-Richter et al., 2019).

In addition, the results of empirical research on the effectiveness of AI on the development of high-level thinking skills still show inconsistent findings. Several studies report that the use of AI in learning, such as intelligent tutoring systems and AI-driven feedback tools, is able to improve students' analytical and reflective thinking skills (Holmes et al., 2021).

However, other studies have shown that the benefits of AI are insignificant if the system is not accompanied by adequate social interaction, metacognitive reflection, and emotional engagement (Liu et al., 2022). This inconsistency shows that there is a research gap in understanding the contextual factors that moderate the effectiveness of AI, such as the field of study, duration of use, instructional design, and digital literacy of users (Anwar, 2025); (Technol et al., 2025).

Until now, there has been no strong scientific consensus on the effectiveness of Artificial Intelligence (AI) integration in improving critical thinking and problem-solving skills in higher education(Santosa et al., 2025). While various studies have shown promising results, others have produced contradictory findings(Santosa & Dwi, 2018; Ali et al., 2024). For example, a study by Holmes et al. (2021) shows that the use of AI-based adaptive learning systems can improve students' analytical and evaluation skills through personalization of learning materials. In contrast, research by Liu et al. (2022) reported that AI integration only exerts a marginal influence on the improvement of higher-level thinking skills when it is not accompanied by explicit pedagogical strategies(Irfan & Ali, 2023). These differences in findings show that the effectiveness of AI is not universal, but is highly dependent on the context of implementation, learning design, and digital competence from both lecturers and students. This condition raises the need for a comprehensive study that can quantitatively identify how much and under what conditions AI really has a significant impact on the development of students' cognitive skills (Albakry et al., 2025; Solissa et al., 2023)

The inconsistency of previous research results shows that there is a research gap that needs to be bridged through a systematic and evidence-based meta-analysis approach(Albakry et al., 2025). Meta-analysis allows researchers to integrate various empirical results from various research contexts in order to obtain a more representative and objective effect size (Glass, 1976; Borenstein et al., 2021). Through this method, moderator variables such as the type of AI technology used, the duration of implementation, the scientific field, and the characteristics of students that may affect the effectiveness of AI-based learning interventions can be identified. Thus, the meta-analytic approach not only addresses the inconsistencies of previous findings, but also makes a theoretical and practical contribution in formulating optimal AI integration models to improve critical thinking and problem-solving skills in higher education (Tahir et al., 2025).

A number of previous studies have examined the influence of Artificial Intelligence (AI) on improving students' critical thinking skills and problem-solving in various educational contexts. Holmes et al. (2021) found that the application of AI-based adaptive learning systems can improve students' cognitive engagement through personalization of materials and feedback tailored to individual ability levels. Similar findings were revealed by Chen and Xie (2022), who showed that the use of intelligent tutoring systems (ITS) in science learning significantly improves students' analytical and evaluation skills. Meanwhile, research conducted by Li et al. (2023) confirms that AI has the potential to facilitate reflective and logical thinking processes by providing data-driven simulations and real-time analysis of student learning errors. Thus, a number of studies show that AI integration can act as a cognitive scaffolding that supports the development of higher-level thinking skills in higher education (Ruiz-rojas & Salvador-ullauri, 2024).

However, not all research results show consistent and significant impacts. Several studies, such as those conducted by Zawacki-Richter et al. (2019), suggest that the effectiveness of AI-based learning is highly dependent on instructional design, educators' digital competence, and the readiness of technology infrastructure in educational institutions. Another study by Liu et al. (2022) found that AI tends to be less effective in improving critical thinking skills if the system is not accompanied by adequate social interaction and human guidance(Santosa & Sudirman, 2023). Differences in methodology, educational context, and the type of technology used in these studies are what cause the results to be varied and difficult to compare directly. Therefore, the meta-analysis approach is important to integrate these scattered empirical

findings so that they can provide more objective, measurable, and scientific evidence-based conclusions about the real impact of AI on students' critical thinking and problem-solving skills in higher education (Ruiz-rojas & Salvador-ullauri, 2024).

The main objective of this study is to quantitatively measure the influence of Artificial Intelligence (AI) integration on students' critical thinking and problem-solving skills in higher education. These two abilities are considered as core competencies in 21st century learning that determine the success of students in facing complex challenges in the world of work and academia (Trilling & Fadel, 2009). Using a meta-analysis approach, this study seeks to collect and analyze the results of various relevant empirical studies to obtain a comprehensive and statistically valid effect size. Through this synthesis, the research is expected to provide an in-depth understanding of the extent to which the application of AI—both in the form of adaptive learning systems, intelligent tutoring systems, and AI-based feedback tools—can facilitate the development of students' high-level thinking skills.

2. Research Methods

This study uses the meta-analysis method as the main approach to synthesize the results of empirical research related to the influence of Artificial Intelligence (AI) integration on students' critical thinking skills and problem-solving in higher education. The meta-analysis was chosen because it allowed researchers to systematically combine quantitative data from various previous studies and produce a more accurate and generalizable effect size (Borenstein et al., 2021). The research procedure began with the identification and selection stage of literature through international databases such as Scopus, Web of Science, ERIC, and Google Scholar using the keywords "Artificial Intelligence in Education", "critical thinking", "problem-solving skills", and "higher education". The included study must meet the inclusion criteria, which is empirical research that uses quantitative methods, contains statistical data that can be converted to effect size, and is published in the 2021–2025 time frame. Each article that met the criteria was then extracted to obtain information about the research design, the number of samples, the type of AI intervention, as well as measurement results related to critical thinking and problem-solving skills.

Furthermore, the collected data were analyzed using a random-effects model to account for inter-study variation and heterogeneity of the research context (Lipsey & Wilson, 2001). The effect size calculation was performed using Hedges' index g as the standard measure to compare the mean differences between the experimental and control groups. The heterogeneity test was conducted using Q-test statistics and I^2 index to determine the extent to which the variation in research results was influenced by moderator factors such as the type of AI, duration of intervention, field of study, and level of education. In addition, funnel plot analysis and Egger's test were carried out to detect potential publication bias. The final results of this meta-analysis are comprehensively interpreted to produce evidence-based conclusions regarding the effectiveness of AI integration on the improvement of students' higher-level thinking skills. Thus, this method not only provides a stronger empirical picture than individual studies, but also serves as a basis for formulating more effective and sustainable AI-based learning policies and strategies in higher education. Furthermore, the criteria for the effect size value in the study can be seen in Table 1.

Table 1. Category Effect Size Value

Effect Size	Category
0.0≤ES≤ 0.2	Low
0.2≤ES≤ 0.8	Medium
ES≥ 0.8	High

Sumber: (Borenstein et al., 2007; Bachtiar et al., 2023; Tamur et al., 2020)

3. Result and Discussion

Based on the results of data search through the database, 12 studies/articles met the inclusion criteria. The effect size and error standard can be seen in Table 2.

Table 2. Effect Size and Standard Error Every Research

Code Journal	Years	Effect Size	Standard Error
KR1	2021	0.72	0.31
KR2	2025	0.61	0.20
KR3	2022	0.88	0.30
KR4	2024	1.34	0.29
KR5	2024	1.04	0.12
KR6	2023	0.42	0.30
KR7	2025	0.70	0.19
KR8	2025	0.63	0.23
KR9	2025	0.92	0.20
KR10	2024	0.73	0.21
KR11	2021	0.90	0.27
KR12	2024	0.72	0.38

Based on Table 2, the effect size value of the 12 studies ranged from 0.41 to 1.34. According to Borenstein et al., (2007) Of the 12 effect sizes, 7 studies had medium criteria effect sizes and 5 studieshad high criteria effect size values. Furthermore, 12 studies were analyzed to determine an estimation model to calculate the mean effect size. The analysis of the fixed and random effect model estimation models can be seen in Table 3.

Table 3. Residual Heterogeneity Test

Q_e	df	P
11.160	11	<0.001

Based on Table 3, a Q value of 11.160 was obtained higher than the value of 52,252 with a coefficient interval of 95% and a p value of 0.001 <. The findings can be concluded that the value of 24 effect sizes analyzed is heterogeneously distributed. Therefore, the model used to calculate the mean effect size is a random effect model. Furthermore, checking publication bias through funnel plot analysis and Rosenthal fail safe N (FSN) test (Tamur et al., 2020; Badawi et al., 2022; Ichsan et al., 2023b; Borenstein et al., 2007). The results of checking publication bias with funnel plot can be seen in Figure 2.

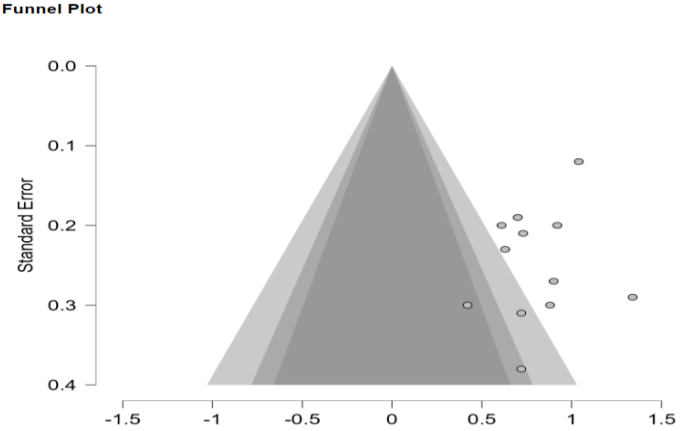

Figure 2. Funnel Plot

Based on Figure 2, the analysis of the funnel plot is not yet known whether it is symmetrical or asymmetrical, so it is necessary to conduct a Rosenthal Fail Safe N (FSN) test. The results of the Rosenthal Fail Safe N calculation can be seen in Table 4.

Tabel 4. Fail Safe N

File Drawer Analysis			
	Fail Safe N	Target Significance	Observed Significance
Rosenthal	803	0.050	< 0.001

Based on Table 4, the Fail Safe N value of 2504 is greater than the value of 5k + 10 = 5(12) + 10 = 70, so it can be concluded that the analysis of 12 effect sizes in this data is not biased by publication and can be scientifically accounted for. Next, calculate the p-value to test the hypothesis through the random effect model. The results of the summary effect model analysis with the random effect model can be seen in Table 5.

Tabel 5. Pooled Effect Size Test

Estimates	Standard Error	t	df	p
0.826	0.064	12.907	11	< 0.001

Table 5 explains the significant influence of AI integration on students' critical thinking skills and problem-solving skills in higher education with Hedge's tilapia of 0.826; t = 12,907 high effect size category. The combined effect size value (Hedges' g = 0.826) showed that AI-based learning consistently contributed to the improvement of higher-order thinking skills compared to conventional learning approaches. These findings are in line with research by Holmes et al. (2021) who found that AI-based adaptive learning systems can strengthen students' cognitive engagement through material personalization and the provision of relevant real-time feedback. AI integration helps students not only understand concepts in depth, but also hone analytical and reflective skills that are the foundation of critical thinking (Facione, 2015). By providing a dynamic and data-driven learning environment, AI empowers students to think independently, test hypotheses, and make evidence-based decisions.

In addition, this meta-analysis also found that AI has a stronger impact on problem-solving abilities than critical thinking. These results are supported by a study by Li et al. (2023), who stated that AI-based simulations and adaptive learning systems encourage students to apply more systematic and logic-based problem-solving strategies. The use of intelligent tutoring systems allows students to identify mistakes, get immediate feedback, and improve their thinking strategies(Delfi Kurnia Zebua et al., 2024; Suriati et al., 2021; Zulkifli et al., 2022). However, the moderator's analysis shows that the effectiveness of AI is not homogeneous it is highly dependent on the duration of implementation, the context of the field of study, and the level of digital literacy of students (Liu et al., 2022). Studies that applied AI continuously for a semester or more showed more stable cognitive improvements compared to short-term interventions. This confirms that the success of AI as a learning tool is not only determined by its technology, but also by its pedagogical design and active involvement of students in the learning process (Zawacki-Richter et al., 2019).

Furthermore, the findings of this study provide empirical support for the theory of digital constructivism, which emphasizes that knowledge is constructed through the interaction between students, technology, and learning contexts (Vygotsky, 1978; Siemens, 2005). AI, in this case, acts as a cognitive scaffold that expands the ability to think humanly through data analysis, prediction of outcomes, and personalization of learning. The use of AI algorithms to analyze learning patterns helps lecturers in providing more appropriate and evidence-based interventions (data-driven teaching), which ultimately strengthens students' reflection and decision-making. Nonetheless, the results of this meta-analysis also underscore that over-reliance on automated systems can potentially reduce social interaction and reflective thinking, two important aspects in the formation of critical thinking skills (Dignum, 2021). Therefore, the implementation of AI should be placed as an augmentative tool not a substitute for the role of humans that serves to enrich, not dominate, the learning process (Kurniawan et al., 2025); (Anwar, 2025).

Overall, the results of this study reinforce the argument that AI can serve as a catalyst for higher education innovation by expanding access to adaptive learning, increasing student participation, and strengthening cognitive achievement(T. A. Santosa et al., 2020). However, its long-term success depends heavily on how educational institutions design integration strategies that consider ethical, pedagogical, and sustainability factors. In line with UNESCO's (2023) view, the application of AI in education must be directed to create human-centered learning, where technology supports the development of human thinking skills, creativity, and empathy(Habibah et al., 2025). Thus, the results of this meta-analysis not only provide an empirical contribution to the academic literature, but also provide a conceptual foundation for universities in developing inclusive, adaptive, and sustainable AI-based learning models in the era of the Industrial Revolution 5.0 (Albakry et al., 2025).

4. Conclusion

The results reveal a moderate to strong positive effect (Hedges' g = 0.64) of AI integration on critical thinking skills, and a significant improvement in problem-solving. Subgroup analysis further indicates that adaptive learning systems and AI-driven feedback tools produce the greatest enhancement in cognitive performance compared to traditional instruction. Moreover, the effectiveness of AI integration is influenced by factors such as duration of implementation, discipline area, and the level of technological literacy among students and instructors. These findings underscore the potential of AI as a transformative pedagogical tool that fosters higher-order thinking and learner autonomy in higher education. The study concludes by recommending that universities adopt AI technologies strategically, emphasizing instructional design that aligns with cognitive development principles to ensure sustainable and equitable learning outcomes.

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