

BEGINNER

Journal of Teaching and Education Management

Journal Website: https://beginner.my.id/

ISSN: 2987-596X (Online) Vol. 4 No. 2 (2026)
DOI: https://doi.org/10.61166/bgn.v4i2.120 pp. 96-122

Research Article

The Role Of Artificial Intelligence In Supporting Teachers For Personalized E-Learning: Opportunities And Challenges

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Received : August 04, 2026
Revised : September 25, 2026
Accepted : October 09, 2026
Available online : November 20, 2026

How to Cite: Ikram Chelliq, Lamya Anoir, & Mohamed Khaldi. (2026). The Role Of Artificial Intelligence In Supporting Teachers For Personalized E-Learning: Opportunities And Challenges. *Beginner: Journal of Teaching and Education Management*, *4*(2), 96–122. https://doi.org/10.61166/bgn.v4i2.120

Abstract. Artificial Intelligence (AI) is increasingly influencing the development of personalized e-learning by offering new possibilities for understanding learners and supporting teachers in their pedagogical practices. This article examines how AI can support teachers in designing and implementing personalized learning experiences while preserving the central role of human expertise. The study analyzes the main applications of AI in personalized e-learning, including learner profiling, learning analytics, content adaptation, pedagogical recommendations, and the identification of individual learning needs. The analysis highlights that AI can assist teachers in processing learner data, identifying learning patterns, selecting appropriate educational resources,

and adapting learning activities to different learner profiles. These capabilities can facilitate more flexible learning environments and support teachers in making informed pedagogical decisions. However, the integration of AI also presents significant challenges related to data privacy, algorithmic bias, transparency, ethical responsibility, reliability of automated recommendations, and teacher–technology interaction. The findings emphasize that the effectiveness of AI-supported personalized learning depends not only on technological capabilities but also on appropriate pedagogical integration and human supervision. The article therefore highlights the need for teacher-centered and learner-centered approaches in which AI complements, rather than replaces, teachers' pedagogical expertise.

Keyword: Artificial Intelligence, Personalized E-Learning, Teachers, Adaptive Learning, Learning Analytics, Educational Technology.

INTRODUCTION

Digital technologies have gradually changed the way teaching and learning take place. In E-learning environments, Learners don't necessarily have to follow the same content or activities. Their prior knowledge, learning preferences, motivation, and challenges can vary considerably, making it increasingly difficult to offer the same learning experience to all learners (Chelliq et al., 2026). Personalized learning is therefore becoming more and more important in terms of an approach aimed at adapting learning experiences to the specific characteristics and needs of each learner. Recent research shows that artificial intelligence is playing an increasingly significant role in this process, particularly through adaptive learning paths, personalized content, feedback, and learner analytics (Almasri, 2024; Wang et al., 2024). The emergence of artificial intelligence (AI) offers new opportunities to make personalization more dynamic. Unlike traditional digital learning systems, AI-based technologies can analyze large amounts of learner data and identify trends that are not visible to teachers. This data—which includes learners' interactions with resources, assessment results, progress, and learning behaviors—can be used to provide insights into their needs and challenges. These capabilities pave the way for tailoring instructional resources and activities to individual learners' activities and learning situations (Wang et al., 2024).

However, personalization cannot be limited to the processing of learner data. Teachers remain responsible for understanding the educational context in which learning takes place and for making decisions regarding the appropriateness of specific educational resources or activities. The data generated by online learning platforms can provide teachers with information about learners' outcomes, strengths, weaknesses, and progress, which can then assist them in making instructional decisions (Ikram et al., 2025; Hase & Kuhl, 2024).

AI can therefore be viewed as an additional resource that helps teachers better understand data and consider possible adjustments, rather than as an autonomous

decision-making system. This perspective becomes increasingly relevant as AI-based personalized learning systems grow in complexity. Machine learning techniques, natural language processing systems, recommendation systems, and generative AI can be applied at various stages of the learning process. In particular, they can help identify learner profiles, recommend instructional resources, generate explanations or feedback, and facilitate the adaptation of instructional activities. Research on AI-based personalized learning has highlighted potential benefits such as adaptive learning paths, tailored content, and real-time feedback, while also identifying persistent concerns related to data privacy, ethical issues, technological infrastructure, and teacher readiness (Alam & Mohanty, 2025).

At the same time, the growing presence of AI in education raises an important question about the role of the teacher. The purpose of AI should not be limited to automating pedagogical decisions. Pedagogical decisions involve contextual, social, and ethical considerations that cannot always be deduced from learner data alone. A human-centered approach is therefore necessary to ensure that technological capabilities remain aligned with educational objectives and the actual needs of learners. In its 2023 report, UNESCO emphasizes the importance of adopting human-centered, ethical, safe, and relevant approaches when integrating generative AI into education and research. Another issue concerns the relationship between the information provided by AI systems and teachers' professional judgment. An AI system can identify a pattern in a learner's behavior or generate a recommendation, but interpreting that recommendation still requires pedagogical knowledge (UNESCO, 2023). Teachers need to verify whether a suggested resource is appropriate, whether a learner's difficulty is temporary or persistent, and whether an adaptation aligns with the learning objective. Research on human-centered learning analytics and AI in education also highlights the importance of human oversight, trust, reliability, and stakeholder involvement in the development and use of intelligent educational systems (Anoir et al., 2025; Alfredo et al., 2024).

These considerations suggest that the value of AI in personalized online learning should not be assessed solely on the basis of its technical capabilities. Its educational value also depends on how effectively it is integrated into teachers' practices. The challenge, therefore, is to establish a productive relationship between artificial intelligence and teachers' pedagogical skills. Within such a relationship, AI can handle tasks related to data processing, pattern recognition, prediction, and the formulation of recommendations, while teachers retain a key role in interpretation, pedagogical decision-making, interaction, and guidance. Despite researchers' growing interest in artificial intelligence in the field of education, the question of how AI can concretely assist teachers in the context of personalized online learning remains significant. Much of the current literature examines AI applications from the perspective of learner outcomes or technological capabilities, whereas the teacher's

role in interpreting and utilizing AI-generated information deserves sustained attention (Ikram et al., 2024).

This issue is particularly important in personalized learning environments, where effective personalization requires combining learner data, tailored instructional resources, learning objectives, and professional judgment. Consequently, this article examines the role of artificial intelligence (AI) in supporting teachers in personalized e-learning. It focuses on the main ways in which AI can help teachers understand learner profiles, analyze learning behaviors, identify individual needs, adapt instructional content, and recommend appropriate learning activities. At the same time, the article examines the main challenges associated with these applications, particularly those concerning privacy, ethical issues, reliability, bias, and teacher preparation. The goal is to provide a balanced perspective on AI-assisted personalization and to highlight the conditions under which AI can serve as a meaningful support for teachers while preserving the human dimension of education (Ikram et al., 2024; Anoir et al., 2024).

RESEARCH METHODS

This study adopts a conceptual and analytical approach to examine how Artificial Intelligence can support teachers in the personalization of e-learning environments. The proposed approach is based on the integration of three complementary perspectives: the characteristics of personalized learning, the capabilities of Artificial Intelligence, and the pedagogical role of teachers.

The methodology is therefore not limited to examining the technical capabilities of AI. It seeks to establish a relationship between the information collected about learners, the intelligent processing of this information, and the pedagogical decisions made by teachers. On this basis, a conceptual framework is developed to illustrate how AI can assist teachers in understanding learners, selecting appropriate resources, adapting learning activities, and monitoring learning progress.

The methodological approach consists of four main components: personalized e-learning, learner modeling, Artificial Intelligence technologies, and teacher decision support. These components are subsequently integrated into a conceptual architecture for AI-supported personalized e-learning.

Personalized E-Learning

Definition of personalized learning

Personalized learning refers to an educational approach in which learning experiences are adapted to the characteristics, needs, preferences, and progress of individual learners. Unlike a uniform instructional model in which learners are generally exposed to the same content and activities, personalization seeks to introduce greater flexibility into the learning process. In digital environments,

personalization can concern several elements of learning, including the content presented to the learner, the sequence of activities, the level of difficulty, the learning pace, feedback, assessment, and recommended resources. According to Pane et al. (2015), personalized learning can involve adapting learning according to learners' individual needs and providing different learning pathways rather than requiring all learners to follow an identical progression (Pane et al., 2015).

In the context of e-learning, personalization is particularly relevant because digital platforms can continuously collect information about learners' interactions and performance. This information can subsequently be used to support decisions concerning the adaptation of the learning environment.

Dimensions of personalized e-learning

For this study, personalized e-learning is considered through five dimensions:

Table 1 Dimensions of personalized e-learning

Dimension	Description
Learner profile	Characteristics, preferences, prior knowledge and learning needs
Content	Selection or adaptation of educational resources
Activities	Selection of appropriate learning tasks and exercises
Learning pathway	Adaptation of the sequence and progression of learning
Feedback	Personalized information provided according to learner performance

These dimensions form the basis for determining where AI can intervene and how teachers can use AI-generated information.

Learner Modeling

A learner model represents information about an individual learner within an adaptive or personalized learning system. It provides a structured representation of learner characteristics that can be used to support personalization. Depending on the design of the system, the learner model may include information related to prior knowledge, learning performance, learning preferences, learning behavior, interaction history, learning progress, identified difficulties, and learning objectives.

In adaptive learning environments, learner modeling constitutes an important link between the learner and the adaptation mechanism. Brusilovsky and Millán (2007) describe learner modeling as a fundamental component of adaptive educational systems because adaptation requires information about the learner.

For the conceptual framework proposed in this study, the learner model is organized into four complementary categories: profile, knowledge, behavior, and preferences. The profile category includes demographic information, educational

background, and learning objectives. The knowledge category covers learning performance, acquired competencies, and identified difficulties. The behavior

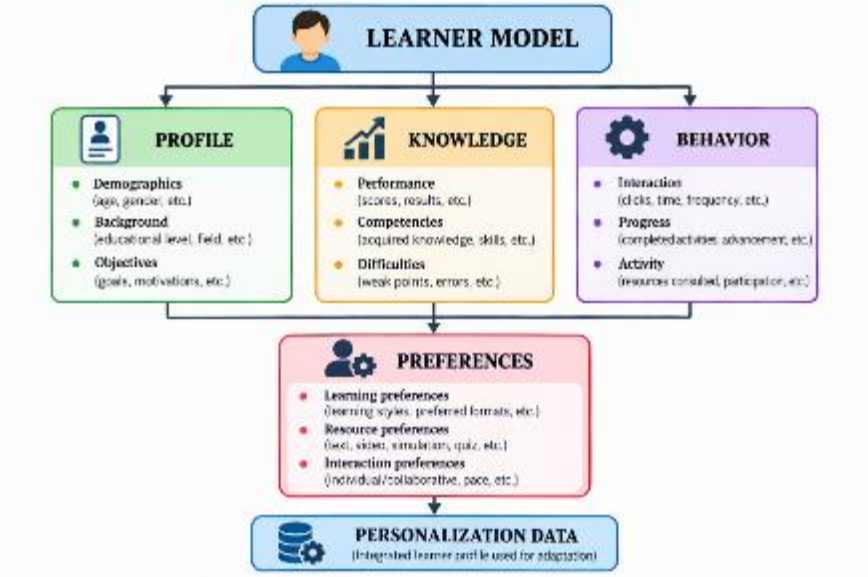


Figure 1. Learner model for personalized e-learning

category concerns learners' interactions with educational resources, their activity patterns, and their progress through learning tasks. Finally, the preferences category includes learning preferences, preferred resource formats, and interaction preferences. These four categories are illustrated in Figure 1.

As shown in Figure 1, the four categories contribute to the construction of an integrated learner profile, represented as personalization data. This information provides the basis for the AI component to ana lyze learners' situations and formulate recommendations for appropriate educational resources and activities. The learner model is not intended to be a fixed representation of the learner; it can be updated as new information becomes available through subsequent learning interactions. AI-generated recommendations should nevertheless be interpreted in context and reviewed by the teacher before being implemented.

Artificial Intelligence in E-Learning

Artificial intelligence encompasses a range of computational techniques that can support different stages of personalized learning. These techniques do not have the same function: some are mainly used to analyse learner data, while others support prediction, recommendation, interaction, or content generation.

In a personalized e-learning environment, their value therefore depends less on the use of a particular technology than on how it is integrated into the pedagogical process. Table 2 summarizes the main AI technologies that can contribute to personalization and their potential educational roles.

Table 2 AI technologies and their potential educational roles

AI technology	**Main capability**	**Possible application in personalized e-learning**	**Support provided to teachers**
Machine Learning	Identifying patterns and learning relationships from data	Predicting learner performance, identifying behavioral patterns	Provides evidence for pedagogical decisions
Classification	Assigning data to predefined categories	Learner profiling, risk identification, learning-level classification	Helps identify learner groups and specific needs
Clustering	Discovering naturally similar groups	Grouping learners according to behavior, performance, preferences, or learning characteristics	Supports differentiated teaching strategies
Recommendation Systems	Selecting relevant items according to learner characteristics	Recommending resources, activities, exercises, or learning paths	Reduces the time required to select appropriate resources
Natural Language Processing	Processing and interpreting human language	Automated feedback, question answering, dialogue, language learning	Supports feedback and interaction with learners
Generative AI	Producing new textual, visual, or multimodal content	Generating explanations, examples, exercises, summaries, and alternative formulations	Assists teachers in preparing and adapting learning materials
Predictive Analytics	Estimating probable future outcomes	Early identification of learning difficulties, dropout risk, or performance decline	Enables earlier pedagogical intervention

The objective is not to use all these technologies simultaneously. Rather, they represent different possibilities through which AI can contribute to personalized learning.

Machine learning represents one of the main technological foundations of AI-based personalization. It enables systems to identify relationships and patterns in learner data, such as assessment results, interaction frequency, activity completion, or learning trajectories. Based on these patterns, models can estimate possible future outcomes, including learner performance or the probability of encountering difficulties. In personalized e-learning, machine learning can therefore transform raw learner activity into information that can support pedagogical decision-making. Rather than replacing the teacher's judgment, such models can provide additional evidence about learners who may require attention or additional support.

Classification techniques have a different function because they assign learners or learning situations to predefined categories. For example, learners can be classified according to achievement level, engagement level, risk status, or other characteristics defined by the learning environment. Classification can also be used to identify whether a learner requires reinforcement, regular progression, or more advanced activities. This type of processing can facilitate learner profiling and help teachers distinguish between learners with different educational needs.

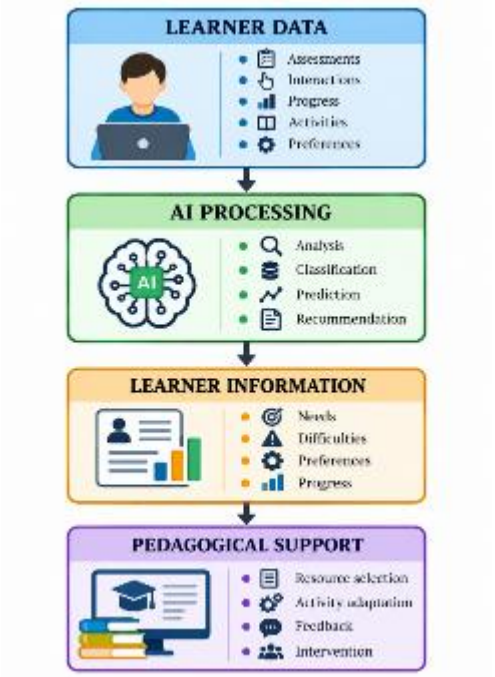
Clustering is particularly useful when predefined learner categories are not available. Unlike classification, clustering attempts to discover groups of learners who present similar characteristics. For example, learners may be grouped according to their interaction patterns, performance, preferences, or progression through a course. These groups can subsequently be associated with different pedagogical strategies. In this sense, clustering can support differentiated instruction while avoiding the assumption that all learners should follow exactly the same learning path.

Recommendation systems are directly related to the personalization of learning resources and activities. Once information about a learner has been collected and analyzed, a recommendation system can select resources that are considered relevant to the learner's current situation. These resources may include videos, texts, exercises, assessments, examples, or specific learning activities. The main contribution of recommendation systems is therefore not simply to provide more content, but to reduce the gap between the large amount of available educational material and the resources that are most appropriate for a particular learner. For teachers, this can reduce part of the effort involved in manually selecting resources for learners with different needs.

Natural Language Processing (NLP) introduces another dimension of personalization by allowing educational systems to process and generate human language. NLP can be used in conversational agents, automated feedback systems, question-answering systems, writing support, and language-learning applications.

In an e-learning environment, a learner can interact with an AI-based system using natural language and receive feedback or explanations adapted to the interaction. For teachers, NLP can also provide information about learners' questions, difficulties, and written responses, thereby offering additional evidence about areas that may require pedagogical attention.

Generative AI extends these possibilities by enabling the production of new educational content. Large language models and other generative models can assist in producing explanations, examples, summaries, exercises, questions, or alternative formulations of existing material. This is particularly relevant to teacher support because the same learning objective may need to be presented in different ways depending on learner needs. For example, a teacher may use generative AI to prepare a simpler explanation for a learner experiencing difficulty or generate additional exercises for learners who require further practice. However, generated material still requires pedagogical validation because fluency and apparent relevance do not guarantee accuracy or educational appropriateness.



Predictive analytics focuses on estimating future learner outcomes from available data. In personalized e-learning, predictive models can be used to identify learners who may be at risk of low performance, disengagement, or interruption of their learning process. The important pedagogical value of prediction is its potential to support early intervention. Instead of waiting until a learner fails an assessment, a teacher may receive an indication that the learner is experiencing difficulties and can intervene earlier. Nevertheless, predictive results should be considered as indicators rather than definitive judgments about learners, since predictions can contain errors and may be influenced by the quality and representativeness of the available data.

These technologies should not be considered independent or necessarily used simultaneously. Their roles correspond to different stages of the personalization process. Machine learning, classification, clustering, and predictive analytics primarily contribute to learner analysis and prediction; recommendation systems contribute to the selection of appropriate learning resources; NLP supports interaction and feedback; and generative AI contributes to the creation or adaptation of educational content. Consequently, an AI-supported personalized learning environment may combine several techniques according to its pedagogical objectives and available learner data.

More importantly, the technologies described above do not eliminate the role of the teacher. Their educational value lies in their capacity to transform learner data into information, recommendations, or resources that can assist teachers in making pedagogical decisions. The teacher remains responsible for interpreting these outputs, assessing their relevance, validating AI-generated content, and deciding whether a particular adaptation is appropriate for the learner. This human–AI complementarity is particularly important in personalized e-learning, where personalization involves not only technical adaptation but also pedagogical judgment and knowledge of the learner.

Figure 2 From Learner Data to Pedagogical Information

AI-Based Learner Analysis

One of the principal roles of artificial intelligence in personalized e-learning is to analyze learner information in order to identify learning needs, monitor progress, and provide relevant information for pedagogical decision-making. Digital learning environments generate different types of data, including assessment results, interactions with learning resources, activity completion, response patterns, and learner preferences. However, these data do not automatically provide a clear understanding of a learner's difficulties or educational needs. AI-based techniques can help identify patterns in this information and transform them into meaningful indicators that support personalization.

As illustrated in Figure 2, the process involves four main stages: learner data collection, AI processing, the identification of learner characteristics, and the provision of pedagogical support. During the processing stage, AI techniques such as classification, prediction, and pattern recognition can be used to examine learner activity and identify possible difficulties or specific learning needs. The resulting information may help teachers determine whether a learner requires additional explanations, further practice, alternative learning resources, or more individualized feedback.

For example, when a learner repeatedly provides incorrect answers to questions related to a particular concept, an AI-based component can analyze the learner's previous assessment results and interactions to identify a possible learning difficulty. Based on this analysis, the system may suggest additional exercises, alternative explanations, or other resources that address the identified need. Such recommendations should not be interpreted as definitive diagnoses, but rather as indicators that can inform the teacher's understanding of the learner's situation.

The transformation of learner data into pedagogically meaningful information is therefore an important step in personalized e-learning. Nevertheless, the effectiveness of this process depends on the quality of the available data, the reliability of the AI techniques, and the teacher's ability to interpret and validate the resulting information. AI consequently serves as a support mechanism for

pedagogical decision-making rather than a replacement for the teacher's professional judgment.

AI-Supported Pedagogical Recommendation and Teacher Decision-Making

Pedagogical recommendation constitutes an important component of personalized e-learning because it establishes a relationship between the learner's current situation, the intended learning objectives, and the educational resources available within the learning environment. Adaptive educational systems have traditionally relied on learner models to represent information about users and support the selection of content adapted to their characteristics (Brusilovsky & Millán, 2007). More recent applications of artificial intelligence extend these possibilities through data analysis, prediction, recommendation, and content generation (Wang et al., 2024). Nevertheless, identifying a potentially relevant resource does not necessarily mean that the resource is pedagogically appropriate for a particular learner.

Within the proposed approach, the recommendation process begins with information collected from the learner model, including previous performance, learning progress, interactions with educational resources, identified difficulties, and preferences when available. This information is considered alongside the learning objective and the characteristics of the available pedagogical resources. The AI component then analyses these elements to propose resources or activities that may respond to the learner's needs. For example, a learner experiencing persistent difficulties with a specific concept may be directed towards an alternative explanation, a worked example, or an additional exercise. Conversely, a learner who has demonstrated sufficient understanding may be offered a more advanced activity.

The process also requires a clear distinction between computational recommendation and pedagogical decision-making. AI-generated suggestions are based on the information available to the system and may not capture every relevant aspect of the learning situation. The teacher must therefore examine whether the proposed resource is consistent with the curriculum, the intended learning outcome, the learner's actual needs, and the conditions in which learning takes place. This distinction is consistent with Seo et al. (2025), whose study of K–12 teachers identified several areas in which teachers envisioned AI as a complementary resource, including instructional material development, foundational learning support, student evaluation, and personalized curriculum design. Their findings emphasize the importance of designing AI systems around teachers' needs rather than expecting teachers to adapt their practices to the system.

Table 3 summarizes the relationship between AI-supported functions and the corresponding responsibilities of the teacher. It highlights the complementary nature of these contributions: AI assists with data processing and the formulation of

suggestions, whereas the teacher interprets the available evidence and determines the appropriate pedagogical response.

Table 3 AI-supported pedagogical recommendation and teacher responsibilities

Function	Contribution of AI	Responsibility of the teacher
Learner analysis	Identifies patterns in performance and interaction data	Interprets the findings in relation to the learner's context
Resource recommendation	Identifies potentially relevant educational resources	Checks pedagogical relevance and alignment with learning objectives
Activity recommendation	Suggests exercises or activities according to identified needs	Selects, modifies, or rejects the proposed activities
Learning difficulty prediction	Estimates the possibility of future difficulties	Examines the evidence and determines whether intervention is necessary
Feedback support	Generates preliminary feedback or explanations	Verifies accuracy, clarity, and pedagogical appropriateness
Learning pathway adaptation	Suggests possible changes in the sequence or level of activities	Determines whether the proposed progression is appropriate

The distinction presented in Table 3 provides the basis for the proposed framework. Rather than transferring pedagogical authority to an automated system, the approach positions AI as a decision-support mechanism that can help teachers identify relevant information, explore possible interventions, and adapt learning resources. The teacher retains responsibility for the final decision, while subsequent learner interactions provide new information that can inform later recommendations.

Proposed Conceptual Framework for AI-Supported Personalized E-Learning

Building on the preceding discussion, this study proposes a conceptual framework that explains how learner information, artificial intelligence, teacher expertise, and personalized educational activities can be connected within an e-learning environment. The framework draws on the principle of learner modeling in adaptive educational systems (Brusilovsky & Millán, 2007) and on research

examining the range of applications and functions of AI in education (Wang et al., 2024). Its distinctive emphasis is the explicit integration of the teacher into the recommendation and adaptation process.

The framework comprises five interconnected layers. The learner layer represents the individual who interacts with the learning environment and generates information through assessments, activities, and other learning interactions. The data and learner model layer organizes relevant information about the learner, including prior knowledge, progress, interaction patterns, and preferences when these have been established. This representation provides the basis for understanding the learner's current situation, while remaining open to revision as new information becomes available.

The artificial intelligence layer processes the available information to identify patterns, estimate potential difficulties, classify learner situations, and formulate recommendations. Depending on the system's design, it may also support the generation or adaptation of educational content. These functions are not necessarily implemented together in every system; their selection depends on the pedagogical objectives, the available data, and the technical capabilities of the learning environment. The AI layer consequently produces information and suggestions rather than making all pedagogical decisions independently.

The teacher decision-support layer constitutes a central component of the framework. Teachers examine AI-generated outputs, compare them with their knowledge of the learner and the curriculum, and determine whether a proposed intervention is appropriate. This human validation is particularly important when recommendations are uncertain, when learner data are incomplete, or when a pedagogical decision requires contextual understanding. The emphasis on teacher involvement is consistent with the complementary role of AI discussed by Seo et al. (2025) and with UNESCO's (2023) human-centred guidance for the use of generative AI in education and research.

Finally, the personalized learning layer represents the educational response resulting from the teacher's decision. It may involve selecting a different resource, modifying an activity, changing the sequence of learning tasks, providing additional feedback, or proposing further practice. Learner interactions with these adapted activities subsequently generate new data, allowing the learner model to be updated and the process to continue.

Figure 3 presents the relationships between the five layers and illustrates how AI-generated recommendations are mediated by teacher judgment before being translated into personalized learning activities.

As illustrated in Figure 3, personalization does not result directly from the application of an AI algorithm. Instead, it emerges from the interaction between

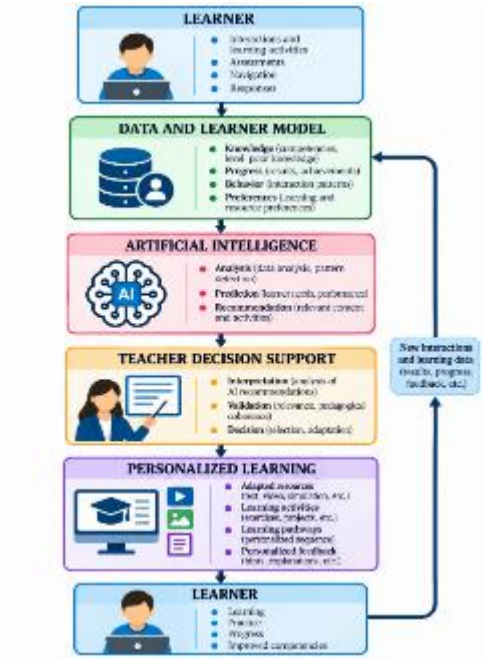
Figure 3 Conceptual framework of AI-supported personalized e-learning

learner information, computational analysis, teacher judgment, and the implementation of an appropriate educational response. The teacher's position between AI recommendations and personalized learning is intentional: it allows the system to provide analytical support without assuming that its outputs are automatically correct or suitable. The return of new learner information also indicates that the framework is dynamic rather than a one-time sequence of operations.

The framework should be understood as a conceptual proposal rather than as a fully implemented or experimentally validated system. Its purpose is to clarify the relationships between the principal components and provide a basis for subsequent implementation and empirical evaluation.

Iterative Personalization, Opportunities, and Challenges

The framework described above operates through an iterative personalization process. Learners interact with educational resources, their activities generate new information, and the learner model is updated when sufficient and relevant evidence



becomes available. AI can then analyse the updated information and formulate new recommendations, which the teacher evaluates before deciding whether an adaptation is necessary. This process reflects the adaptive nature of personalized learning: educational support may need to change as learners acquire knowledge, encounter difficulties, or demonstrate progress.

Figure 4 summarizes this operational cycle and distinguishes the computational stages from the teacher's pedagogical intervention. Unlike Figure 3, which describes the overall architecture of the framework, Figure 4 focuses on the sequence through which personalization is renewed over time.

As shown in Figure 4, the cycle connects data analysis with a pedagogical action and subsequent learner interaction. Its operation depends on the quality of the information collected, the relevance of the AI-generated recommendations, and the teacher's ability to interpret the results. It also requires the system to update learner information appropriately rather than treating an initial profile as a permanent description of the learner. In practice, updates should be based on meaningful evidence and should account for uncertainty, missing data, and changes in learning circumstances.

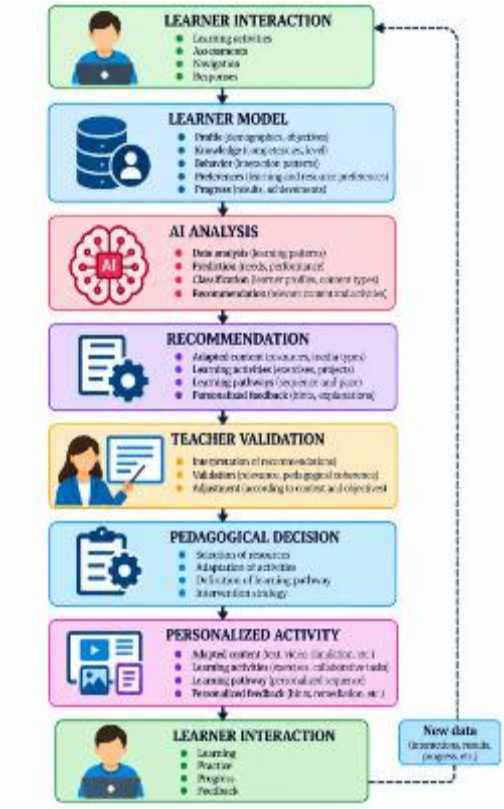


Figure 4 . Iterative cycle of teacher-mediated personalization

The proposed approach offers several potential benefits. Learner analysis may help teachers identify patterns that are difficult to detect through manual observation alone. Recommendation functions may reduce the time required to search for relevant educational resources, while content-generation tools may assist in preparing alternative explanations and exercises. Predictive functions may also help draw attention to learners who could benefit from additional support. These possibilities are consistent with the diversity of AI applications identified by Wang et al. (2024), although the practical value of each application depends on its design and educational context.

However, these opportunities must be considered alongside technical, pedagogical, and ethical limitations. Incomplete or inaccurate learner data may produce misleading recommendations. Algorithms may reproduce biases present in the data or inadequately represent learners whose circumstances differ from those reflected in the training data. Generated educational content may contain factual errors, unsuitable explanations, or material that does not align with curriculum objectives. Moreover, excessive reliance on automated recommendations could reduce teachers' autonomy if the system does not make its reasoning sufficiently understandable or leaves limited room for professional judgment. UNESCO (2023) consequently emphasizes a human-centred approach to generative AI that addresses privacy, appropriate use, and the responsibilities of educational institutions.

Table 4 brings together the principal opportunities and challenges associated with the proposed framework. Rather than treating these dimensions as separate

concerns, the table connects each potential benefit to the conditions required for its responsible implementation.

Table 4 Opportunities and challenges of AI-supported personalized e-learning

Dimension	**Potential opportunity**	**Main challenge**	**Implication for implementation**
Learner analysis	Better identification of learning needs and progress	Incomplete, inaccurate, or insufficiently representative data	Examine data quality and communicate uncertainty
Personalization	Adaptation of resources and activities to learner needs	Inappropriate or overly restrictive adaptation	Align adaptations with learning objectives and review their effects
Pedagogical recommendation	More efficient identification of potentially relevant resources	Recommendations may be unsuitable or biased	Require teacher review and allow recommendations to be rejected
Teacher support	Assistance with planning, feedback, and resource preparation	Over-reliance on automated outputs	Preserve teacher autonomy and professional judgment
Generative AI	Rapid preparation of alternative explanations and exercises	Factual errors and pedagogical inconsistency	Verify content before using it with learners
Learning monitoring	Earlier identification of possible difficulties	False predictions and misinterpretation of learner behavior	Use predictions as indicators, not definitive judgments
Efficiency	Reduction of certain repetitive tasks	Unequal access and differences in AI literacy	Provide training and assess accessibility
Ethics and governance	More deliberate and accountable use of educational AI	Privacy, transparency, and accountability concerns	Establish appropriate data protection and human oversight

The relationship between opportunities and challenges suggests that the effectiveness of AI-supported personalization cannot be assessed solely by the

sophistication of its algorithms. It must also be considered in relation to pedagogical relevance, the quality of learner information, the transparency of recommendations, and the conditions under which teachers use AI-generated outputs. A recommendation may be computationally plausible but educationally inappropriate if it disregards the learning objective or the learner's circumstances. Similarly, an automatically generated resource may save preparation time but still require substantial review before classroom use.

Overall, the proposed framework positions AI as a means of supporting teachers rather than replacing their pedagogical responsibilities. Its central assumption is that personalization emerges through a continuing interaction between learner data, AI-supported analysis, teacher decision-making, and adapted learning activities. This conceptual contribution provides a foundation for future empirical work examining the usability, pedagogical relevance, reliability, and educational outcomes of teacher-mediated AI personalization.

RESULTS AND DISCUSSION

The results presented in this section are based on a descriptive and thematic synthesis of published research on AI-supported personalized e-learning, with particular attention to the support provided to teachers. Rather than reporting data collected through a new experiment, the analysis compares findings from selected literature reviews and empirical studies to identify the main AI technologies, approaches to personalization, teacher-related applications, and implementation challenges. The quantitative figures reported below correspond to the evidence presented in the cited publications. Since these publications differ in scope, study selection criteria, and periods covered, their numerical findings are presented descriptively and are not combined into a single quantitative estimate. The synthesis also informs the interpretation of the conceptual framework proposed in this article.

Quantitative overview of the evidence

The reviewed literature reflects growing research interest in the use of artificial intelligence (AI) to support personalized learning. Recent systematic reviews have examined the technologies, instructional applications, and educational contexts associated with AI-driven personalization. For example, Bayly-Castaneda et al. (2024) analyzed 78 studies published between 2019 and 2024 and identified 11 categories of AI-mediated solutions for designing personalized learning paths. These solutions include adaptive learning environments, recommendation systems, intelligent conversational agents, learning analytics, and generative language technologies. Other reviews have broadened the scope of investigation by examining AI-based personalized learning across educational levels and by focusing on the technical approaches used to adapt learning experiences (Farhood et al., 2025; Hariyanto et al., 2025).

Table 5. Quantitative overview of selected studies on AI-supported personalized learning

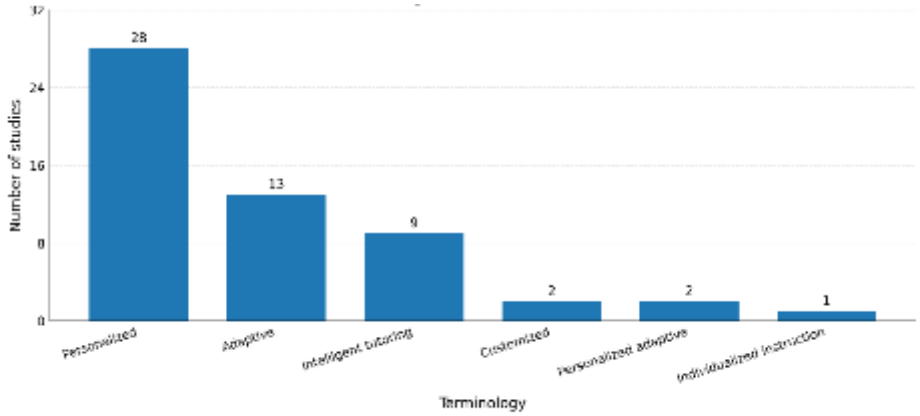
Study	**Publication period covered**	**Evidence base**	**Main focus**
Bayly-Castaneda et al. (2024)	2019–2024	78 studies	AI-mediated personalized learning paths
Fortuna et al. (2025)	2019–2024	25 studies	AI-based personalization in higher education
Farhood et al. (2025)	2015–June 2025	125 studies	AI-based personalized learning across educational contexts
Hariyanto et al. (2025)	2015–2025	142 empirical studies	AI techniques for adaptive education
Khalifeh et al. (2026)	2019–2025	861 screened; 55 retained	Personalized learning in the AI era
Tunç and Baş (2024)	Previous five years	20 studies	AI and education in Türkiye

The scale and scope of these reviews are summarized in Table 5. Farhood et al. (2025) examined 125 studies, while Hariyanto et al. (2025) synthesized 142 empirical studies addressing AI-based personalization and adaptive education. Fortuna et al. (2025), in turn, analyzed 25 Scopus-indexed articles published between 2019 and 2024, with a particular focus on tertiary and higher education. Another systematic review screened 861 papers and retained 55 studies for its analysis of personalized learning in the AI era (Khalifeh et al., 2026).

Distribution of Terminology in Personalized Learning Research

The terminology used in research on AI-supported personalization reflects different approaches to adapting learning experiences. In their review, Khalifeh et al. (2026) retained 55 studies from an initial set of 861 screened papers and examined the terminology used to describe this field. As shown in Figure 5, personalized learning was the most frequently used term, appearing in 28 studies (50.9%). Adaptive learning appeared in 13 studies (23.6%), while intelligent tutoring was used

Figure 5 Distribution of Terminology in Personalized Learning Research



Source: Khalifeh et al. (2026). Counts transcribed from the supplied chart; verify against the original review.

in nine studies (16.4%). The remaining five studies used the terms customized learning, personalized adaptive learning, or individualized instruction.

The distribution indicates that personalized learning is the dominant term in this review, accounting for approximately half of the included studies. Nevertheless, the terminology should not be treated as interchangeable. Adaptive learning generally emphasizes adjustments to content, difficulty, or learning sequences, whereas intelligent tutoring focuses on providing instructional guidance through a tutoring system. Personalized learning can encompass these mechanisms as well as other forms of adaptation based on learner characteristics, preferences, progress, or educational needs. These distinctions are important when comparing studies and interpreting the different ways AI can contribute to teachers' decisions (Bayly-Castaneda et al., 2024; Khalifeh et al., 2026).

AI Technologies Supporting Personalization

The reviewed studies indicate that AI-supported personalization relies on a combination of technologies rather than on a single technique. Machine learning and predictive models can analyze learner data and estimate potential difficulties; clustering can identify groups of learners with similar characteristics; and recommendation systems can suggest resources or activities according to learners' profiles. Natural language processing and intelligent tutoring systems can support dialogue and instructional feedback, while generative AI can assist in producing explanations, examples, exercises, and other learning materials. Reinforcement learning and multimodal analytics have also been investigated as approaches to dynamic adaptation and the integration of different types of learner information (Bayly-Castaneda et al., 2024; Farhood et al., 2025; Fortuna et al., 2025; Hariyanto et al., 2025).

Table 7. AI technologies and their potential contributions to personalized learning

AI technology or approach	Main function	Potential educational application
Machine learning and predictive models	Classification and prediction	Identifying learner profiles and estimating possible learning difficulties
Clustering	Identifying similarities in learner data	Grouping learners with similar needs or characteristics
Recommendation systems	Matching learners with relevant resources	Suggesting learning materials and activities
Natural language processing and intelligent tutoring systems	Language interaction and instructional support	Providing dialogue-based assistance and targeted feedback
Generative AI and large language models	Generating and adapting content	Preparing explanations, examples, exercises, and alternative formulations
Reinforcement learning	Supporting dynamic adaptation	Adjusting the sequence of learning activities
Learning analytics and multimodal analytics	Analyzing learner activity and combining information sources	Monitoring progress and informing pedagogical interventions

To clarify the relationship between these technologies and teachers' work, Table 7 groups the principal approaches according to their potential personalization functions and educational applications. Rather than presenting every technology as a separate outcome, the table highlights how different techniques can contribute to a broader instructional process.

Quantitative Evidence Concerning the Teacher's Role

The teacher's role is particularly relevant because personalized e-learning involves more than automatically adjusting digital content. It also requires decisions about learning objectives, instructional strategies, assessment, and the suitability of proposed adaptations. Seo et al. (2025) investigated teachers' needs regarding the complementary role of AI in personalized learning. In the first study, 15 K–12 teachers participated in focus-group interviews. The sample included nine female teachers (60%) and six male teachers (40%), with five participants from each of the elementary, middle, and high-school levels. All participants had more than five years of teaching experience and had previously used AI-based educational services.The researchers identified eight roles that AI could potentially augment: personalized curriculum design, instructional material development, foundational learning support, self-reflection, student evaluation, career guidance, student management, and administrative support (Seo et al., 2025). These roles extend beyond

recommending learning resources: they also involve lesson preparation, the monitoring of learning, and the organization of teaching activities. The researchers' second study involved 128 teachers, providing a broader basis for examining teachers' expectations concerning AI-supported personalization (Seo et al., 2025).

Figure 6 illustrates the composition of the first study's sample, rather than the relative importance of the eight AI-supported roles. The findings suggest that teachers may need AI assistance across several aspects of their professional practice, including planning, material preparation, learner support, evaluation, and administration. However, the first study's sample of 15 participants is limited, and its composition does not establish how frequently these expectations occur among teachers in general.

The results should therefore be interpreted as evidence of the roles identified in this investigation, not as a representative estimate of all teachers' views. Overall, the study supports an approach in which AI assists teachers while pedagogical interpretation and decision-making remain under human responsibility.

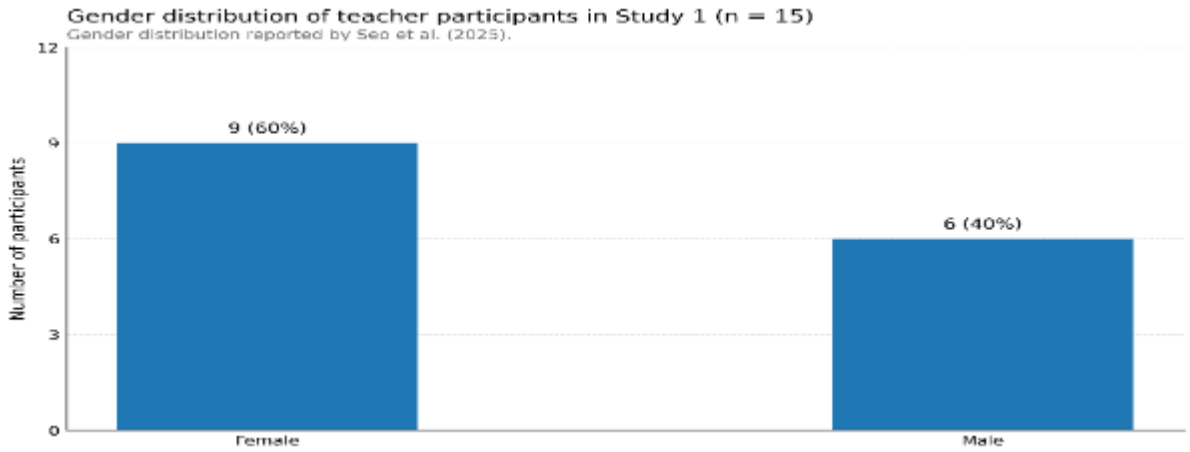


Figure 6 Demographic and Educational-Level Composition of the Teacher Sample in Study 1

Levels of Personalization and Implications for Teaching

The technologies identified in the reviewed literature can support personalization at several levels, from selecting appropriate learning resources to adapting the organization of an entire learning pathway. At the resource level, AI can help teachers identify materials that correspond to learners' current knowledge or difficulties. At the activity level, it can support the selection of exercises, alternative explanations, and tasks with different levels of complexity. At the pathway level, AI-supported systems can propose a sequence of activities based on learner progress, while feedback and assessment mechanisms can help teachers identify areas requiring additional instruction (Bayly-Castaneda et al., 2024; Farhood et al., 2025; Fortuna et al., 2025).

These levels are interconnected rather than independent. For example, when a learner experiences difficulty understanding a concept, an AI-supported system may analyze available performance data, recommend an alternative explanation, and suggest additional exercises. The teacher can then examine whether the recommendation corresponds to the learning objective and the learner's actual needs. Conversely, when a learner demonstrates sufficient understanding, the system may propose a more challenging activity. In both cases, the proposed adaptation should be considered a pedagogical option rather than an automatic decision that must be followed. This interpretation is consistent with the importance of learner modeling in adaptive educational systems, where information about the learner informs the adaptation of the learning experience (Brusilovsky & Millán, 2007).

The proposed process places the teacher between AI-generated recommendations and their educational implementation. Learner data can inform the system's analysis, but the resulting recommendation still needs to be assessed in relation to curriculum requirements, learning objectives, and classroom circumstances. Subsequent learner activity can provide new information for later decisions. This feedback process positions personalization as an ongoing cycle of analysis, pedagogical judgment, implementation, and review rather than as a one-time automated adjustment.

Opportunities, Challenges, and Overall Synthesis

The reviewed literature identifies several potential opportunities associated with AI-supported personalized e-learning. These include adapting educational resources to learner needs, identifying possible learning difficulties, supporting feedback and assessment, assisting teachers with instructional material preparation, and reducing some repetitive administrative tasks. The findings reported in the Moroccan study by Baba et al. (2024) and the meta-synthesis conducted in Türkiye

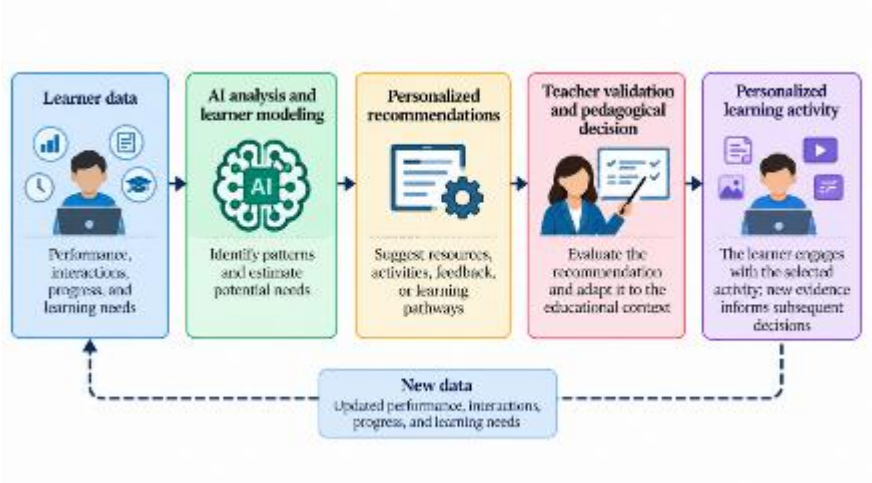


Figure 7 Proposed Conceptual Framework for Teacher-Supported Personalized E-Learning

by Tunç and Baş (2024) illustrate the range of potential benefits investigated in different educational contexts. The study by Seo et al. (2025) further indicates that

teachers' anticipated uses of AI extend beyond direct learner support to curriculum planning, evaluation, and administration.

These opportunities must nevertheless be considered alongside implementation challenges. Personalized recommendations depend on the quality and relevance of the available data, while inaccurate or biased outputs may lead to inappropriate instructional decisions. The collection and analysis of learner information also raise concerns about privacy, data protection, transparency, and accountability. Generative AI introduces additional questions concerning the reliability of generated content and the need to verify its educational accuracy. These concerns are consistent with the emphasis on human oversight and responsible implementation in UNESCO's guidance on generative AI in education and research (UNESCO, 2023).

Table 8 synthesizes the principal opportunities and challenges identified across the reviewed literature. It distinguishes potential educational contributions from the conditions that influence their responsible use.

Table 8. Opportunities and challenges of AI-supported personalized e-learning

Dimension	**Potential opportunities**	**Main challenges**
Learner analysis	Better understanding of learner progress and needs	Incomplete, inaccurate, or biased data
Content and activity adaptation	More relevant resources and differentiated activities	Recommendations may not match learning objectives
Feedback and assessment	Timely feedback and identification of learning gaps	Reliability and validity of AI-generated feedback
Teacher support	Assistance with planning, materials, and administrative tasks	Overreliance on automated outputs
Learning pathways	Flexible sequencing of activities according to progress	Limited transparency in some recommendation processes

Data and governance	Evidence-informed pedagogical decisions	Privacy, data protection, accountability, and ethical concerns

The overall synthesis indicates that AI can support personalized e-learning through complementary functions that connect learner analysis with recommendations, adaptation, and feedback. Its potential contribution to teaching extends beyond content personalization to include instructional preparation, learner monitoring, and the organization of educational activities. However, the reviewed evidence does not justify treating the availability of AI technologies as proof of improved learning outcomes in every context. The effectiveness of a given application depends on its design, the quality of the supporting evidence, its alignment with educational objectives, and the way teachers incorporate its outputs into practice.

Taken together, these findings highlight the need for an approach that connects AI-supported analysis with pedagogical decision-making and the implementation of personalized learning activities. To represent these relationships, this article proposes a conceptual framework for teacher-supported personalized e-learning.

The framework connects learner information, AI-supported analysis, pedagogical recommendation, teacher validation, and the implementation of personalized learning activities within an iterative process. It consists of five interconnected components. The first is learner modeling, which organizes available information about learners, including their learning progress, performance, interaction patterns, and identified difficulties. The second component is AI-supported analysis, through which learner information can be examined to identify potential learning needs and inform personalization. The third component is pedagogical recommendation, which uses the results of this analysis to suggest relevant educational resources, activities, or learning pathways. The fourth component is teacher validation and pedagogical decision-making. At this stage, teachers examine the proposed recommendations in relation to learning objectives, curriculum requirements, and the educational context. The fifth component is personalized learning activity, where the selected adaptations are implemented and the learner engages with the proposed resources or activities.

These components operate within an iterative cycle rather than a strictly linear sequence. Learner interactions and subsequent performance provide new information that can update the learner model and inform later recommendations. This feedback mechanism allows personalization to evolve as learning progresses.

The central characteristic of the proposed framework is the explicit integration of teacher validation between AI-generated recommendations and their educational implementation. AI supports the analysis of learner information and the formulation

of possible adaptations, while teachers retain responsibility for evaluating their pedagogical relevance and deciding whether they are appropriate for a given learning context. As a conceptual contribution, the framework provides a basis for future research investigating its usability, the relevance and reliability of its recommendations, and its potential effects on teaching practices and learning outcomes. These aspects remain to be examined through implementation and empirical evaluation.

CONCLUSION AND PERSPECTIVES

This article examined how Artificial Intelligence can support teachers in personalized e-learning through learner analysis, pedagogical recommendation, content adaptation, and learning monitoring. The analysis indicates that AI offers several possibilities for helping teachers interpret learner-related information, identify potential learning needs, and prepare educational resources adapted to different learning situations. Nevertheless, these possibilities should not be equated with guaranteed improvements in learning outcomes. Their educational value depends on the quality of the available data, the relevance of the recommendations, and their integration into pedagogical practice.

The main contribution of this study is a conceptual framework that connects learner information, AI-supported analysis, teacher decision-making, and personalized learning activities. By explicitly incorporating teacher validation into the personalization process, the framework emphasizes that computational recommendations and pedagogical decisions are related but distinct. AI can provide analytical and generative support, while teachers remain responsible for interpreting the results, assessing the suitability of proposed adaptations, and ensuring their alignment with educational objectives.

The study also highlights several challenges that must be addressed for responsible implementation, including data privacy, algorithmic bias, transparency, the reliability of generated content, and teachers' preparedness to use AI-supported tools. These issues indicate that the development of personalized e-learning environments requires collaboration between educational practitioners, researchers, and technology developers.

A principal limitation of this work is that the proposed framework has not yet been implemented or empirically validated. Future research should therefore focus on developing a prototype and evaluating its practical use in authentic educational settings. Such investigations could assess the relevance of pedagogical recommendations, the usability of the system for teachers, the time required to prepare adapted learning activities, and the potential effects on learner engagement and learning outcomes. Further research could also examine how teacher expertise, educational context, and different forms of learner information influence the personalization process.

In conclusion, Artificial Intelligence should be understood as a means of strengthening teachers' capacity to design and manage personalized learning experiences, rather than as a substitute for their professional judgment. The proposed framework provides a conceptual foundation for future implementation and evaluation, with the broader objective of developing personalized e-learning environments that combine technological capabilities with pedagogical responsibility and attention to individual learners.

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