

Artificial Intelligence-Based Personalized Learning in Twenty-First Century Learning Transformation

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ABSTRACT

The advancement of Artificial Intelligence (AI) has accelerated the transformation of learning toward a more adaptive and learner-centered approach through the implementation of personalized learning. This article aims to analyze the concepts, implementation, challenges, and strengthening strategies of AI-based personalized learning within the context of general education. The study employed a qualitative descriptive library research method by reviewing scientific publications published over the last five years. The findings indicate that AI supports the analysis of learners' characteristics, develops adaptive learning pathways, provides timely feedback, and facilitates the creation of learning materials tailored to individual needs. This approach has significant potential to improve learning effectiveness, student engagement, and the development of twenty-first-century competencies. Nevertheless, its implementation continues to face challenges related to teachers' readiness, AI literacy, data privacy, algorithmic bias, and ethical considerations. Therefore, the successful implementation of AI-based personalized learning requires synergy among technological innovation, teachers' pedagogical competence, responsible governance, and educational policies that promote adaptive, inclusive, and sustainable learning.

Keywords: *Adaptive Learning, Artificial Intelligence, Educational Transformation, Learner-Centered Learning, Personalized Learning.*

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1. | INTRODUCTION

The transformation of education in the digital era has driven a paradigm shift in learning from a uniform model to a more student-centered approach. The learning needs of each individual that are different in terms of initial ability, learning speed, interests, and learning style require a learning strategy that is able to accommodate these diversity effectively. In this context, personalized learning is one of the approaches that is getting more attention because it places students at the center of the learning process and provides a learning experience that is tailored to the characteristics of each individual (Shemshack & Spector, 2020; Kucirkova et al., 2021).

The development of Artificial Intelligence (AI) opens up new opportunities in the implementation of personalized learning. AI has the ability to analyze student learning data, identify learning patterns, and provide recommendations for learning materials and activities that suit individual needs. The use of AI in education is growing rapidly through various forms, such as adaptive learning systems, learning analytics, intelligent tutoring systems, and generative AI that are able to support the learning process more adaptively (Chen et al., 2020; Zhai et al., 2021).

A number of studies show that the integration of AI in personalized learning can help students obtain a learning path that is more in line with their level of competency mastery. AI-based systems are able to provide feedback in real time, adjust the difficulty level of the material, and predict the learning needs of students so that the learning process becomes more effective and efficient (Hwang et al., 2020; Li et al., 2021). In addition, AI also enables the development of more flexible learning experiences and supports lifelong learning through dynamic content adjustment (Bayly-Castaneda et al., 2024; Wu et al., 2024).

The emergence of generative AI technology further expands the potential of personalized learning. Generative AI can help produce learning materials, practice questions, simulations, and explanations that are tailored to the needs of individual learners. The use of this technology provides an opportunity to create a learning environment that is more interactive and responsive to the needs of students (Baidoo-Anu & Ansah, 2023; Xiaoyu et al., 2024). Within the framework of Education 4.0 and Education 5.0, AI is seen as a strategic technology that supports adaptive, collaborative, and competency-oriented learning in the 21st century (Ramírez-Montoya et al., 2022; Rane et al., 2024).

However, the implementation of AI-based personalized learning is inseparable from various challenges. Issues related to data privacy, algorithm bias, AI literacy, teacher readiness, and potential dependence on technology are important concerns in the development of AI-based learning (Chen et al., 2020; Zhai et al., 2021). In addition, personalized learning cannot only depend on technology, but needs to be combined with pedagogic strategies that consider the psychological, social, and character aspects of learners (Brod, 2024; Benkovska et al., 2024).

Previous studies have generally addressed AI as a learning medium or discussed personalized learning separately, while studies that integrate the two comprehensively in a general education perspective are still relatively limited. In fact, the combination of AI analytical capabilities and personalized learning principles has the potential to produce a learning model that is more adaptive and relevant to future educational needs (Laak & Aru, 2025; Bakri, 2024). On the other hand, digital technology has been shown to make a significant contribution in supporting personalization of learning through content customization, activities, and learning evaluations (Varona Klioukina & Engel, 2024; Reyes Parra et al., 2024).

Based on this description, this study aims to analyze the concepts, implementations, challenges, and strategies for strengthening personalized learning based on Artificial Intelligence in the context of general education. This study is expected to make a conceptual contribution on how AI can be used as a driver of learning that is more adaptive, student-centered, and in line with the demands of 21st century educational transformation.

2. | RESEARCH METHOD

This study uses a library research method with a descriptive qualitative approach to comprehensively examine the concepts, implementations, challenges, and strategies for strengthening personalized learning based on Artificial Intelligence (AI) in the context of general education. Literature studies were chosen because they allow researchers to gain an in-depth understanding of theoretical developments, empirical research results, as well as various scientific findings that have been published related to the integration of AI in personalized learning. This approach is oriented towards the synthesis of existing knowledge so that it is able to produce a systematic conceptual analysis that is relevant to the development of contemporary education. The entire research process is carried out through the identification, selection, evaluation, organization, and interpretation of various scientific sources that are directly related to the research topic so that a strong theoretical foundation is obtained to explain the phenomenon of AI-based personalized learning.

The data sources used are secondary data from scientific articles, reputable international journals, accredited national journals, scientific proceedings, and reports from international institutions published during the 2020–2024 period. The time limit is carried out so that the resulting studies reflect the latest developments regarding AI in education, especially after the increasing use of adaptive learning, learning analytics, intelligent tutoring systems, and generative artificial intelligence. Literature search was conducted through Google Scholar as the main indexing engine using a combination of keywords, including personalized learning, artificial intelligence in education, adaptive learning, learning analytics, student-centered learning, AI-based education, generative AI, education 4.0, education 5.0, and AI for personalized learning. Furthermore, the articles found are selected based on the suitability of the topic, the quality of the

publication, the year of publication, and the relevance to the research objectives so that only references that have a direct contribution to the discussion are used as sources of analysis.

The data analysis process is carried out through several stages that are mutually sustainable. The first stage is data reduction, which is to select literature that is directly related to the concept of personalized learning and the application of AI in learning. The second stage is in the form of categorization, which is grouping information based on main themes that include the basic concept of personalized learning, the development of AI in education, the implementation of AI in adaptive learning, changes in the role of teachers and students, challenges in the application of AI, and strategies to strengthen AI-based personal learning. The third stage is content analysis by comparing, connecting, and integrating various findings from each literature to obtain patterns, tendencies, similarities, and differences of views that have developed in previous research. The last stage is in the form of synthesis withdrawal, which is to develop a comprehensive interpretation of AI's contribution in supporting more adaptive learning, student-centered, and oriented towards improving the quality of learning processes and outcomes.

To ensure the quality of research results, each literature source is evaluated based on the author's credibility, the reputation of the publisher or journal, the consistency of the research methodology, and the relevance of the substance to the focus of the study. In addition, the synthesis process is carried out by comparing various perspectives from previous research so as to produce an objective, comprehensive discussion, and not only relying on one reference source. Through this literature study approach, it is hoped that a complete picture of the development of AI-based personalized learning will be obtained, as well as produce conceptual recommendations that can be a reference for the development of adaptive learning at various levels of education in the future.

3. | RESULTS AND DISCUSSION

Digital transformation has changed the educational paradigm from a learning system that is oriented towards the delivery of materials uniformly to learning that is able to accommodate the diversity of student characteristics. These changes are driven by the increasing need for a learning process that not only focuses on achieving learning outcomes, but also pays attention to learning experiences that are in accordance with each individual's abilities, interests, needs, and development. In this context, personalized learning is one of the approaches that is seen as able to answer the challenges of modern education because it places students as the center of learning while providing flexibility in determining the path, speed, and learning strategy that suits their characteristics. This approach is different from conventional learning which tends to use a uniform approach so that it is often not able to accommodate the diversity of students' abilities. Therefore, the implementation of personalized learning is seen as one of the important strategies in improving the quality of learning that is more

inclusive, adaptive, and oriented towards the development of individual competencies (Shemshack & Spector, 2020; Kucirkova et al., 2021).

The development of Artificial Intelligence (AI) provides a new dimension in the implementation of personalized learning. AI allows the learning process to no longer depend entirely on teachers' decisions in determining materials, activities, or evaluations, but also to utilize the ability of intelligent systems to process learning data in an ongoing manner. Through machine learning technology, learning analytics, and intelligent tutoring systems, AI is able to identify students' learning patterns based on the track record of learning activities, the level of material mastery, the frequency of errors, and the learning preferences shown during the learning process. This information is then used to produce learning recommendations that are more in line with individual needs so that the learning process becomes more effective and efficient. Thus, AI not only functions as a technological tool, but also develops into a decision support system that is able to improve the quality of learning personalization on an ongoing basis (Chen et al., 2020; Zhai et al., 2021).

AI's ability to analyze learning data automatically is one of the main factors that distinguishes AI-based personalized learning from previous personalized learning approaches. In the conventional model, teachers must identify initial abilities, determine learning needs, arrange different materials, and evaluate student development manually. The process takes a long time and is often difficult to implement in a classroom with a large number of students. On the contrary, AI is able to carry out the analysis process quickly through the use of algorithms that study students' learning behavior continuously. The results of the analysis are then used to adjust the difficulty level of the material, provide additional training on competencies that have not been mastered, or offer more complex challenges to students who have reached a certain level of mastery. With this mechanism, learning becomes more adaptive to the development of each individual's abilities without eliminating the role of the teacher as a manager of the learning process (Hwang et al., 2020; Li et al., 2021).

Furthermore, the development of AI technology also encourages the birth of the concept of a learning pathway that allows each student to have a different learning path according to their needs and competency achievements. The learning path is built through data analysis that considers initial abilities, formative assessment results, learning speed, and students' tendency to complete learning activities. Thus, two students who study the same material can obtain different sequences of activities, learning resources, and forms of evaluation because the AI system automatically adjusts recommendations based on the results of each individual's data analysis. This approach shows that learning personalization is not only differentiating teaching materials, but also developing learning experiences that are truly in accordance with the characteristics of learners so that they are able to increase motivation, engagement, and learning independence (Bayly-Castaneda et al., 2024; Wu et al., 2024).

Advances in generative AI further strengthen the implementation of personalized learning through its ability to produce various learning resources that can be directly tailored to the needs of students. This technology allows the preparation of material summaries, sample questions, adaptive exercises, learning simulations, and different feedback for each individual based on the difficulties they experience. Compared to previous digital learning systems that generally only presented material in static form, generative AI is able to generate learning content dynamically according to user demand. This condition provides opportunities for students to obtain a more flexible learning experience while accelerating the process of achieving competencies through the provision of more diverse learning resources. On the other hand, teachers also receive support in developing a variety of learning materials so that they can focus more attention on the mentoring process, character building, and strengthening students' critical thinking skills (Baidoo-Anu & Ansah, 2023; Xiaoyu et al., 2024).

The implementation of AI-based personalized learning not only has an impact on students, but also changes the paradigm of the teacher's role in the learning process. If previously teachers played the role of the main source of information, then in AI-based learning teachers function more as facilitators, learning experience designers, mentors, and pedagogical decision makers. AI is able to help with various administrative tasks, such as analyzing learning outcomes, preparing material recommendations, and providing initial feedback, so teachers have more time to build meaningful interactions with students. These changes show that AI is not intended to replace the role of teachers, but rather to strengthen teachers' capacity to provide learning services that are more personalized, effective, and oriented to the needs of students. Within this framework, the collaboration between human intelligence and artificial intelligence becomes an important foundation for the development of future learning that not only takes advantage of technological advances, but also maintains pedagogical and humanitarian values in education (Ramírez-Montoya et al., 2022; Rane et al., 2024).

However, the success of the implementation of AI-based personalized learning is not only determined by technological sophistication, but also influenced by the quality of the learning design developed. AI is only able to produce optimal recommendations if it is supported by clear learning objectives, valid assessments, and learning strategies designed based on pedagogical principles. Therefore, learning personalization needs to be understood as a collaborative process between technology, teachers, and learners in building adaptive and meaningful learning experiences. This approach emphasizes that AI is a supporting instrument that expands teachers' ability to manage learning, not replacing the professional responsibility of educators in guiding the intellectual, social, and character development of students. Thus, AI integration should be placed as part of educational innovation that remains based on the principles of student-centered learning, 21st century competency development, and lifelong learning.

Although it offers various advantages, the implementation of AI-based personalized learning also presents a number of challenges that need to be anticipated

so that its use really has a positive impact on the quality of learning. One of the main challenges is the accuracy of AI systems in building learners' learning profiles. The recommendations generated by AI depend heavily on the quality, completeness, and representativeness of the data used in the analysis process. If the available data does not reflect the abilities, interests, or development of students as a whole, then the system has the potential to produce inappropriate recommendations so that the goal of learning personalization cannot be achieved optimally. In addition, AI algorithms can also contain algorithmic bias, which is the tendency of the system to produce less objective decisions due to the limitations of training data and the algorithm design used. These conditions show that the use of AI in education still requires human supervision so that every learning decision considers pedagogical, psychological, and social aspects that are not fully understood by machines (Chen et al., 2020; Zhai et al., 2021).

The next challenge relates to the protection of privacy and security of student data. The implementation of AI-based personalized learning requires the collection of various types of data, such as assessment results, learning activities, task completion time, interaction patterns, and history of use of digital platforms. The data has a very important value in building adaptive learning models, but on the other hand it also increases the risk of misuse of information if it is not managed responsibly. Therefore, every educational institution needs to implement data governance that ensures security, confidentiality, and ethical use of data. Transparency regarding the type of data collected, the purpose of its use, and privacy protection mechanisms are important aspects in building trust among all stakeholders in the implementation of AI in education (Laak & Aru, 2025; Bakri, 2024).

In addition to the technological aspect, the readiness of human resources is a factor that greatly determines the success of the implementation of AI-based personalized learning. Teachers are no longer enough to only master pedagogic and professional competencies as in conventional learning, but also need to have digital literacy and AI literacy in order to be able to utilize technology effectively in the learning process. Understanding how AI works, interpreting learning analysis results, compiling effective prompts on generative AI, and the ability to evaluate the validity of AI outputs are new competencies that are increasingly needed. Without mastery of these competencies, there is a risk that teachers will only use AI as an automation tool without being able to integrate it into learning strategies that truly support the achievement of educational goals. Thus, increasing teacher capacity through continuous training is one of the important prerequisites in supporting the successful implementation of AI-based personalized learning (Baidoo-Anu & Ansah, 2023; Xiaoyu et al., 2024).

On the student side, the use of AI also requires the development of independent learning skills, critical thinking, and information literacy. The ease of obtaining answers instantly through generative AI can provide benefits if used as a means of knowledge exploration, but it also has the potential to cause dependency if used without the ability to evaluate the quality of the information produced. Therefore, students need to be

equipped with the ability to verify information, reflect on learning outcomes, and use AI as a learning partner, not as a substitute for the thought process. This approach is in line with the principle of self-regulated learning, where learners remain responsible for their own learning process, while AI serves as a support that helps identify learning needs and provide relevant learning resources (Shemshack & Spector, 2020; Brod, 2024).

Recent studies show that the success of personalized learning is determined not only by the ability of technology to adapt learning materials, but also by the quality of the underlying pedagogical strategy. Personalized learning needs to integrate diagnostic assessments, continuous monitoring of learning progress, constructive feedback, and opportunities for learners to reflect on their learning outcomes. In this context, AI plays a role as a support for the decision-making process, while teachers remain the party who determines pedagogical interventions according to the needs of students. Such integration results in more adaptive learning because every learning decision is based on a combination of AI-generated data analysis and the professional considerations of teachers as educators (Kucirkova et al., 2021; Hwang et al., 2020).

Strengthening the implementation of AI-based personalized learning also requires the development of an educational ecosystem that supports learning innovation. The ecosystem includes the provision of adequate digital infrastructure, the development of ethical AI use policies, the improvement of teacher competence, the provision of quality digital learning resources, and an evaluation system that is able to measure the development of student competencies authentically. This approach shows that the transformation of AI-based education is not enough through the adoption of technology alone, but must be accompanied by a change in learning culture that encourages collaboration, creativity, communication, and problem-solving skills as the main competencies of the 21st century. Thus, AI functions as a catalyst for educational innovation that supports the realization of more flexible, inclusive, and developmental learning that is oriented towards the optimal development of students' potential (Li et al., 2021; Ramírez-Montoya et al., 2022).

Furthermore, the development of Education 5.0 places collaboration between humans and AI as the main foundation in the implementation of future education. This paradigm emphasizes that technology should not replace human interaction, but rather strengthen the ability of teachers and students to build meaningful learning experiences. AI can take over routine work, such as data analysis and the preparation of learning recommendations, while teachers focus their role on character building, creativity development, the formation of ethical values, and the strengthening of high-level thinking skills. This approach reflects the concept of human-centered artificial intelligence, which is the use of AI that still upholds human values as the core of the educational process. Thus, the success of educational transformation is not only measured by the level of technology adoption, but also by the extent to which

technology is able to improve the quality of learning interactions between teachers and students (Rane et al., 2024; Bayly-Castaneda et al., 2024).

Overall, the results of the study show that AI-based personalized learning is an approach that has great potential in improving the quality of learning through adjusting the learning experience based on individual characteristics of students. AI's ability to analyze learning data, develop adaptive learning paths, provide feedback quickly, and support the development of learning materials makes this technology one of the strategic innovations in educational transformation. However, its implementation needs to be supported by teacher readiness, student AI literacy, responsible data governance, and education policies that prioritize the principles of ethics, inclusivity, and student-centered learning. By combining the power of AI analytics and teachers' pedagogical competence, personalized learning can develop into a more adaptive, effective, and sustainable learning model so that it is able to respond to the demands of 21st century education while preparing students to face the dynamics of a knowledge- and technology-based society (Wu et al., 2024; Benkovska et al., 2024; Varona Klioukina & Engel, 2024; Reyes Parra et al., 2024).

4. | CONCLUSION

Personalized learning based on Artificial Intelligence (AI) is one of the strategic innovations that is able to answer the demands of educational transformation in the digital era through the implementation of learning that is more adaptive, flexible, and student-centered. This approach allows each student to gain a learning experience that is tailored to their initial abilities, needs, interests, learning speed, and competency development. The integration of AI in the learning process supports continuous learning data analysis, the preparation of personalized learning paths, the provision of quick feedback, and the development of dynamic learning resources so that the learning process becomes more effective and efficient. The role of AI in this context is not intended to replace teachers, but rather to strengthen teachers' capacity in designing, implementing, monitoring, and evaluating learning based on student characteristics.

On the other hand, the implementation of AI-based personalized learning also faces various challenges that require serious attention, including related to data quality, potential algorithm bias, privacy protection, AI literacy, teacher readiness, and ethical aspects in the use of technology. Therefore, the success of implementation does not only depend on technological sophistication, but also on the quality of pedagogical design, strengthening educator competence, developing an adaptive learning culture, and the availability of policies that support the use of AI responsibly and oriented to the interests of students.

AI-based personalized learning has huge prospects as a future learning model that is able to integrate artificial intelligence with pedagogical values. The collaboration between AI analytics capabilities and teachers' professional competencies can result in a more personalized, inclusive learning experience, and encourage the development of

critical thinking skills, creativity, independent learning, and lifelong learning. Thus, the development of AI-based personalized learning needs to continue to be encouraged as part of an educational transformation that is oriented towards improving the quality of learning as well as optimally developing the potential of students in facing the challenges of the 21st century.

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The authors declare that there is no conflict of interest.

Ethical Approval and Originality Statement

Ethical approval was obtained for this study. The manuscript represents original work and has not been previously published, nor is it under consideration by another journal.

Data Disclosure Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

- Baidoo-Anu, D., & Ansah, L. O. (2023). Education in the era of generative artificial intelligence (AI): Understanding the potential benefits of ChatGPT in promoting teaching and learning. *Journal of AI*, 7(1), 52-62.
- Bayly-Castaneda, K., Ramirez-Montoya, M. S., & Morita-Alexander, A. (2024, August). Crafting personalized learning paths with AI for lifelong learning: a systematic literature review. In *Frontiers in Education* (Vol. 9, p. 1424386). Frontiers.
- Benkovska, N., Kharchenko, N., Kulbach, L., Rabokorovka, G., & Bolotnykova, T. (2024). Analyzing pedagogical strategies for personalized learning to compensate for students' learning losses. *Revista Eduweb*, 18(1), 235-244.
- Brod, G. (2024). There are multiple paths to personalized education, and they should be combined. *Current Directions in Psychological Science*, 33(3), 153-158.
- Chen, X., Xie, H., Zou, D., & Hwang, G. J. (2020). Application and theory gaps during the rise of artificial intelligence in education. *Computers and education: Artificial intelligence*, 1, 100002.
- Hwang, G. J., Sung, H. Y., Chang, S. C., & Huang, X. C. (2020). A fuzzy expert system-based adaptive learning approach to improving students' learning performances by considering affective and cognitive factors. *Computers and Education: Artificial Intelligence*, 1, 100003.
- Kucirkova, N., Gerard, L., & Linn, M. C. (2021). Designing personalised instruction: A research and design framework. *British Journal of Educational Technology*, 52(5), 1839-1861.
- Laak, K. J., & Aru, J. (2025). AI and personalized learning. *Educational Technology & Society*, 28(4), 133-150.
- Li, F., He, Y., & Xue, Q. (2021). Progress, challenges and countermeasures of adaptive learning. *Educational Technology & Society*, 24(3), 238-255.
- Ramírez-Montoya, M. S., Castillo-Martínez, I. M., Sanabria-Z, J., & Miranda, J. (2022). Complex thinking in the framework of education 4.0 and open innovation—a systematic literature review. *Journal of Open Innovation: Technology, Market, and Complexity*, 8(1), 4.
- Rane, N., Choudhary, S., & Rane, J. (2023). Education 4.0 and 5.0: Integrating artificial intelligence (AI) for personalized and adaptive learning. *Available at SSRN* 4638365.
- Reyes Parra, D., Rozo García, H. A., & Buitrago Espitia, J. E. (2024). Aportes de la tecnología al aprendizaje personalizado: Una revisión a la literatura.
- Shemshack, A., & Spector, J. M. (2020). A systematic literature review of personalized learning terms. *Smart learning environments*, 7(1), 33.
- Klioukina, S. V., & Engel, A. (2024). Prácticas de personalización del aprendizaje mediadas por las tecnologías digitales: una revisión sistemática. *EduTec, Revista Electrónica De Tecnología Educativa*, (87), 236-250.
- Wu, S., Cao, Y., Cui, J., Li, R., Qian, H., Jiang, B., & Zhang, W. (2024). A comprehensive exploration of personalized learning in smart education: From student modeling to personalized recommendations. *arXiv preprint arXiv:2402.01666*.

- Xiaoyu, W., Leng, C. H., & Zainuddin, Z. (2024). The effectiveness of generative AI in education: A systematic review of empirical study. *JuKu: Jurnal Kurikulum & Pengajaran Asia Pasifik*, 12(4), 48-66.
- Zhai, X., Chu, X., Chai, C. S., Jong, M. S. Y., Istenic, A., Spector, M., ... & Li, Y. (2021). A Review of Artificial Intelligence (AI) in Education from 2010 to 2020. *Complexity*, 2021(1), 8812542.