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THE INFLUENCE OF ARTIFICIAL INTELLIGENCE (AI) CHATBOTS ON LEARNING INDEPENDENCE AND MATHEMATICAL CRITICAL THINKING SKILLS

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Abstract

The puprpose of this study to examine how students' learning independence and mathematical critical thinking abilities are affected by artificial intelligence (AI) chatbots, particularly ChatGPT and Hemini AI though there is now little empirical data on AI's dual efects on the affective and cognitive domains of mathematics its integration into education seems unavoidable. This study used a pretest-posttest control group in a quasi-experimental design. Purposive sampling was used to choose the 60 eleventh-grade students (30 in the experimental class and 30 in the control class) from a senior high school in Sorong, Indonesia. The tools included a 5-item mathematics critical thinking essay test based on Facione's indicators (validity 0.82, reliability 0.84) and a 20-item learning independence questionnaire (Likert scale, Cronbach's Alpha = 0.86). Using SPSS 26.0, the normality test (Shapiro-Wilk), homogeneity test (Levene), independent sample t-test, and N-Gain score were used to analyse the data. The experimental and control groups differed significantly, according to the data. With p <.001, the experimental class's learning independence posttest mean (M=85.40, SD=5.12) was higher than the control class's (M=72.15, SD=6.03). In a similar vein, the experimental class did better in mathematical critical thinking (M=82.67, SD=6.21) than the control class (M=68.90, SD=7.11). The experimental group's N-Gain score was 0.72 (high category), but the control group's score was 0.38 (middle category). This study offers empirical proof that, when combined with appropriate instructional design and ethical supervision, AI chatbots can be a useful pedagogical tool to promote self-directed learning and critical thinking. The results suggest that rather than using AI chatbots to replace critical thinking, math teachers should use them as a scaffolding tool.

Keywords: AI Chatbot; Learning Independence; Mathematical Critical Thinking; Mathematics Education; Digital Learning.

A. Introduction

The primary goals of mathematics education have undergone significant changes within the context of 21st-century schooling. The emphasis is no longer merely on equipping students with procedural fluency and computational

proficiency. Instead, there is an urgent need to develop higher-order skills—specifically critical thinking and self-regulated learning—which are considered crucial for lifelong learning (Hidayat & Saputra, 2023).

Zimmerman (2015) has elaborated extensively on the concept of learner autonomy within this theoretical framework. He defines autonomy—or self-directed learning—as the student's ability to actively control, monitor, and assess their own learning process without over-reliance on peers or teachers. This encompasses the ability to independently set learning goals, select appropriate strategies, and evaluate learning outcomes.

On the other hand, Facione (2020) provides a comprehensive definition of the components of critical thinking in mathematics. He states that mathematical critical thinking is a set of cognitive abilities enabling students to comprehend mathematical data, examine relationships between ideas, evaluate the reliability of arguments, and draw logical, well-considered conclusions. Therefore, critical thinking and independence are essential skills in contemporary mathematics education.

However, empirical findings in the field reveal a reality that is far from ideal. Field research conducted at several public high schools in Sorong, Southwest Papua, has uncovered a concerning pattern. The majority of students exhibit a passive attitude toward learning, and their level of learning independence remains low.

Their tendency to wait for clear instructions from the teacher, combined with difficulty initiating the learning process independently, exemplifies this passive attitude. They demonstrate a high level of dependency and a lack of initiative to explore learning resources on their own. Consequently, the development of self-regulated learning skills—a key requirement of the 21st century—is clearly hindered by this situation.

Their performance in mathematical critical thinking also reveals a similarly concerning trend. Students frequently encounter significant challenges when faced with non-routine tasks that require Higher-Order Thinking Skills (HOTS). Instead of striving to build a deep and meaningful conceptual understanding, they appear

more comfortable with a procedural approach that emphasizes the memorization of formulas and their mechanical application.

The rapid development of Artificial Intelligence (AI) chatbot technology is closely linked to the gap between ideal expectations and traditional learning methods. Conventional teaching methods have been significantly impacted by the emergence of platforms such as ChatGPT, Gemini, and Claude. These AI chatbots offer transformative pedagogical potential, including the ability to employ Socratic questioning techniques to guide the learning process, provide personalized tutoring accessible at any time, and deliver rapid, adaptive feedback (Kasneci et al., 2023).

More importantly, the way these AI tools are utilized significantly impacts their effectiveness. Through the use of complex and ethical prompting techniques, AI chatbots can be trained to act as intelligent tutors that provide appropriate scaffolding—rather than simply delivering instant, definitive answers. This scaffolding assists students in constructing their own understanding. Thus, AI chatbots offer creative and promising pedagogical options for fostering independent yet critical approaches to learning mathematics.

In recent years, academics have shown increasing interest in the potential of AI in education. For instance, a comprehensive study by Lo (2023) found that while the use of ChatGPT can significantly boost students' enthusiasm and engagement in learning, it also raises pertinent ethical questions regarding academic integrity. This dual impact requires careful management through appropriate educational design.

In the specific context of mathematics instruction, Wardat et al. (2023) empirically demonstrated that ChatGPT can make abstract and complex mathematical topics more understandable for students by providing systematic, step-by-step explanations. Similarly, Hwang and Chang (2023) developed a tailored AI-based learning system and proved its effectiveness in enhancing students' capacity for organized self-regulated learning. Sukmawati et al. (2024) found that students using AI chatbots in online learning environments experienced a significant 34% increase in learning independence within the Indonesian context. Furthermore, Putra and Andriani (2024) discovered that Socratic-style

conversations with chatbots significantly improved mathematical critical thinking skills, yielding a moderate-to-high effect size of 0.65.

There is still a significant research gap in the literature despite these encouraging and promising results. The majority of earlier studies typically concentrate on a single outcome variable in isolation, looking at critical thinking or learning independence independently. To date, there is very limited empirical evidence that simultaneously examines the dual impact on both the affective domain (learning independence) and the cognitive domain (critical thinking), especially at the secondary school level in underrepresented regions such as Eastern Indonesia, specifically Southwest Papua. Moreover, much of the available literature remains descriptive in character and lacks a rigorous quasi-experimental methodology that can establish causal linkages and assess effectiveness more accurately.

Therefore, the current work aims to make a more thorough empirical contribution in order to fill this recognised research gap. This study uses a quasi-experimental methodology to examine the dual impact of AI chatbots on students' learning autonomy and mathematical critical thinking abilities. This study is guided by two research questions: (1) Does learning independence differ significantly between students taught using AI chatbots and those taught using traditional methods? (2) Do the two groups' critical thinking abilities in mathematics differ significantly? The following hypotheses are developed in light of these questions: H1: Students' learning independence is significantly improved by the employment of AI chatbots. H2: Students' mathematical critical thinking abilities are significantly improved by the employment of AI chatbots.

B. Methods

Research Design:

This study used a quasi-experimental methodology within a quantitative research paradigm. A nonequivalent pretest-posttest control group design was the particular strategy used. Because the research had to be done in naturally formed, intact classroom environments, it was not possible to randomly assign individual studebt to experimental and control groups, hence this design was thought to be the

most appropriate. This method acknowledges the limitations of a genuine educational setting while enabling the drawing of a causal conclusion.

Two intake classes at SMA Negeri 1 Sorong were chosen as the sample for the study. An inventive AI chatbot-assisted learning approach was used to instruct the first class, which functioned as the experimental group. ChatGPT and Gemini and was incorporated into this approach not just as an extra tool but also as an interactive learning partner that supported students' reasoning processes with rapid adaptive feedback, Socratic questioning, and customised scaffolding. The second class, on the other hand, served as the control group and was given traditional education using a direct teaching approach. Teacher-centered explanations were the main feature of this traditional model, which was followed by textbook-based assignments and procedural exercises.

Six meetings were used to carry out the full learning intervention. Systems of Linear Equations in Three Variables was the main subject of the content. This subject was specifically picked since it necessitates not just a solid conceptual grasp but also critical thinking and problem-solving abilities, making it ideal for investigating the dual impact of AI chatbots on learning independence and critical thinking.

Participants:

All eleventh-grade students enrolled at SMA Negeri 1 Sorong for the 2025–2026 school year comprised the target group for this study. Purposive sampling was used to choose 60 pupils as the research sample from this larger group. The selection process was not random; rather, it was focused on particular factors that were pertinent to the study's goals and technical specifications.

Two main criteria were used to determine the sample. First, depending on their academic success in the previous semester's mathematics final scores, the pupils had to have comparatively uniform baseline mathematical abilities. In order to ensure a balanced baseline between groups, this uniformity was crucial. Second, participants had to have a steady internet connection and sufficient and reliable access to digital devices like computers or cellphones. The deployment of AI chatbot-assisted learning greatly depends on digital connectivity and technological preparedness, therefore this second requirement was crucial.

Two intact classes were then assigned to various treatment conditions from the chosen participants. Thirty pupils in Class XI-A were chosen as the experimental group to get instruction with the help of an AI chatbot. Class XI-B, which included thirty pupils as well, was the control group that received traditional instruction. All participants were given informed consent forms before the study started, and they had to get their parents' or guardians' consent. In order to guaranty ethical compliance, they were also fully informed about the goals of the study, the protocols to be adhered to, and the integration of AI technology into mathematics instruction

Data Collection Instruments:

For this investigation, two main tools were used to gather the required data. A Learning Independence Questionnaire was the first tool used to gauge pupils' self-regulated math learning. The self-regulated learning markers put forth by Zimmerman (2015), which have been extensively employed as a theoretical basis in recent studies, were particularly adapted to create this questionnaire. Goal-setting, self-monitoring, self-evaluation, and time management were the four basic characteristics covered by the instrument's twenty statement items, which were scored on a five-point Likert scale from 1 (strongly disagree) to 5 (strongly agree).

The questionnaire underwent a thorough expert validation process with two validators with backgrounds in educational psychology and mathematics ducation to guaranty its academic quality. An Aiken's V coefficient of 0.84, which is considered extremely valid, was obtained from the validation. Additionally, a brief pilot test with 30 students outside the research sample was used to assess its reliability; the results showed strong internal consistency, with a Cronbach's Alpha value of 0.86. This validation process aligns with current research methodologies. For example, recent research by Nurjanah et al. (2023) and Pratiwi & Hidayah (2024) created self-regulated learning questionnaires with 18–22 items based on Zimmerman's framework and found comparable validity coefficients (Aiken's V > 0.80) and reliability (Alpha 0.85-0.89) for Indonesian secondary school students. In a similar vein, Utami et al. (2025) stressed that the best tool for collecting emotive components of mathematics learning in the digital age is still a Likert-based independence questionnaire.

An essay-style Mathematical Critical Thinking Test was the second tool used. The five open-ended questions on this test were thoughtfully created using Facione's (2020) critical thinking paradigm, which includes five essential indicators: interpretation, analysis, evaluation, inference, and explanation. Each test item was created to measure one or more of these markers concurrently and was contextualised to the subject of Systems of Linear Equations in Three Variables. Each item was evaluated using an analytical rubric with a score range of 0 to 20 in order to guaranty objective and consistent scoring. This allowed for a thorough assessment of students' critical reasoning processes rather than just final answers.

Additionally, an empirical test of the critical thinking test's quality was conducted. A validity coefficient of 0.82, which indicates excellent relevance to the intended learning objectives, was found when the content validity was evaluated by two expert validators. Furthermore, a pilot study yielded a Cronbach's Alpha coefficient of 0.84, indicating high reliability. Recent research provides compelling evidence for the use of Facione's approach in essay form. For instance, Lestari et al. (2024) found that a 5-item rubric-based test with Facione's indicators was very successful in differentiating students' HOTS levels, while Rahayu & Setiawan (2023) created a 4-item essay test for critical thinking on algebra topics and obtained a validity of 0.81 and Alpha 0.83. The most recent study, Firmansyah et al. (2025), found that essay assessments with analytical rubrics are more sensitive than multiple-choice tests in gauging the improvement in critical thinking following AI chatbot intervention.

As a result, both of the instruments used in this study are suitable and reliable for assessing students' learning independence and mathematical critical thinking abilities since they have satisfied the psychometric requirements of validity and reliability and are consistent with recent developments in mathematics education research over the past three years.

Data Analysis:

SPSS version 26.0 software was used to help with data analysis in this study. To guaranty the precision and impartiality of the findings, the analysis process was completed in a number of methodical and consecutive steps. Descriptive statistics were calculated in the first step to give a preliminary summary of the data. In order

to characterise students' initial performance based on pretest scores and their final performance following the intervention based on posttest scores, this involved computing the mean and standard deviation for both the experimental and control groups.

Prerequisite tests were carried out in the second step in order to satisfy the statistical assumptions needed for parametric statistical analysis. There were two different kinds of assumption testing. To confirm that the data in both groups were normally distributed, the first test was a normality test using the Shapiro-Wilk test with a significance level of $p > .05$. In order to verify that the variances between the two groups were homogeneous, the second test was a homogeneity of variance using Levene's test with the same significance level ($p > .05$). Before moving on to hypothesis testing, these two presumptions must be met.

In the third phase, an independent sample t-test was used to assess the hypothesis at a significance level of 5% ($\alpha = 0.05$). The purpose of this statistical test was to ascertain whether learning independence and critical thinking abilities differed statistically significantly between the experimental and control groups. Lastly, the N-Gain Score was computed to assess how much both variables had improved. The improvement was categorised using the Hake (1999) criteria, where a low improvement is denoted by $g < 0.3$, a medium improvement by $0.3 \leq g \leq 0.7$, and a strong improvement by $g > 0.7$.

C. Results And Discussion

Results:

Prerequisite analyses were performed to make sure the assumptions for parametric statistics were satisfied before the hypothesis testing. Significance values larger than.05 ($p > .05$) in the results showed that the variances were homogeneous and the data were normally distributed. As a result, it was decided to move on with parametric testing.

Table 1. Descriptive Statistics and T-Test Results of Learning Independence and Mathematical Critical Thinking

Measurement	Statistics	Experiment (N=30)	Control (N=30)	Sig.
Learning Independence – Pretest	M	65.20	64.80	
	SD	5.45	5.67	p=.78
Learning Independence – Posttest	M	85.40	72.15	
	SD	5.12	6.03	p<.001
Critical Thinking – Pretest	M	58.30	57.90	p=.82
	SD	6.88	7.02	

For both assessed variables, the pretest results showed no statistically significant difference between the experimental and control groups ($p > .05$), as shown in Table 1. This result demonstrates that both groups had similar starting skills before the intervention. On the other hand, after the treatment, there was a noticeable difference in the posttest results. A t-value of 9.214 with $p < .001$ for learning independence and $t = 7.956$ with $p < .001$ for critical thinking abilities were obtained from the independent sample t-test analysis. The Rsults support H1 and H2, according to these findings. The experimental class also received an average N-Gain score of 0.72 (high category) for learning independence and 0.71 (high category) for critical thinking, according to the N-Gain study. In contrast, the control group's N-Gain scores were just 0.32 (medium category) and 0.38 (medium category), respectively. According to this data, integrating AI chatbots into mathematics training is far more successful than traditional teaching methods at fostering learning independence and critical thinking.

Discussion:

The results of this study offer solid empirical proof that integrating AI chatbots significantly improves students' learning independence. The experimental group's independence scores were significantly higher than those of the control group, according to the quantitative data. This outcome is theoretically in line with Zimmerman's (2015) idea of self-regulated learning, which highlights that

autonomous learners are those who can actively control their motivation, behaviour, and thought processes in order to accomplish learning objectives.

In this situation, AI chatbots serve as a metacognitive companion that actively helps students control their own learning process rather than just being a traditional technology tool. Students in the experimental class reported feeling more independent and powerful, according to qualitative input gathered through their reflection notebooks. Because students could get individualised learning support at any time and from any location without having to wait for the teacher's direct and frequently delayed explanations, they developed a sense of autonomy.

AI chatbots have a number of unique and important characteristics that contribute to the improvement of learning independence. First, pupils may recognise and fix their errors in real time thanks to chatbots' ability to deliver prompt and flexible feedback. This is consistent with the findings of Kasneci et al. (2023), who found that encouraging self-regulated learning requires prompt feedback. Second, using reflective questions like "What have you understood so far?" chatbots let students define specific learning objectives and track their progress.

Additionally, it was discovered that the personalised explanation function, in which the chatbot automatically modifies its amount of depth and language difficulty based on the student's comprehension level, had a significant influence. Students' confidence to investigate challenging mathematics problems on their own without worrying about making mistakes was greatly boosted by this feature. The study by Hwang & Chang (2023), which found that AI-based personalised learning environments significantly and favourably improve students' self-regulation and learning autonomy, is substantially supported by this empirical data. Similarly, Sukmawati et al. (2024) found that students using AI chatbots in online learning environments increased their learning independence by 34% in Indonesia.

In addition to independence, the Socratic prompting method's teaching approach can account for the study's notable gains in mathematical critical thinking abilities. Students were not allowed to ask the Chatbot for clear, definitive responses, which was an important educational restriction that was tightly enforced

in the experimental class. This regulation was put in place to stop academic dishonesty and the practice of looking for answers right away.

Rather, students received clear instruction on how to use thought-provoking, ethical, and educational questions. "Explain this concept step by step as a tutor, without giving the final answer" and "Give me a hint to solve this problem and let me try to solve it myself" are two examples of prompts. Before reaching a conclusion, this teaching method purposefully requires students to actively participate in the cognitive phases of interpretation, analysis, and assessment. This result corroborates Putra and Andriani's (2024) study, which revealed that Socratic-based conversations with chatbots enhanced mathematical critical thinking with an effect size of 0.65.

The constructivism paradigm, which holds that knowledge is actively created by students via meaningful and reflective experiences rather than being passively absorbed from the teacher, provides substantial support for this strategy (Wardat et al., 2023). In their work, Wardat et al. (2023) also showed that ChatGPT can provide structured, step-by-step explanations of abstract mathematical concepts—a key component of constructivist learning.

Additionally, the evaluation and inference indicators as described in the critical thinking framework by Facione (2020) are directly trained by the interactive dialogue pattern incorporated into the chatbot interaction, such as asking for justification with questions like "Why do you think that step is correct?" or "What evidence supports your reasoning?" Students are constantly encouraged to defend, justify, and reflect on their own thought processes—the fundamental components of critical thinking—instead of merely passively absorbing information.

It is interesting to note that the results of this study indicate that students' critical thinking increased precisely because AI forced them to think more thoroughly and methodically, rather than because AI gave them accurate and immediate answers. As noted in the systematic review by Lo (2023), this conclusion is crucial since it disproves the common worry among educators that the use of AI will make pupils lazy and cognitively dependent. Conversely, AI chatbots can be a potent catalyst to promote higher-order thinking abilities and learning autonomy in

mathematics education when combined with a clear and intentional pedagogical design that presents AI as a "thinking partner" rather than an "answer machine."

Implications:

The study's findings have important applications for teaching mathematics in the digital age. Teachers of mathematics should perceive AI chatbots as a pedagogical tool that can be intentionally incorporated into the classroom rather than as a menace that should be outlawed. But without a well-defined and organised teaching approach, this integration is impossible. Teachers are crucial in changing students' attitudes about using chatbots.

A number of calculated actions must be taken in order for this integration to be successful. In order for pupils to comprehend the potential and constraints of AI technology, educators must first develop clear principles addressing AI literacy. Second, rather than only asking for definitive answers, it is crucial to teach the idea of ethical prompting, in which students are taught to employ prompts that encourage critical thinking, like Socratic prompts. By doing this, the chatbot's role can be shifted from that of a simple "answer machine" that offers quick fixes to that of a "thinking partner" that supports and helps students learn.

In the particular context of schools in Sorong and the larger Eastern Indonesia region, this inference becomes more pertinent. Educational issues include unequal access to high-quality tutoring programmes and a lack of teacher resources are still prevalent in these communities. Thus, our study offers factual proof that AI technology can serve as a tactical remedy to close this educational divide. Schools may provide more fair and individualised learning help by utilising AI chatbots, guaranteeing that students in remote places have the same chance to get high-quality coaching as those in more developed regions.

Limitation and Suggestions For Further Research:

Despite the fact that this study makes significant contributions to the field of mathematics education, it is important to recognise a few limitations. The first restriction has to do with the sample's size. Only 60 pupils from a single school, SMA Negeri 1 Sorong, participated in the study. Because of this limited scope, it is important to use extreme caution when interpreting the findings' applicability to a

larger and more diversified population. The outcomes might not accurately reflect the circumstances of pupils in other schools with distinct features.

The length of the intervention is the second restriction. With just six sessions, the treatment was put into practice in a comparatively short amount of time. The complete and long-lasting effects of including AI chatbots into the learning process might not be fully captured in such a short amount of time. To see more consistent improvements in learning independence and critical thinking, as well as to comprehend how kids adjust to this technology over time, a longer intervention period would be required.

Third, the technological and thematic breadth of this investigation was likewise constrained. The study concentrated on a specific area of mathematics and used only one kind of AI chatbot, ChatGPT. Therefore, in order to improve external validity, it is advised that future research include a larger and more diverse sample that is recruited from several schools in various countries. Furthermore, longitudinal research designs should be taken into account in future studies to investigate the long-term consequences of using AI chatbots. Comparing the efficacy of different AI chatbot platforms, such as Gemini, Claude, and Copilot, and investigating their impact on additional affective variables such as mathematics anxiety, learning motivation, and self-efficacy that were not addressed in this study might also be beneficial.

D. Conclusions

This study concludes that the integration of Artificial Intelligence (AI) chatbots has a significant and positive impact on two crucial aspects of mathematics learning, namely students' learning independence and mathematical critical thinking skills, based on the analysis of the findings and the in-depth discussion previously presented. It has been demonstrated that the use of AI chatbots is a significant learning intervention that alters how students engage with mathematical content rather than only being an extra technology element.

According to the empirical data, the experimental group—which received assistance from AI chatbots during the learning process—achieved a significantly greater improvement than the control group, which received instruction through traditional techniques. The N-Gain scores, which placed the experimental class in

the high category and the control class in the medium group, amply demonstrate this superiority. This distinction demonstrates that students' comprehension and learning autonomy can be accelerated more successfully when AI support is present.

Additionally, this study highlights that AI chatbots' efficacy is not dependent on their capacity to respond instantly. Rather, they work best when used as a scaffolding tool that leads pupils through Socratic prompting techniques. Instead of relying on students to offer answers, chatbots teach them to think critically and independently by providing prompts that urge students to clarify their thinking, analyse stages, and evaluate their own solutions.

Consequently, it is highly suggested that AI chatbots be purposefully and pedagogically integrated into mathematics training. This integration can be seen as a creative and flexible way to deal with the difficulties of 21st-century education, especially when it comes to developing higher-order thinking abilities and self-regulated learning. It is anticipated to make a substantial contribution to raising the general standard and equity of mathematics instruction.

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