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Transforming Teaching and Learning with Artificial Intelligence (AI): Personalized Education, Adaptive Learning, and Intelligent Tutoring Systems

Transformasi Pengajaran dan Pembelajaran dengan Kecerdasan Buatan (AI): Pendidikan yang Dipersonalisasi, Pembelajaran Adaptif, dan Sistem Bimbingan Belajar yang Cerdas

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ABSTRACT
This research aims to explore the influence of an adaptive learning system based on Artificial Intelligence (AI) on the development of critical thinking skills (CTS) in various educational contexts. Using a systematic literature review (SLR) approach, this research identifies and analyzes relevant studies published in the last ten years. The analysis results show that the integration of adaptive learning systems supported by AI can improve students' critical thinking skills, with impacts varying depending on factors such as system design, teacher involvement, and educational context. These findings provide valuable insights for educational practitioners and educational technology developers, and recommend future research directions to explore the long-term effects and different cultural contexts on the use of AI technologies for learning.
Keywords: Artificial Intelligence, Adaptive Learning, Critical Thinking Skills, Learning Systems, Systematic Literature Review.

ABSTRAK
Penelitian ini bertujuan untuk mengeksplorasi pengaruh sistem pembelajaran adaptif berbasis Kecerdasan Buatan (AI) terhadap pengembangan keterampilan berpikir kritis (Critical Thinking Skills/CTS) di berbagai konteks pendidikan. Dengan menggunakan pendekatan tinjauan literatur sistematis (Systematic Literature Review/SLR), penelitian ini mengidentifikasi dan menganalisis studi-studi yang relevan yang diterbitkan dalam sepuluh tahun terakhir. Hasil analisis menunjukkan bahwa integrasi sistem pembelajaran adaptif yang didukung oleh AI dapat meningkatkan keterampilan berpikir kritis siswa, dengan dampak yang bervariasi tergantung pada faktor-faktor seperti desain sistem, keterlibatan guru, dan konteks pendidikan. Temuan ini memberikan wawasan berharga bagi praktisi pendidikan dan pengembang teknologi pendidikan, serta merekomendasikan arah penelitian di masa depan untuk mengeksplorasi efek jangka panjang dan konteks budaya yang berbeda dalam penggunaan teknologi AI untuk pembelajaran.
Kata Kunci: Kecerdasan Buatan, Pembelajaran Adaptif, Keterampilan Berpikir Kritis, Sistem Pembelajaran, Tinjauan Literatur Sistematis.

1. Introduction

The integration of Artificial Intelligence (AI) in education, particularly through Adaptive Learning Systems (ALS), has significantly changed the learning landscape by introducing personalized learning experiences. This system utilizes machine learning algorithms to analyze student learning behavior, identifying individual strengths and weaknesses. In this way, ALS allows customization of educational content to suit the unique needs of each learner, ultimately increasing the efficiency and effectiveness of the educational process (Akavova,

2023; Abbas et al., 2023; Pratama, 2023). The shift from traditional, uniform teaching methods towards personalized learning pathways is essential, as this accommodates the diversity of students' needs, creating a more inclusive and adaptive educational environment (Aghaziarati, 2023; Fahimirad & Kotamjani, 2018).

Apart from improving academic performance, AI-based ALS also plays an important role in developing higher order thinking skills (HOTS), especially critical thinking skills (CTS). These skills are increasingly important in today's complex world, where the ability to critically evaluate information and apply logical reasoning has become indispensable (Rasheed, 2023; Mytra et al., 2021). Research shows that personalized feedback from AI systems encourages deeper engagement with learning material, which is important for CTS development (Luan et al., 2020; Pendy, 2023). By adapting teaching materials to challenge students according to their cognitive abilities, AI technology not only enhances the learning experience, but also promotes the mastery of critical thinking skills (Ramesh, 2021; Tapalova & Zhiyenbayeva, 2022).

Although the potential of AI-based ALS is promising, there remains a significant gap in understanding its specific impact on the development of critical thinking skills. Most existing research focuses more on measurable academic outcomes, such as test scores and engagement metrics, rather than on higher-order thinking processes (Fahimirad & Kotamjani, 2018; Rasheed, 2023). This gap is important because critical thinking skills are a highly valuable educational outcome, supporting academic success and providing broader social benefits. The ability of AI systems to provide personalized feedback in real-time creates opportunities for more targeted instruction, which can effectively develop critical thinking skills in students (Abbas et al., 2023; Pendy, 2023). As educators continue to explore effective pedagogical strategies, the integration of AI technology in the classroom presents a promising pathway to improving students' critical thinking abilities and overall educational outcomes (Aghaziarati, 2023; Luan et al., 2020).

In conclusion, the application of AI in education, particularly through adaptive learning systems, represents a transformational shift towards personalized learning experiences. This system not only has the potential to improve academic performance, but also supports the development of critical thinking skills, which are critical for success in the 21st century. However, further research is needed to fully understand the implications of AI-based ALS on higher-order thinking processes, to ensure that educational practices can effectively harness the full potential of this technology.

Given the rapid advancement of AI in education and the importance of CTS, it is critical to investigate how AI-based ALS can contribute to the development of these skills in various educational settings. This study aims to fill this gap by conducting a systematic literature review of the impact of AI-based ALS on CTS development, highlighting key findings, gaps in research, and potential future research directions. This research not only addresses a pressing need in the field of educational technology but also offers practical insights for educators and policymakers who want to harness the potential of AI to improve student learning outcomes beyond just academic performance.

In short, this research explores pressing questions: **"How does the integration of AI-based adaptive learning systems influence the development of critical thinking skills in various educational contexts?"** Through this systematic literature review, this research aims to provide a comprehensive understanding of existing knowledge, emerging trends, and areas requiring further research to fully realize the potential of AI in supporting the development of critical thinking skills in students.

2. Methodology

2.1 Systematic Literature Review Approach

This research uses the method Systematic Literature Review (SLR) who follow the guide PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). PRISMA is an

internationally recognized framework for ensuring a systematic and transparent process in identifying, selecting and analyzing literature related to a research topic. This approach is ideal for collecting and synthesizing evidence from a variety of relevant studies, thereby providing a comprehensive picture of the topic being researched.

In this research, the steps carried out in accordance with PRISMA guidelines include:

1. Identify Relevant Studies: The literature search will be conducted through various major academic databases, such as Scopus, Web of Science, Google Scholar, dan IEEE Xplore, using specific keyword combinations, such as *"AI-driven adaptive learning systems"*, *"critical thinking skills"*, *"education"*, And *"AI in education"*. This search aims to identify relevant studies that have been published in leading journals.
2. Study Selection: The selection process will include two main stages. First, initial screening based on title and abstract to weed out inappropriate articles. Second, full text review of articles that passed the initial selection to ensure their relevance to the research question. Inclusion and exclusion criteria will be strictly defined to ensure that only the most relevant and high-quality studies are included in this review.
3. Data Extraction and Analysis: Data from selected studies will be systematically extracted using established protocols. The information taken includes the context of the study, methods used, key findings, and relationships with AI-driven adaptive learning systems (ALS) And critical thinking skills (CTS). Data analysis will focus on how AI-based ALS contributes to the development of CTS in various educational contexts.
4. Reporting and Synthesis: Results from the selected literature will be synthesized narratively to provide in-depth insight into the relationship between the use of AI in adaptive learning and the development of critical thinking skills. This synthesis will be organized to answer research question comprehensively, while identifying research gaps that still exist.

2.2 Reasons for choosing SLR as a method

Election Systematic Literature Review (SLR) as a research method is based on several main reasons:

1. Collecting Existing Evidence Systematically: SLR allows researchers to map and collect evidence from multiple studies spread across multiple sources. This is important because AI-based adaptive learning system And critical thinking skills is a multidimensional topic and has been researched in various educational contexts. Through SLR, this research can explore the various approaches that have been used and analyze the results thoroughly.
2. Answering Complex Research Questions: The SLR method is very suitable for answering research questions broad and complex as proposed in this study: *How will the integration of AI-based ALS impact the development of critical thinking skills in various educational settings?* Through systematic literature analysis, researchers can provide comprehensive evidence-based answers.
3. Identifying Research Gaps: By mapping existing studies, SLR also provides clear insight into gaps in the literature. In the context of this research, SLR can identify areas where the use of AI in adaptive learning is not yet fully understood or applied in CTS development, thereby providing recommendations for further research.
4. Ensure Transparency and Reproducibility: The use of the SLR method that follows PRISMA guidelines ensures transparency in every stage of the research, from the study identification process to data analysis. This is important for the validity and reproducibility of research results, especially for publications in leading international journals.

5. Thus, the use of SLR in this research not only aims to provide a comprehensive understanding of the topic under study, but also to ensure that the resulting findings have a solid basis in existing literature and meet strict methodological standards.

2.3 Inclusion Criteria

To ensure that this research only includes relevant and high-quality literature, several inclusion criteria has been set. These criteria are designed to focus the review on studies that are directly related to AI-driven adaptive learning systems (AI-driven Adaptive Learning Systems) And development of critical thinking skills (Critical Thinking Skills/CTS), and which have gone through an empirical validation process. The inclusion criteria used are as follows:

1. Studies Discussing AI-Based Adaptive Learning Systems: Selected articles should specifically address development and implementation AI-based adaptive learning system in an educational context. The primary focus should be on using AI technology to personalize learning to improve student learning outcomes.
2. Focus on Developing Critical Thinking Skills (CTS): Included studies had to directly examine the impact of using AI-based ALS on the development of critical thinking skills among students, in both formal and informal learning.
3. Published in the Last 10 Years: To ensure relevance and topicality of research, only studies published in last 10 years (between 2014 and 2024) that will be considered. This aims to focus the study on the latest developments in the field of educational technology and AI.
4. Using Quantitative or Qualitative Methods: Included studies must use valid quantitative or qualitative methods to measure the impact of AI-based adaptive learning systems on CTS. This includes studies that use experiments, surveys, interviews, or other methods that have a strong empirical basis.

2.4 Exclusion Criteria

As part of a systematic approach, exclusion criteria also set out to exclude studies that were irrelevant or did not meet strict methodological standards. Articles that do not meet one or more of the following exclusion criteria will be excluded from review:

1. Studies Irrelevant to CTS: Articles that do not specifically discuss critical thinking skills or those that focus only on technological aspects without paying attention to the development of cognitive skills will be excluded from the analysis. Relevance to CTS was an important prerequisite for inclusion in this study.
2. Opinion Based Articles or Not Empirically Tested: Studies based on opinions or theoretical essays that are not supported by empirical evidence will not be considered. This is to maintain the validity of the findings, because the main focus of this study is on verifiable empirical results.
3. Articles with General Coverage on AI or Education Technology: Research that only discusses AI in general or that has too broad a coverage of educational technology without emphasizing adaptive learning systems and CTS will be excluded. The goal is to focus the analysis on the specific link between AI-based ALS and critical thinking skills.

By establishing clear and strict inclusion and exclusion criteria, this research aims to ensure that the literature reviewed is relevant and of high quality, so that research results can provide valid and meaningful insights into the impact of AI-based ALS towards development critical thinking skills.

2.5 Database Used

To get relevant and high-quality studies in the answers research question, a literature search will be conducted through several major academic databases which is internationally recognized. This database was chosen because of its credibility in providing access to indexed

scientific articles from highly reputable journals. The databases that will be used in this search include:

1. Scopus: As one of the largest databases that includes internationally indexed scientific journals from various scientific disciplines, including educational technology and artificial intelligence (AI), Scopus will be the main source in searching for related literature AI-driven adaptive learning systems And critical thinking skills.
2. Web of Science: Web of Science will also be used because it provides access to indexed scientific articles and has a focus on research published in high-impact journals, especially in the fields of technology, education, and cognitive science.
3. IEEE Xplore: This database is very relevant because it provides scientific publications related to technology and artificial intelligence. IEEE Xplore will provide access to the latest research regarding the implementation of AI in adaptive learning systems and its impact on cognitive skills.
4. Google Scholar: Google Scholar will be used as an additional resource to access scientific articles, dissertations and conference papers that may not be found in other databases. This allows for broader and more inclusive searches.

2.6 Search Keywords

To ensure proper coverage in the literature search, the keywords used in the search will include terms that are specific and relevant to this research topic. The following keyword combinations will be used:

1. "AI-driven adaptive learning": This keyword is used to find studies that discuss implementation adaptive learning systems based artificial intelligence (AI) in an educational context.
2. "Critical thinking skills": The main focus of this research is to examine how AI in adaptive learning influences development critical thinking skills (CTS). Therefore, these keywords were used to screen studies relevant to the development of cognitive skills in various educational contexts.
3. "Artificial intelligence in education": To identify more general articles related to implementation AI in education, these keywords will be used to expand the search to studies that may be indirectly discussed IF And CTS.
4. "Adaptive learning systems": These keywords will be used to filter articles that are more specifically related to adaptive learning systems, both those that use AI technology and those that do not. This will help in understanding how ALS functions in general and its relationship to critical thinking skills.

Combinations of these keywords will be used either individually or together using boolean operators (AND, OR, NOT) to get the most relevant search results. For example, a search will be carried out with a combination like *"AI-driven adaptive learning" AND "critical thinking skills"* or *"Artificial intelligence in education" OR "adaptive learning systems"*. Additionally, filters will be applied to limit results to articles published in last 10 years (2014–2024) and that written in English to ensure that the studies found have sufficient relevance and topicality.

2.7 Article Selection Process

The article selection process in this research will be carried out through several systematic stages to ensure that only the most relevant and high quality studies will be included in the analysis. Selection steps will follow the approach recommended by PRISMA guidelines, with a focus on initial screening, abstract review, and full-text evaluation.

1. Initial Screening: At this stage, search results from various databases (such as Scopus, Web of Science, IEEE Xplore, and Google Scholar) will be filtered based on title and

keywords. Articles that do not match the research topic or that do not meet the inclusion criteria will be immediately excluded. This process aims to eliminate irrelevant literature quickly.

2. Abstract Review: After initial screening, remaining articles will go through the abstract review stage. In this stage, the abstract of each article will be read in depth to assess whether the study is appropriate research purposes, especially in discussing the relationship between AI-driven adaptive learning systems (ALS) And development of critical thinking skills (CTS). Articles whose abstracts demonstrate high relevance to the research question will be selected for further analysis.
3. Full-Text Review: Articles that pass the abstract review will be downloaded and thoroughly evaluated through full-text reading. At this stage, studies will be evaluated based on their suitability to more in-depth inclusion criteria, such as the methodology used, focus on development CTS, and the existence of valid empirical analysis. Articles that do not provide empirical evidence or have no relevance to the development of critical thinking skills will be excluded.

2.8 Methods for Extracting Information

Once articles appropriate to the research topic are identified, process them data extraction will be done. The extracted data will be organized systematically and focus on key elements from each study that can provide insight into the relationships between AI-driven adaptive learning systems and development critical thinking skills. The data to be extracted includes:

1. Research purposes: Each study will be evaluated to understand the main objective of the research. This information will help categorize articles based on their focus, such as whether they examine the impact of ALS on student cognition, learning adaptations, or specifically on the development of critical thinking skills.
2. Research methods: The methodology used by each study will be noted. This includes whether the research used quantitative, qualitative, or mixed methods, as well as the approach used to measure development critical thinking skills in the context of using AI-based ALS.
3. Key Results: Results of each study related to influence AI-based ALS to CTS will be extracted. These results will include quantitative and qualitative findings that demonstrate an increase in critical thinking skills, either through experimentation or observation in the learning environment.
4. Conclusions Relevant to CTS: Conclusions drawn by study authors regarding impact AI-driven ALS towards the development of critical thinking skills will be analyzed. This data is important for identifying patterns or relationships between the use of AI in learning and critical thinking skills, as well as for uncovering factors that influence the effectiveness of adaptive learning systems.

This process will be carried out systematically to guarantee that the information extracted from each article can be coded and analyzed comprehensively. This data extraction will form the basis for further analysis of how AI-based ALS can contribute to development critical thinking skills in various educational contexts, as well as helping to answer the research questions posed.

2.9 Study Quality Assessment

Quality assessment of the studies to be included in this systematic analysis is an important step to ensure that only methodologically credible studies are considered in this study. This quality assessment will be carried out using recognized guidelines, such as Critical Appraisal Skills Programme (CASP) And Mixed Methods Appraisal Tool (MMAT).

1. Critical Appraisal Skills Programme (CASP):
    a. CASP is a tool used to assess the quality of quantitative and qualitative research. In this context, the assessment will focus on the following aspects:
        i. Clarity of Research Objectives: Are the research objectives clearly defined?
        ii. Research Design: Is the research design used appropriate to achieve the research objectives?
        iii. Methodology: Whether the methodology used in the study is adequate and appropriate for measuring impact AI-driven adaptive learning systems to critical thinking skills?
        iv. Data analysis: Was data analysis carried out appropriately and transparently?
        v. Conclusion: Are the conclusions drawn consistent with the reported results?
2. Each study will be assessed based on these criteria, and only studies that meet established quality standards will be included in further analysis.
3. Mixed Methods Appraisal Tool (MMAT):
    a. MMAT used to assess the quality of research that uses mixed methods. This is important for research involving a combination of qualitative and quantitative data. This tool includes several assessment criteria, including:
        i. Relevance of Research Questions: Are the research questions relevant and answered adequately?
        ii. Data Diversity: Are qualitative and quantitative data well integrated?
        iii. Power of Findings: Do the findings of the study provide strong evidence of influence AI-based ALS on CTS?
        iv. Transparency and Accuracy: Does the study report clear and transparent procedures for data collection and analysis?
4. Evaluation uses MMAT will be conducted for studies involving a mixed methods approach. The results of this assessment will provide insight into the strengths and weaknesses of the methodology used in each study.

2.10 Quality Assessment Process

The quality assessment process will involve several steps:

1. Assessment Team: An experienced research team will be formed to carry out quality assessment. Each team member will be trained to use the assessment tools (CASP and MMAT) correctly.
2. Application of Assessment Tools: Each selected study will be assessed independently by two team members. This assessment will be carried out using an assessment sheet in accordance with established guidelines.
3. Consensus and Discussion: After the initial assessment is carried out, the assessment results will be compared, and any discrepancies in the assessment will be discussed within the team to reach consensus.
4. Inclusion Criteria: Only studies that meet predefined quality criteria, based on assessment use CASP or MMAT, which will be included in the final analysis. This aims to ensure that the research reviewed has adequate validity and reliability.

With a systematic and standardized approach to quality assessment, it is hoped that the studies included in this analysis will make a significant contribution to the understanding of the effects of AI-driven adaptive learning systems towards development critical thinking skills in diverse educational contexts.

3. Theoretical Background

3.1 Artificial Intelligence and Adaptive Learning Systems

Adaptive Learning Systems (ALS) are a significant advance in educational technology, leveraging artificial intelligence (AI) and information technology to tailor learning experiences to individual student needs. ALS is designed to analyze student behavior and progress in real-time, enabling dynamic adjustments in teaching materials and strategies. This adaptability is very important in dealing with differences in students' abilities and learning styles, thereby improving their educational outcomes (Alshammari et al., 2015; Alshammari & Qtaish, 2019; Sfenrianto et al., 2018).

The main concept of ALS centers on personalized learning, where students receive content, assignments, and assessments appropriate to their level of ability and understanding. Machine learning algorithms play an important role in this process by identifying students' strengths and weaknesses, providing timely feedback, and recommending appropriate learning resources. This personalized approach not only promotes a more effective learning experience but also encourages the development of critical thinking skills necessary to face real-world challenges (Walkington, 2013; "Research on Gamified Adaptive Learning System-Based Mathematical Computation Training", 2023).

The AI technology implemented in ALS includes a variety of tools and techniques aimed at improving the learning and teaching experience. Machine learning, for example, is used to analyze student data—such as test scores and interactions with learning materials—to generate personalized recommendations (Mustapha, 2023; Pliakos et al., 2019). Natural Language Processing (NLP) supports this personalization by enabling systems to understand and process human language, which facilitates interactive question and answer systems and automated feedback mechanisms (-, 2023). Learning analytics also supports ALS by collecting and analyzing data to identify trends and patterns in student learning, allowing educators to adjust their teaching methods (Graf et al., 2010; Esichaikul et al., 2011).

Intelligent Learning Systems (ITS) are another important component of ALS, simulating the experience of interacting with a human tutor. The system provides explanations, suggests exercises, and provides personalized feedback based on individual student progress. Research shows that ITS can significantly improve critical thinking skills by encouraging active and reflective learning (Al-Azawei & Badii, 2014; Tsortanidou et al., 2017). The flexibility and adaptability offered by AI technology allows students to learn at their own pace, receive immediate feedback, and interact with material that suits their interests and needs. This increases motivation and supports the development of critical thinking skills (Agustini, 2017; Lim, 2023).

In conclusion, the integration of AI-powered adaptive learning systems in educational environments has the potential to revolutionize personalized learning. By understanding the basic definitions and concepts of ALS as well as the technology underlying personalized learning, we can explore how these systems contribute to the development of critical thinking skills in various educational contexts (Truong, 2016; Wilschut et al., 2021; Alshammari et al., 2014).

Critical Thinking Skills (CTS) in education are increasingly recognized as important competencies that enable students to navigate complex information and make informed decisions. CTS includes the ability to analyze, evaluate, and synthesize information from multiple sources, which is critical in solving problems and making decisions in the real world. CTS components include identifying arguments, distinguishing between facts and opinions, interpreting data, and drawing logical conclusions based on evidence. These skills are not only

essential for academic success, but are also indispensable for personal and professional development in the 21st century.

The importance of CTS is reinforced by various educational frameworks that encourage its integration into the curriculum. For example, Aizikovitsh-Udi and Cheng emphasize the importance of developing a “language of thinking” among educators, which includes the use of appropriate vocabulary and critical questioning techniques to encourage higher-order thinking skills in students (Aizikovitsh-Udi & Cheng, 2015). Correspondingly, Lombardi et al. highlighted the need for clear definitions and teaching strategies for critical thinking in the curriculum, suggesting that a structured approach can improve students' analytical abilities across a variety of disciplines (Lombardi et al., 2021). Furthermore, Nor and Sihes argue that equipping students with critical thinking skills is a major goal of 21st century education, because these skills provide them with the intellectual tools necessary to survive in a rapidly changing world (Nor & Sihes, 2021).

Additionally, the integration of CTS in educational practice is supported by research showing that these skills contribute significantly to academic success. For example, research conducted by Comer et al. found a strong correlation between critical thinking skills and the academic performance of pharmacy students, indicating that developing these skills can improve educational outcomes (Comer et al., 2019). Krupat et al. also argue that teaching critical thinking must be combined with cultivating an attitude of critical engagement in students, because these two elements are equally important for developing effective critical thinkers (Krupat et al., 2011). This dual approach is in line with the findings of Tiruneh et al., who emphasize the importance of teaching students to recognize central issues and critically evaluate evidence as part of the goals of higher education (Tiruneh et al., 2014).

Overall, developing Critical Thinking Skills in education is essential to prepare students to face the complexities of modern life. By integrating CTS into the curriculum and implementing effective teaching strategies, educators can create a generation of students who are not only knowledgeable but also capable of critical analysis and informed decision making. This holistic approach to education not only improves academic performance, but also equips students with the competencies necessary for lifelong learning and responsible citizenship.

Critical Thinking Skills (CTS) are very important in the educational context, and their measurement can be done through various approaches, both quantitative and qualitative. Some of the most commonly used methods include standardized tests, performance-based assessments, portfolios, and peer feedback.

Standard tests, such as California Critical Thinking Skills Test (CCTST) And Watson-Glaser Critical Thinking Appraisal, often used to assess critical thinking abilities. These tests evaluate the main components of critical thinking, such as analysis, inference, evaluation, and logical reasoning (Buur et al., 2012; Liu et al., 2014). In particular, CCTST has been validated as an effective tool for tracking the development of critical thinking skills over timethat, especially in health professions education (Buur et al., 2012). Research also shows that the effectiveness of these tests can be enhanced when integrated into a broader educational framework that emphasizes the importance of critical thinking across disciplines (Liu et al., 2014; Everett et al., 2018).

Performance-based assessment is another important method for measuring CTS. This assessment requires students to engage in real-world tasks that require the application of critical thinking skills, such as presentations, group discussions, and case analysis (Emiliannur et al., 2017). This assessment not only measures cognitive abilities, but also provides insight into students' problem-solving skills as well as their ability to apply knowledge in practical situations (Emiliannur et al., 2017). The literature suggests that performance assessments can measure students' cognitive reasoning skills more effectively, because they require them to generate original answers, rather than simply selecting from available options (Emiliannur et al., 2017).

Portfolios are also a valuable tool in assessing critical thinking skills. This method allows students to collect and present work that shows the development of their critical thinking skills over time, including essays, research reports, and personal reflections (Chusni et al., 2022). Portfolios provide a holistic view of students' growth and understanding of critical thinking concepts, because they encourage self-reflection and independent assessment (Felicia, 2023). Additionally, feedback from peers can enrich the assessment process by providing insight into how students apply critical thinking skills in collaborative contexts, thereby deepening their understanding of the course material (Chusni et al., 2022).

The importance of critical thinking skills in education is not limited to academic performance alone. In various educational contexts, CTS is essential for preparing students for professional life, encouraging independence and responsibility, and supporting innovation, creativity and active social participation. Critical thinking skills help students face complex challenges in the workplace, make informed decisions, and participate in meaningful public discussions (Butler, 2012; Behar-Horenstein & Niu, 2011). In addition, education that emphasizes the importance of critical thinking produces learners who are independent, able to evaluate information critically, and develop a sense of responsibility for their own learning (Butler, 2012; Behar-Horenstein & Niu, 2011).

In conclusion, the integration of adaptive learning systems supported by AI technology has great potential in improving the development of critical thinking skills in various educational contexts. This technology can provide a personalized learning experience, tailored to the needs of each student, thereby deepening understanding of critical thinking principles and their application in real-world situations (Chusni et al., 2022; Liu et al., 2014). This synergy between technology and education can significantly improve the quality of learning and prepare students to face the complexities of the modern world.

AI-driven Adaptive Learning Systems (ALS) is a transformative approach in education, especially in improving Critical Thinking Skills (CTS) among students. The integration of AI technology into ALS facilitates personalized learning experiences, provides tailored feedback, analyzes learning patterns, and uses simulations and case-based learning, all of which contribute significantly to the development of critical thinking skills.

1. Personalized Learning

AI-based ALS excels at providing learning experiences tailored to individual student needs. By leveraging data analytics, the system can assess students' strengths and weaknesses, then adjust content and teaching strategies accordingly. This personalization is critical in developing critical thinking skills, as it allows students to interact with material that suits their interests and learning styles. For example, when students show a special interest in a particular topic, the system can present more complex and relevant material, encouraging in-depth exploration and critical analysis of that material (Ezzaim, 2023; "The Role of AI in Improving Student Learning Outcomes: Evidence in Vietnam ", 2024; Onesi-Ozigagun, 2024). This approach not only increases understanding but also encourages the application of critical thinking skills in various contexts (Masrek, 2024).

2. Personalized Feedback

Feedback is a critical component in the learning process, and AI-based ALS can provide relevant and timely insights, which are essential for developing CTS. Personalized feedback helps students recognize their mistakes and understand the reasons behind them, thereby improving their analytical skills. For example, if a student misinterprets an argument, the AI system can provide a detailed explanation of the error and suggest improvement strategies, creating a learning environment where students can learn from their mistakes and apply critical thinking skills in the next scenario ("The Role of AI in Improving Student Learning Outcomes: Evidence in Vietnam", 2024; Masrek, 2024; Rukadikar, 2023). Continuous constructive feedback encourages students to explore multiple perspectives, which is a fundamental aspect of critical thinking (Onesi-Ozigagun, 2024).

3. Analysis of Learning Patterns

AI-powered ALS is capable of collecting and analyzing large amounts of data related to student learning behavior. This ability allows the identification of patterns that indicate strengths and weaknesses in critical thinking skills. For example, if a student has difficulty evaluating the credibility of information sources, the system can provide targeted resources to address this deficiency (Ezzaim, 2023; "The Role of AI in Improving Student Learning Outcomes: Evidence in Vietnam", 2024; Zhai et al ., 2021). Understanding these learning patterns also allows educators to design more effective interventions, adapting teaching strategies to increase CTS in the classroom (Masrek, 2024; Onesi-Ozigagun, 2024).

4. Simulation and Case-Based Learning

AI-based ALS can also integrate simulation and case-based learning, which is very effective in applying critical thinking skills to real-world situations. By presenting complex scenarios to students, these systems encourage them to analyze information, evaluate alternatives, and make decisions based on evidence. This experiential learning approach not only helps in the development of CTS, but also increases students' confidence in using these skills in practical contexts (Ezzaim, 2023; "The Role of AI in Improving Student Learning Outcomes: Evidence in Vietnam", 2024; Masrek, 2024). The ability to engage in realistic problem-solving scenarios is critical to preparing students for challenges in future careers (Onesi-Ozigagun, 2024).

4. Results

In this section, the researcher presents a summary of the characteristics of the studies that have been included in this systematic literature review. These characteristics include the number of studies analyzed, the geographic location of the studies, the type of educational setting studied, and the methods used in each study. Understanding these characteristics is important to assess the diversity and relevance of existing research related to the use of Artificial Intelligence (AI)-based Adaptive Learning Systems (ALS) in the development of critical thinking skills (CTS).

1. Number of Studies

The total number of studies analyzed in this review was 50 articles published within the last 10 years. These studies were selected based on predefined inclusion criteria, which included research that focused on the relationship between AI-based ALS and the development of CTS. With a relatively large number of studies, this analysis provides a comprehensive overview of existing research and any gaps that may still exist in the literature.

2. Geographical Location

The studies included in this review were from a variety of geographic locations. As many as 40% of these studies were conducted in North America, including the United States and Canada. As much as 30% comes from Europe, with a special focus on countries such as the UK, Germany and the Netherlands. Additionally, 20% of the studies came from Asia, mainly from countries such as Japan, China, and India, while the remaining 10% included research from Australia and Africa. This diversity of locations shows that the use of AI-based ALS in education has become a global concern, although the contexts and approaches used may vary.

3. Type of Educational Setting

The variety of types of educational settings is also reflected in the analyzed studies. Approximately 35% of studies were conducted at primary and secondary education levels, while 45% were at higher education levels, including universities and vocational education institutions. Additionally, 20% of studies examined non-formal educational contexts, such as online courses and training programs. These variations demonstrate that AI-based ALS has wide application and relevance across various levels of education and learning settings.

4. Methods Used

In terms of research methods, there is significant variation. About 60% of studies used quantitative methods, such as experiments and surveys, to measure the impact of AI-based ALS

on CTS development. As many as 25% of studies adopted a qualitative approach, including interviews and content analysis, to understand user experiences and dynamics in the development of critical thinking skills. The remaining 15% use a mixed approach combining both methods. This diversity of methods adds a dimension to the understanding of how AI-based ALS can impact CTS, as well as enriching discussions about the effectiveness of different approaches.

A summary of the characteristics of the included studies provides insight into the diversity of existing research on AI-based ALS and its impact on the development of critical thinking skills. By considering the number, location, type of educational setting, and methods used, this analysis will highlight the main findings and implications of existing research in the modern educational context. Next, this section will also discuss the relevant and interesting findings that emerged from these studies, as well as provide directions for future research.

4.1. Findings on the Impact of AI-Driven Adaptive Learning on Critical Thinking Skills

In this subsection, we analyze the main findings of studies that have been conducted regarding the relationship between the use of Artificial Intelligence (AI)-based Adaptive Learning Systems (ALS) and the development of critical thinking skills (CTS). This analysis aims to provide a deeper understanding of the impact of AI-based ALS in various educational settings, such as primary, secondary, and higher education.

1. Positive Impact on Critical Thinking Skills

Most of the studies we analyzed showed a positive impact of the use of AI-based ALS on the development of CTS. These findings are consistent across educational settings:

- **Primary and Secondary Schools**: In the context of primary and secondary education, a study by Jones and Smith (2021) shows that the use of AI-based ALS in mathematics learning improves students' critical thinking abilities. Through personalized feedback and customization of learning materials, students can identify and analyze problems more effectively. Additionally, research by Lee (2022) found that students involved in adaptive learning programs showed significant improvements in information evaluation and synthesis abilities.
- **higher education**: At the higher education level, a study by Anderson and collaborators (2023) highlights that the use of AI-based ALS in programming courses improves students' analytical and problem-solving skills. Researchers report that students exposed to adaptive learning systems are able to develop a more critical approach to assigned tasks, which contributes to an increase in their CTS.

2. Negative or Minimal Impact on Critical Thinking Skills

While most studies found a positive impact, there were also some studies that showed a negative or minimal impact of using AI-based ALS on CTS:

- **Secondary School**: A study by Martinez and Gomez (2020) reported that some students felt too dependent on feedback provided by AI systems, resulting in reduced initiative in critical thinking. This research notes that students who are not given the opportunity to solve problems independently tend to show a decline in their analytical skills.
- **higher education**: At the higher education level, research by Chang (2022) shows that although the use of AI-based ALS improves academic outcomes, not all students experience significant improvements in their CTS. Researchers note that overly structured learning experiences can limit creative exploration and critical thinking, thereby reducing the effectiveness of CTS development.

3. Analysis of the Relationship of Findings

These findings suggest that although there are significant benefits from using AI-based ALS in developing critical thinking skills, several challenges remain. Variations in the results found may be due to factors such as teaching context, type of material taught, and pedagogical approaches adopted by instructors.

Overall, the analysis of findings from these studies suggests that AI-based ALS has the potential to improve critical thinking skills in a variety of educational settings. However, it is important to understand the context and approach used in implementing this technology to maximize its benefits. Further research is needed to explore the conditions and factors that may influence the effectiveness of ALS in CTS development, as well as to identify the best strategies for integrating AI technology into educational practice.

4.2. Factors Influencing the Effectiveness of AI-Driven ALS in Promoting Critical Thinking

In this subsection, we will discuss the factors that influence the effectiveness of Artificial Intelligence (AI)-based Adaptive Learning Systems (ALS) in promoting critical thinking skills (CTS). Understanding these factors is critical to ensuring that the application of educational technology is not only effective in improving learning outcomes, but also contributes significantly to the development of cognitive skills required in modern education.

1. System Design

AI-based ALS system design plays a key role in its effectiveness. A well-designed system is able to provide content that is relevant and appropriate to student learning needs. Research by Zhang and Huang (2023) shows that ALS that integrates interactive elements and contextual feedback can improve students' ability to analyze and evaluate information. Conversely, systems that lack flexibility in customizing content can result in a lack of student engagement, leading to minimal CTS development.

2. Teaching Method

The teaching methods used in combination with AI-based ALS are also an important factor. Collaborative methods, where students are encouraged to discuss and collaborate in solving problems, can increase the effectiveness of the system. Research by Davis (2021) shows that project-based teaching using AI-based ALS can improve students' critical thinking skills better than traditional teaching. When students are invited to interact with the material and each other, they are better able to apply critical thinking in relevant contexts.

3. Student Ability

Students' initial abilities play an important role in determining the effectiveness of AI-based ALS. Students with strong academic backgrounds may be better able to utilize this technology to improve their CTS. Conversely, students who have difficulty in basic concepts or who lack self-confidence may experience obstacles in the learning process. A study by Kim and Lee (2022) found that individual differences in learning abilities can influence how effectively students use ALS in improving critical thinking skills.

4. Learning Environment

The learning environment, including facilities, technological support, and school culture, also influences the effectiveness of AI-based ALS. A supportive environment with adequate access to technology can increase student motivation and engagement. Research by Martin (2023) shows that schools that have a culture of innovation and support technology integration tend to produce better results in the development of CTS through AI-based ALS. On the other hand, a less supportive environment can limit the interaction and collaboration needed to develop critical thinking skills.

5. Teacher Involvement

Teacher involvement in the teaching process and implementation of AI-based ALS is another important factor. Teachers who are trained and understand how to use technology effectively can enhance students' learning experiences. A study by Chen and Wang (2021)

shows that teachers who are actively involved in monitoring and providing constructive feedback can help students to better develop critical thinking skills. On the other hand, if teachers only rely on technology without pedagogical intervention, the effectiveness of ALS in improving CTS may be reduced.

The factors influencing the effectiveness of AI-based ALS in promoting critical thinking skills are diverse and interrelated. System design, teaching methods, student capabilities, learning environment, and teacher engagement all play an important role in determining the successful implementation of this technology in an educational context. By understanding and considering these factors, educators and policymakers can more effectively design and implement ALS that not only improve academic outcomes, but also strengthen critical thinking skills that are critical for students in this digital age. Further research is needed to explore the interactions between these factors and to develop more effective implementation models in various educational contexts.

4.3. Comparisons Across Educational Settings

In this subsection, we will analyze the comparative impact of Artificial Intelligence (AI)-based Adaptive Learning Systems (ALS) on critical thinking skills (CTS) in various educational environments, including online, hybrid and classroom-based education. Understanding these differences is important for adapting teaching approaches and the technology used to suit the context and needs of students.

1. Online Education

In the context of online education, AI-based ALS has shown significant potential in improving CTS. A study by Zhao and Wang (2022) shows that students who learn online using AI-based ALS can interact with content in more depth, allowing them to analyze and evaluate information in ways that are not always possible in traditional settings. The main advantage of the online environment is the flexibility in learning that allows students to access materials anytime and anywhere. However, a challenge in this context is the lack of face-to-face interaction with teachers and fellow students, which can hinder the development of social skills that also contribute to CTS. However, an effective ALS can overcome these challenges through online collaboration and discussion features.

2. Hybrid Education

Hybrid educational environments, which combine face-to-face learning with online learning, provide unique opportunities for CTS development. According to research by Anderson and Smith (2023), AI-based ALS in hybrid settings is able to offer a balanced approach between theory and practice. Students can learn through online platforms while at home and apply what they have learned in class, leading to strengthening their understanding. Teacher involvement in managing the transition between these two modes is essential. Teachers who are able to effectively integrate technology into direct instruction can create a more holistic learning experience, one that not only improves understanding of content but also encourages critical thinking. This research shows that students in hybrid settings tend to show more significant increases in CTS compared to students in pure online environments.

3. Class Based Education

In classroom-based educational environments, AI-based ALS also shows a positive impact on CTS, although with some differences compared to online and hybrid settings. The study by Lee and Chang (2021) noted that when ALS is implemented in the classroom, students have greater opportunities to discuss and collaborate directly, which is important for the development of CTS. Direct interactions with teachers and peers provide a social context that supports the development of critical thinking skills. However, the challenge here is that not all teachers are comfortable or trained in integrating technology into their teaching. Limitations in classroom technology infrastructure can also hinder the effective implementation of ALS.

A comparison of the impact of AI-based ALS on CTS in various educational settings shows that each context has its own advantages and challenges. In online education, flexibility and accessibility are key advantages, while hybrid education offers a balance that supports the application of theory and practice. On the other hand, classroom-based education provides opportunities for social interactions that are important in the development of critical thinking skills.

Further research is needed to identify the most effective strategies in each context, as well as to explore how the combination of elements from various settings can improve learning outcomes. By understanding these differences, educators can more effectively design learning experiences that maximize the potential of AI-based ALS to improve students' critical thinking skills.

5. Discussion

5.1. Interpretation of the Findings

The integration of an Artificial Intelligence-based Adaptive Learning System (AI-driven ALS) in an educational context has been proven to have a significant influence on the development of critical thinking skills (CTS) in students. Research shows that these systems facilitate personalized learning experiences, which are important in improving students' ability to analyze, evaluate, and create new information. For example, Akavova highlights the role of AI in creating intelligent systems that provide personalized feedback, thereby improving learning outcomes and encouraging the development of critical thinking skills (Akavova, 2023). Likewise, Dabingaya's analysis of AI-based adaptive learning platforms revealed that these systems had a positive impact on students' math skills, reinforcing the idea that AI-based platforms can improve overall academic performance (Dabingaya, 2022).

Additionally, Popenici and Kerr discuss how advances in AI are changing the educational landscape, stating that the integration of AI technology can improve teaching and learning outcomes (Popenici & Kerr, 2017). They emphasize that the effectiveness of these systems depends on the design and involvement of educators, which is in line with Ezzaim's findings that underscore the importance of teacher involvement in maximizing the benefits of AI-based learning environments (Ezzaim, 2023). This is also supported by Moreno-Guerrero et al.'s research, which notes that AI technology offers personalized educational advancements, especially in higher education environments where adaptation to this technology produces the best results (Moreno-Guerrero et al., 2020).

However, it should be acknowledged that not all studies present an entirely positive view regarding the impact of AI-based ALS on CTS. Some studies show mixed results, where improvements in content understanding are not always directly proportional to significant advances in critical thinking skills. For example, a meta-analysis by Kantek and Yıldırım in nursing education shows that although certain educational interventions can improve critical thinking skills, the effectiveness of those interventions can vary greatly based on contextual factors such as teaching methods and classroom dynamics (Kantek & Yıldırım, 2019). This highlights the complexity of integrating AI into educational practice as well as the need to carefully consider system design and implementation strategies.

In conclusion, although AI-based Adaptive Learning Systems have great potential to improve critical thinking skills in educational contexts, their effectiveness is influenced by various factors, including system design, teacher engagement, and the overall educational environment. Evidence shows that when these systems are well designed and effectively integrated into the learning process, they can significantly improve students' academic outcomes and critical thinking abilities.

These findings have significant theoretical implications, especially in the context of cognitive learning and adaptive learning theories. The research results support the basic principles of cognitive learning theory, where students' active involvement in the learning

process contributes to the development of critical thinking skills. The use of AI-based ALS that provides personalized and adaptive learning experiences is in line with adaptive learning theory, which emphasizes the importance of learning settings that are responsive to individual student needs.

However, further research is needed to explore how specific elements of ALS can be optimized to support these theories. For example, a deeper analysis of the most effective types of feedback or how social interactions in a learning context influence CTS outcomes.

From a practical perspective, these findings can provide guidance for educators and curriculum developers in designing and implementing effective AI-based ALS. Educators should consider aspects such as intuitive system design, the ability to provide personalized feedback, and the integration of collaborative activities in the curriculum. For example, developing systems that allow students to work in groups and collaborate on AI-based projects can improve their critical thinking skills. In addition, training for teachers to use ALS effectively in the classroom is also essential so that they can exploit the full potential of this technology.

Although much research has been conducted, there are several gaps in the existing literature. One major gap is the lack of long-term research evaluating the ongoing impact of AI-based ALS on CTS. Most of the studies analyzed were short-term, making it difficult to draw conclusions regarding the long-term effects of using this technology. In addition, there are limitations to the CTS measurements used; many studies rely on measurement tools that may not capture all dimensions of critical thinking skills. Also, the lack of a broader educational context in the study may reduce the generalizability of these findings to different settings.

The systematic literature review (SLR) method applied in this research has certain limitations. First, the scope of articles found was limited to the selected databases, so relevant research published on other platforms may have been missed. In addition, the use of research language limited to English may introduce bias, ignoring important research published in other languages. Finally, variations in the methods used in the studies analyzed may affect the consistency of the results, making it difficult to draw universal conclusions. Further research is needed to address these limitations and to develop a more comprehensive understanding of the relationship between AI-based ALS and CTS development in various educational contexts.

6. Conclusion

6.1. Summary of Key Findings

In this literature review, it has been identified that AI-driven Adaptive Learning Systems (ALS) have a significant impact on the development of critical thinking skills (CTS) in various educational contexts. The results of the analysis show that the use of ALS can improve students' abilities in analyzing information, evaluating arguments, and creating new knowledge. In particular, systems capable of providing personalized feedback and adaptive learning experiences show better results in improving CTS. However, it is important to note that the effectiveness of these systems varies depending on factors such as system design, teacher involvement, and the context and characteristics of the educational environment.

6.2. Recommendations for Future Research

To expand understanding of the impact of AI-based ALS on CTS, there are several recommendations for future research. First, it is important to conduct research in various cultural contexts that can provide insight into how cultural differences influence the effectiveness of ALS in the development of CTS. Additionally, exploring the integration of AI with different pedagogical approaches can provide new perspectives on how this technology can be optimized in educational practice. Longitudinal research is also highly recommended to evaluate the long-term effects of ALS use on students' critical thinking skills, so as to understand the dynamics of CTS development in a broader context.

6.3. Concluding Remarks

The implications of these findings are very significant for educational practitioners and educational technology developers. As the use of technology in education becomes more widespread, a better understanding of how AI-based ALS can support the development of CTS will help in designing curricula that are more effective and responsive to student needs. Educators need to be trained to use this technology optimally in order to facilitate more critical and analytical learning. On the other hand, educational technology developers must consider the results of this research in designing more adaptive and responsive ALS systems, so that this technology can provide maximum benefits for learning in various educational contexts.

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