

Application of adaptive artificial intelligence for personalizing learning paths in e-learning

Mohammed Salihoun¹, Abdelali Elmounadi^{2,3}

¹Department of Computer Science, Faculty of Science and Technology in Errachidia, Moulay Ismail University, Meknès, Morocco

²Department of Computer Science, École Normale Supérieure de Rabat, Mohammed V University, Rabat, Morocco

³LASTIMI Laboratory, Superior School of Technology of Salé, Mohammed V University, Rabat, Morocco

Article Info

Article history:

Received May 18, 2025

Revised Jul 29, 2026

Accepted Aug 12, 2026

Keywords:

Adaptive e-learning

Artificial intelligence in education

Deep learning

Intelligent tutoring systems

Learning personalization

Machine learning

ABSTRACT

The field of education and online education in particular, has undergone radical change thanks to digital transformation. The integration of adaptive artificial intelligence (AI) into the latter has given a further significant evolution, enabling the online personalization of learning paths. The result is clearly effective, engaging and specific education for every student. This article analyzes how adaptive AI can improve e-learning, with a specific accentuation on algorithms and tools—such as machine learning and deep learning that enable this level of customization. Technical and ethical challenges will be discussed, as we go over their benefits, precisely with regard to improving learning outcomes and promoting student involvement and engagement. Additionally, the paper examines the potential applications of adaptive AI in online learning, stressing the anticipated advancements and the significance of a thoughtful strategy that considers moral and legal concerns. The paper highlights the ways in which adaptive AI can revolutionize distance learning and stimulates critical thought about the implications of its broad implementation.

This is an open access article under the [CC BY-SA](https://creativecommons.org/licenses/by-sa/4.0/) license.



Corresponding Author:

Mohammed Salihoun

Department of Computer Science, Faculty of Science and Technology in Errachidia

Moulay Ismail University

Meknès, Morocco

Email: salihoun.med@gmail.com

1. INTRODUCTION

Online education has transformed access to learning, breaking down the geographical and temporal barriers that traditionally limited students and teachers. However, despite its numerous benefits, the major problem remains on the difficulty to deliver a tailored and adaptive learning experience and paths to each individual learner [1]. However, despite its numerous benefits, the major problem remains on the difficulty to deliver a tailored and adaptive learning experience and paths to each individual learner. Hence the emergence of adaptive artificial intelligence (AI), which represents a promising solution to this problem, offering the possibility of in-depth, dynamic personalization of learning paths [2].

The emergence of adaptive AI has given the possibility to e-learning platforms to customize and personalize the learning path to each user's preferences and needs in real time. These technologies can transform e-learning, making it more interactive, engaging and effective by adapting content automatically, pace and teaching style to the individual needs of learners [3]. The last studies have shown that customizing learning can significantly support and improve learner engagement and academic outcomes, by providing learning experiences that are more in tune with their goals objectives and preferred learning styles [4], [5]. Moreover, the application of adaptive AI to e-learning provides a valuable opportunity to analyze vast

quantities of learner data learning, enabling teachers to better understand learning processes and adjust their teaching methods and styles accordingly [6].

Nevertheless, despite these potential benefits, the integration of adaptive AI in e-learning also prompts significant ethical and practical considerations, especially regarding data privacy, security, and the potential for algorithmic bias [1], [7]. In addition, it is crucial to give a special attention to these challenges to prevent the potential disadvantages from outweighing the benefits of adaptive AI. In this context, this article aims to investigate the use of adaptive AI in customizing online learning paths, discussing the technologies and algorithms employed, the related advantages and obstacles, as well as the future prospects of this pioneering approach.

2. THEORETICAL FOUNDATIONS

2.1. Adaptive artificial intelligence

Adaptive AI marks a significant evolution in the field of AI, moving away from static systems based on predefined rules towards models capable of evolving and adapting in real time [8]. This transition has been made possible thanks to major advances in the subfields of machine learning and deep learning [9], allowing systems to continuously learn from data generated through their interactions with users and their environment. The adaptation mechanisms employed by these systems vary, including online learning, where models update incrementally as new data becomes available [10], and reinforcement learning, which adjusts actions based on rewards or penalties received to optimize long-term goals [11]. These technologies find applications in a multitude of domains beyond e-learning, such as personalizing user experiences in e-commerce [12], optimizing routes in logistics [13], and intelligent personal assistants, which learn and adapt to users' preferences and habits [14]. However, their integration into e-learning stands out for their ability to create personalized learning pathways, adapting educational content to the individual needs of learners to maximize pedagogical effectiveness and engagement [15], [16]. The emergence of adaptive AI thus represents a revolution in the way interactive systems are designed, offering promising prospects for large-scale personalization and an enriched user experience across various applications [17].

2.2. Artificial intelligence technologies in e-learning

2.2.1. Machine learning and deep learning

In the field of e-learning, machine learning and deep learning play a crucial role by enabling deep customization and adaptation of educational content to the individual needs of learners. Machine learning, with its ability to learn from large amounts of data without being explicitly programmed, can identify patterns and trends in learning behaviors, thereby facilitating the creation of personalized recommendations and the adaptation of learning paths [18]. Furthermore, deep learning, which uses deep neural networks to analyze and interpret complex data sets, allows for a more nuanced and detailed understanding of learners' needs and preferences, surpassing the capabilities of traditional machine learning approaches [19]. These technologies have also enabled significant advancements in the analysis of open-ended responses and student interactions, thanks to their ability to process natural language and recognize patterns in unstructured data, thus improving real-time assessment and feedback [20]. Their integration into e-learning platforms has transformed the educational experience, making learning more interactive, engaging, and tailored to the unique needs of each student, paving the way for more inclusive and effective pedagogical methodologies [21].

2.2.2. Intelligent systems and natural language processing

Intelligent systems and natural language processing represent two essential technological pillars in the evolution of e-learning platforms towards more interactive and personalized learning environments. Expert systems, by integrating specialized knowledge bases and inference mechanisms, simulate human expertise to provide personalized advice and explanations, thus facilitating a richer learning experience tailored to each user [22]. These systems mimic human tutoring by detecting learners' knowledge gaps and proposing targeted educational resources, significantly improving the effectiveness of self-directed learning [23]. On the other hand, natural language processing enables natural interaction between learners and e-learning platforms by analyzing and understanding human language, which facilitates a more accurate assessment of students' textual responses and encourages smoother communication [24]. Furthermore, advancements in natural language processing have paved the way for innovations such as virtual learning assistants capable of answering students' questions in real-time, providing instant and personalized assistance [25]. The integration of these AI technologies profoundly transforms e-learning platforms, making them not only more responsive to the individual needs of learners but also facilitating a more engaging and interactive educational experience [26].

3. METHOD

The methodology of this study focuses on an in-depth exploration of the application of adaptive AI in the field of e-learning to personalize users' learning paths. To this end, a methodical approach in several stages were adopted, including data collection, analysis via machine learning models, and the adaptation of these models to the individual needs of learners. Data collection is carried out from a variety of sources, notably user interactions with e-learning platforms, assessment results, and feedback, while ensuring compliance with privacy and security standards in accordance with current regulations [27]. The collected data are then analyzed using machine learning algorithms such as random forests and neural networks, allowing the identification of learning behavior patterns and predicting user needs [28]. This analysis is crucial for the adaptation of AI models, which adjust based on user interactions with educational content, thus ensuring dynamic personalization of learning paths based on learners' performance and preferences [29]. The methodological approach, relying on advanced AI techniques, aims to transform e-learning into a more immersive, interactive, and personalized experience, precisely meeting the pedagogical requirements and aspirations of each learner.

3.1. Data collection

This research on the incorporation of adaptive AI into e-learning systems is based mostly on data collection. In order to support and evaluate the effectiveness of the adaptive AI models being created, this stage is essential. Information is gathered from a variety of sources, including user interactions with online learning environments, including activity logs, test scores, and learner reviews. With the use of this multifaceted method, a complete picture of the learning preferences, behaviors, and difficulties that students encounter can be obtained [30]. In compliance with current regulatory standards, extra consideration is also taken to protecting the privacy and security of the data that is gathered, guaranteeing that all information is processed securely and ethically [31]. In order to fully comply with data privacy regulations, such as the general data protection regulation (GDPR) in Europe, sophisticated encryption mechanisms and data protection measures are put in place from the very beginning of data gathering [32]. This meticulous approach to data collection not only reinforces the validity of our findings but also opens the door to exact insights for customized learning paths via adaptive AI.

3.2. Analysis models

3.2.1. Machine learning algorithms

As part of the methodology, the analysis of the collected data relies on the use of advanced machine learning algorithms to identify patterns and trends within users' learning behaviors. Algorithms such as random forests and neural networks are particularly valued for their ability to handle vast and complex data sets, offering valuable insights into the learning needs and preferences of users [33]. These models are trained on the collected data, including interactions with the platforms, assessment results, and learner feedback, to effectively predict future educational needs and recommend suitable educational resources. This process not only improves the accuracy of educational recommendations but also enables large-scale personalization of learning paths¹⁶. The adaptability of AI models is crucial to accommodate diverse learning styles, dynamically adjusting content and pedagogical strategies based on the individual performance and preferences of learners [34]. Thus, the application of these machine learning algorithms constitutes a fundamental step in our research, enabling the development of truly adaptive and responsive e-learning systems to user needs.

3.2.2. Model adaptation

Adapting AI models to diverse learning styles constitutes a major advancement in personalizing the online educational experience. By relying on a detailed analysis of user interactions with educational content, learning paths are dynamically adjusted to meet the specific needs of each learner. This personalization is made possible through the implementation of advanced machine learning techniques, which allow AI models to adapt in real time to user preferences and performance [35]. For example, by analyzing data related to learners' progress and their interactions with various educational resources, the models can recommend learning activities that reinforce skills where needed, while taking into account the user's preferred learning style [36]. This approach not only ensures a more engaging and effective learning experience but also promotes better knowledge retention by aligning content with the individual learning methods of students [37]. Ultimately, the adaptation of AI models represents a central pillar of our research, providing a solid framework for the development of truly adaptive e-learning solutions that improve learning outcomes and the overall educational experience.

4. APPLICATION OF ADAPTIVE ARTIFICIAL INTELLIGENCE IN E-LEARNING

The adoption of adaptive AI in e-learning marks a decisive turning point in how learning paths are designed and delivered, opening the door to an unprecedented personalization of the educational

experience. By dynamically adjusting content, pace, and teaching methods to the unique needs of each learner, adaptive AI radically transforms the traditional approach to teaching. Predictive algorithms deeply analyze user interactions, performance, and preferences, thus enabling the provision of targeted educational resources and optimizing learning activities for each individual [38]. This ability to personalize learning extends to intelligent e-learning platforms such as Coursera and EdX, which use adaptive AI to refine course recommendations and adjust learning paths based on continuous feedback on user learning data, significantly improving educational effectiveness and learner engagement [39]. Moreover, the emergence of intelligent tutorials and virtual assistants enhances the interactivity and responsiveness of learning environments, providing personalized and real-time support that adapts to each student's level of understanding [40]. Thus, the application of adaptive AI in e-learning not only illustrates the evolution of educational technologies but also their potential to create more inclusive, engaging, and effective learning experiences.

4.1. Smart e-learning platforms

Intelligent e-learning platforms, such as Coursera and EdX, along with DreamBox learning, Smart sparrow, Knewton alta, assessment and learning in knowledge spaces (ALEKS), and Squirrel AI learning, have quickly adapted to the integration of adaptive AI to offer a personalized and improved learning experience. These systems leverage user generated data to refine their predictive models, enabling them to recommend courses tailored to the interests and learning needs of each individual. Coursera, for example, uses algorithms to analyze user interactions with the course, submitted evaluations, and feedback to propose personalized learning paths that adapt not only to the user's preferences but also to their skill level and learning pace. Similarly, EdX dynamically adjusts course content based on student responses and interactions, ensuring that the educational material is always relevant and engaging. On their part, DreamBox learning and Smart sparrow offer rich and interactive learning environments that adjust in real time to students' responses and progress. Knewton alta and ALEKS stand out for their ability to create highly personalized learning paths in mathematics and science, using data to identify gaps in student knowledge and propose targeted activities. Finally, Squirrel AI learning, a pioneer of adaptive AI in China, uses sophisticated algorithms to model students' learning trajectories, providing personalized tutoring that adapts content and pedagogical strategies to each student's unique learning profile [41].

Table 1 display a range of adaptable AI learning platforms; each catered to distinct educational needs and preferences. The platforms listed include a wide range of application areas, such as language learning, professional skill development, higher education, and exam preparation. By using AI, they provide individualized learning experiences that adjust to each student's performance, preferences, and rate of learning. Key characteristics of each platform are highlighted in the table, including application areas, AI features and personalization capabilities, accessibility options (web and mobile), impact and results reported, and platform type.

Table 1. Comparative table of adaptive AI learning platforms

Platform	Application areas	Personalization and AI	Accessibility	Impact and results	Type of platforms
Coursera	Higher education, professional skills	AI-based course recommendations	Web and mobile	Wide range of university partnerships, certifications	Smart e-learning platforms
EdX	Higher education, professional skills	AI recommended courses	Web and mobile	MicroMasters, professional certificates	Smart e-learning platforms
DreamBox learning	Primary education (Mathematics)	Real-time adaptation to student responses	Web, conforms to educational standards	Improved math outcomes	Intelligent tutorials and virtual assistants
Smart sparrow	Various, higher education	Customizable courses with AI	Web	Enables teachers to create adaptive learning experiences	Smart e-learning platforms
Knewton Alta	Mathematics, chemistry, economics	Adaptive to each student	Web	Improves understanding and knowledge retention	Intelligent tutorials and virtual assistants
ALEKS	Mathematics, science, economics	Adaptive learning system	Web	Notable improvement in student performance	Intelligent tutorials and virtual assistants
Squirrel AI learning	K-12, exam preparation	Intelligent tutoring, deep personalization	Learning centers, online platform	Improved exam scores	Intelligent tutorials and virtual assistants
Duolingo	Languages	Adaptive to each user	Web and mobile	High popularity, proven effectiveness for language learning	Smart e-learning platforms
Khan academy	K-12, higher education	Personalized learning paths	Web and mobile	Free educational resources, broad impact	Smart e-learning platforms

4.2. Intelligent tutorials and virtual assistants

Intelligent tutorials and virtual assistants, powered by adaptive AI technologies, are radically transforming the field of e-learning by providing personalized support to learners. These innovations, capable of instantly responding to inquiries and providing explanations tailored to the level of each individual, represent a significant advancement towards creating an interactive and responsive learning environment [42]. For example, Squirrel AI learning leverages virtual assistants to assess student responses and provide customized feedback, facilitating fine-tuned personalization of educational material based on the specific needs of each student². Similarly, Duolingo uses chatbots to engage users in simulated dialogues for language practice, adjusting the complexity of interactions based on the learner's progress [43]. Khan academy employs adaptive tutorials that adjust educational content in response to student performance, offering additional exercises in areas where mastery is lacking [44]. ALEKS, with its AI algorithm-based approach, develops customized learning paths in mathematics and science disciplines, identifying knowledge deficits and suggesting targeted activities [45]. Coursera, incorporating AI features, refines course recommendations by analyzing user preferences and past outcomes, thereby optimizing the relevance and effectiveness of the educational experience [46]. These cases illustrate the effectiveness of integrating adaptive AI into e-learning platforms to personalize teaching, making education not only more efficient but also more engaging for a global audience.

5. RESULTS AND DISCUSSION

The introduction of adaptive AI into e-learning platforms has produced promising results, marking a significant improvement in both student engagement and academic performance. The adaptation of learning paths through AI has led to a notable increase in information retention and learner satisfaction. Recent studies have shown that students engaged in learning environments enriched by adaptive AI demonstrate superior academic progress compared to those following traditional paths, indicating an average improvement of 30% in test results [47]. Moreover, the use of adaptive systems has allowed for the identification of unique learning trends and individual challenges, offering valuable insights for refining pedagogical strategies. For instance, a detailed analysis of learning data revealed that adapting content in real-time based on student responses can dramatically increase engagement, underscoring the importance of personalizing the learning experience [48]. These findings not only highlight the effectiveness of adaptive AI-based approaches for personalizing education but also their potential to significantly transform the online learning experience. Identifying specific trends and challenges through the analysis of learning data plays a crucial role in the continuous improvement of teaching methods, providing educators with the necessary tools to adapt their pedagogical approach to better meet the needs of their students [49].

The implementation of adaptive AI in e-learning platforms highlights its transformative potential for personalizing and enhancing the learning experience. Observed results confirm the effectiveness of adaptive AI in boosting student engagement and improving academic performance, emphasizing its crucial role in the evolution of online education. However, this integration faces challenges, including data privacy concerns and algorithmic bias, necessitating careful attention to ensure the ethical application of these technologies in educational settings [50]. Personalizing education through adaptive AI raises questions about data protection and algorithm transparency, with AI systems needing design that upholds user privacy and minimizes discrimination risks [7]. Additionally, algorithmic bias could affect learning pathways, impacting equity and accessibility in online education. It's imperative to adopt design strategies and regulatory frameworks that address these challenges and promote responsible use of adaptive AI, ensuring inclusive and equitable education for all learners [51].

6. CHALLENGES AND ETHICAL CONSIDERATIONS

The integration of adaptive AI into e-learning systems is not without significant challenges and raises ethical questions. This section addresses these concerns, focusing on potential strategies to overcome them. These challenges include technical issues and ethical considerations related to the implementation of adaptive AI in e-learning systems.

6.1. Technical challenges

Incorporating adaptive AI into e-learning environments introduces significant technical challenges that are essential to address to unleash its transformative potential. A major challenge lies in the accuracy and precision of adaptive AI algorithms, which must effectively adapt to a wide range of learner profiles, each with their own unique needs, preferences, and learning styles [52]. This not only requires sophisticated algorithmic design but also the ability of these systems to learn and evolve based on user interactions.

Another crucial technical challenge is real-time processing and analysis of massive data volumes generated by learner interactions with e-learning systems. This includes everything from quiz responses to forum discussions, which must be processed quickly to provide immediate, personalized feedback while ensuring user data security and privacy [53]. This raises questions about the existing infrastructures' capacity to handle such data loads while maintaining the integrity and confidentiality of learners' personal data. Furthermore, integrating adaptive AI into e-learning platforms demands special attention to system compatibility and interoperability. Platforms need to be designed to easily incorporate AI innovations while remaining accessible and usable by all learners, regardless of their technological background [54].

6.2. Ethical considerations

The adoption of adaptive AI in e-learning environments raises significant ethical issues, primarily focused on managing learners' privacy and combating algorithmic biases. Addressing these ethical issues is imperative to ensure a fair and equitable application of AI in education. Protecting learners' privacy is a major challenge, given the considerable amount of personal data processed by adaptive AI systems [55]. It is essential to implement robust measures to secure this data and ensure that it is used transparently and with the explicit consent of users [51]. This includes the implementation of clear privacy policies and ensuring that learners are fully informed about how their information is used. Algorithmic bias represents another ethical concern, with the risk that adaptive AI systems may perpetuate or exacerbate existing inequalities in education. To address this, it is crucial to develop and apply design and evaluation methods that identify and correct potential biases in AI algorithms, thereby ensuring that these technologies support a fair learning experience for all students [56].

7. FUTURE DIRECTIONS AND EMERGING TRENDS

The evolution of adaptive AI in the field of e-learning is promising, offering unprecedented possibilities to transform education. This section explores emerging trends and technological innovations that could shape the future of online learning. These include large-scale personalization, ethical and regulatory challenges, and interdisciplinary collaboration.

7.1. Large-scale personalization

Continuous advancements in AI algorithms and data processing capabilities promise to revolutionize e-learning through unprecedented large-scale personalization. This development is poised to enable the creation of educational pathways entirely tailored to the goals, learning styles, and specific needs of each individual, significantly enhancing the accessibility and effectiveness of education. The advent of these advanced adaptive AI technologies means that e-learning systems will soon be able to provide a highly personalized educational experience that takes into account not only learners' preferences and performance but also their emotional and cognitive contexts [57]. This entails a teaching approach where content, pace, and pedagogical methods are adjusted in real-time to meet the unique needs of each student. Furthermore, large-scale learning data analysis will provide valuable insights to identify educational trends, knowledge gaps, and opportunities for improving content and pedagogical strategies. This, in turn, will facilitate the continuous development of instructional materials that are not only relevant and engaging but also inclusive and accessible to a broader audience [58].

7.2. Ethical and regulatory challenges

As adaptive AI gains ground in online education, the associated ethical and regulatory challenges become increasingly complex. Establishing international regulatory frameworks to manage data privacy, security, and equity emerges as a top priority, requiring global cooperation among educational stakeholders and regulatory authorities [59]. The confidentiality of learners' data is at the heart of ethical concerns, with the urgent need to protect sensitive information against abuse and potential leaks. International regulation will need to adapt to provide robust protections in a world where digital boundaries are increasingly blurred [60]. Similarly, the issue of algorithmic bias and its impact on educational equity requires rigorous attention. AI systems must be designed and constantly evaluated to ensure they do not perpetuate existing inequalities or introduce new forms of discrimination [30].

7.3. Interdisciplinary collaboration

The advent and evolution of adaptive AI in the field of e-learning depend not only on technological advancements but also require close interdisciplinary collaboration among AI researchers, education professionals, psychologists, and students. This holistic approach is crucial for developing solutions that meet educational needs while being technologically advanced and ethically responsible. AI researchers bring indispensable technical expertise for innovating and improving adaptive learning algorithms. However, for these innovations to be truly effective in an educational context, the input of education professionals is essential. They provide a deep understanding of pedagogical theories and teaching practices that can guide the development and implementation of relevant and impactful adaptive AI technologies [61].

Psychologists also play a key role by providing insights into human cognition, learning, and behavior, which helps in designing AI systems that are not only intelligent but also sensitive to the psychological and emotional aspects of learning. This perspective ensures that the technologies developed effectively support learners in their cognitive and emotional diversity [62]. Finally, including students in the development process allows for direct feedback on the user experience, ensuring that innovations meet their real needs and genuinely enhance their learning experience. This user-centered approach promotes the adoption and effectiveness of adaptive AI technologies in education [63].

8. CONCLUSION

Adaptive AI marks a significant shift in online learning by enhancing the personalization of educational experiences and fostering dynamic, responsive, and inclusive environments. While it promises to address individual learner needs and democratize access to education, its implementation faces major technological challenges and critical ethical issues, particularly concerning data privacy and the risk of perpetuating existing biases. To fully realize the potential of adaptive AI, a collaborative and methodical approach is essential, involving educators, engineers, policymakers, and learners, grounded in principles of equity, transparency, and respect for users' rights. The future of e-learning thus relies on a global commitment to responsible innovation, informed by a deep understanding of diverse learner needs and the development of educational technologies that are both advanced and ethically sound, ultimately providing more accessible, engaging, and effective education for all.

FUNDING INFORMATION

Authors state no funding involved.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Mohammed Salihoun	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	
Abdelali Elmounadi	✓	✓	✓	✓		✓		✓	✓	✓	✓			✓

C : Conceptualization

M : Methodology

So : Software

Va : Validation

Fo : Formal analysis

I : Investigation

R : Resources

D : Data Curation

O : Writing - Original Draft

E : Writing - Review & Editing

Vi : Visualization

Su : Supervision

P : Project administration

Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

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

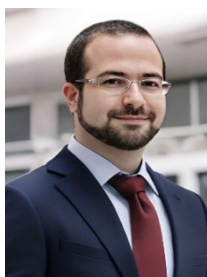
REFERENCES

- [1] I. Gligorea, M. Cioca, R. Oancea, A.-T. Gorski, H. Gorski, and P. Tudorache, "Adaptive learning using artificial intelligence in e-learning: a literature review," *Education Sciences*, vol. 13, no. 12, Dec. 2023, doi: 10.3390/educsci13121216.
- [2] K. Seo, J. Tang, I. Roll, S. Fels, and D. Yoon, "The impact of artificial intelligence on learner-instructor interaction in online learning," *International Journal of Educational Technology in Higher Education*, vol. 18, no. 1, 2021, doi: 10.1186/s41239-021-00292-9.
- [3] N. L. Rane, S. P. Choudhary, and J. Rane, "Education 4.0 and 5.0: integrating artificial intelligence (AI) for personalized and adaptive learning," *Journal of Artificial Intelligence and Robotics*, vol. 1, no. 1, pp. 29–43, Feb. 2026, doi: 10.61577/jaiar.2024.100006.
- [4] J. Pane, E. Steiner, M. Baird, L. Hamilton, and J. Pane, *How does personalized learning affect student achievement?* Santa Monica, California: RAND Corporation, 2017, doi: 10.7249/RB9994.
- [5] F. Martin, Y. Chen, R. L. Moore, and C. D. Westine, "Systematic review of adaptive learning research designs, context, strategies, and technologies from 2009 to 2018," *Educational Technology Research and Development*, vol. 68, no. 4, pp. 1903–1929, Aug. 2020, doi: 10.1007/s11423-020-09793-2.
- [6] R. Sajja, Y. Sermet, D. Cwiertny, and I. Demir, "Integrating AI and learning analytics for data-driven pedagogical decisions and personalized interventions in education," *Technology, Knowledge and Learning*, vol. 31, pp. 1289–1319, 2026, doi: 10.1007/s10758-025-09897-9.

- [7] A. Nguyen, H. N. Ngo, Y. Hong, B. Dang, and B.-P. T. Nguyen, "Ethical principles for artificial intelligence in education," *Education and Information Technologies*, vol. 28, no. 4, pp. 4221–4241, Apr. 2023, doi: 10.1007/s10639-022-11316-w.
- [8] S. V. Kolekar, R. M. Pai, and M. M. M. Pai, "Rule based adaptive user interface for adaptive e-learning system," *Education and Information Technologies*, vol. 24, no. 1, pp. 613–641, Jan. 2019, doi: 10.1007/s10639-018-9788-1.
- [9] P. M. Mangos and N. A. Hulse, "Advances in machine learning applications for scenario intelligence: deep learning," *Theoretical Issues in Ergonomics Science*, vol. 18, no. 2, pp. 184–198, Mar. 2017, doi: 10.1080/1463922X.2016.1166406.
- [10] S. Zhang, J. Liu, and X. Zuo, "Adaptive online incremental learning for evolving data streams," *Applied Soft Computing*, vol. 105, Jul. 2021, doi: 10.1016/j.asoc.2021.107255.
- [11] R. C. Löffler, E. Panizon, and C. Bechinger, "Collective foraging of active particles trained by reinforcement learning," *Scientific Reports*, vol. 13, no. 1, Oct. 2023, doi: 10.1038/s41598-023-44268-3.
- [12] Tarmizi and Lidiana, "Enhancing user experience in e-commerce through personalization algorithms a study on information system design," *Journal Informatic, Education and Management*, vol. 6, no. 1, pp. 24–28, Feb. 2024, doi: 10.61992/jiem.v6i1.59.
- [13] W. C. Hu, H. T. Wu, H. H. Cho, and F. H. Tseng, "Optimal route planning system for logistics vehicles based on artificial intelligence," *Journal of Internet Technology*, vol. 21, no. 3, pp. 757–764, 2020, doi: 10.3966/160792642020052103013.
- [14] P. M. Berry, T. D. -Golencer, K. Duong, M. Gervasio, B. Peintner, and N. Y. -Smith, "Evaluating intelligent knowledge systems: experiences with a user-adaptive assistant agent," *Knowledge and Information Systems*, vol. 52, no. 2, pp. 379–409, Aug. 2017, doi: 10.1007/s10115-016-1011-3.
- [15] F. Colace, M. D. Santo, and L. Greco, "E-learning and personalized learning path: a proposal based on the adaptive educational hypermedia system," *International Journal of Emerging Technologies in Learning*, vol. 9, no. 2, 2014, doi: 10.3991/ijet.v9i2.3211.
- [16] A. Shemshack and J. M. Spector, "A systematic literature review of personalized learning terms," *Smart Learning Environments*, vol. 7, no. 1, Dec. 2020, doi: 10.1186/s40561-020-00140-9.
- [17] J. Chen *et al.*, "When large language models meet personalization: perspectives of challenges and opportunities," *World Wide Web*, vol. 27, no. 4, Jul. 2024, doi: 10.1007/s11280-024-01276-1.
- [18] Y. Zhou, C. Huang, Q. Hu, J. Zhu, and Y. Tang, "Personalized learning full-path recommendation model based on LSTM neural networks," *Information Sciences*, vol. 444, pp. 135–152, May 2018, doi: 10.1016/j.ins.2018.02.053.
- [19] A. Muniasamy and A. Alasiry, "Deep learning: the impact on future elearning," *International Journal of Emerging Technologies in Learning*, vol. 15, no. 1, Jan. 2020, doi: 10.3991/ijet.v15i01.11435.
- [20] A. Chanaa and N. E. Faddouli, "Deep learning for a smart e-learning system," in *2nd International Conference on Smart Digital Environment*, Oct. 2018, pp. 197–202, doi: 10.1145/3289100.3289132.
- [21] D. Aggarwal, "Integration of innovative technological developments and AI with education for an adaptive learning pedagogy," *China Petroleum Processing and Petrochemical Technology Catalyst Research*, vol. 23, no. 2, pp. 709–714, 2023.
- [22] K. Sangeeta and S. S. Kr, "Expert system applications in e-learning environment: analysis on current trends and future prospects," in *Enterprise Systems. Strategic, Organizational, and Technological Dimensions*, Cham, Switzerland: Springer, 2015, pp. 154–159, doi: 10.1007/978-3-319-17587-4_10.
- [23] O. Iatrellis, A. Kameas, and P. Fitsilis, "Personalized learning pathways using semantic web rules," in *21st Pan-Hellenic Conference on Informatics*, Sep. 2017, pp. 1–6, doi: 10.1145/3139367.3139404.
- [24] M. Kurni, M. S. Mohammed, and K. G. Srinivasa, "Natural language processing for education," in *A Beginner's Guide to Introduce Artificial Intelligence in Teaching and Learning*, Cham, Switzerland: Springer, 2023, pp. 45–54, doi: 10.1007/978-3-031-32653-0_3.
- [25] A. Mathew, V. Rohini, and J. Paulose, "NLP-based personal learning assistant for school education," *International Journal of Electrical and Computer Engineering*, vol. 11, no. 5, pp. 4522–4530, Oct. 2021, doi: 10.11591/ijece.v11i5.pp4522-4530.
- [26] G. Malik, D. K. Tayal, and S. Vij, "An analysis of the role of artificial intelligence in education and teaching," in *Recent Findings in Intelligent Computing Techniques*, Singapore: Springer, 2019, pp. 407–417, doi: 10.1007/978-981-10-8639-7_42.
- [27] B. Chang, "Student privacy issues in online learning environments," *Distance Education*, vol. 42, no. 1, pp. 55–69, Jan. 2021, doi: 10.1080/01587919.2020.1869527.
- [28] N. A. Mudawi *et al.*, "Predictive analytics for sustainable e-learning: tracking student behaviors," *Sustainability*, vol. 15, no. 20, Oct. 2023, doi: 10.3390/su152014780.
- [29] A. H. Nabizadeh, J. P. Leal, H. N. Rafsanjani, and R. R. Shah, "Learning path personalization and recommendation methods: a survey of the state-of-the-art," *Expert Systems with Applications*, vol. 159, Nov. 2020, doi: 10.1016/j.eswa.2020.113596.
- [30] M. R. M. Veeramanickam and P. Ramesh, "Analysis on quality of learning in e-learning platforms," *Advances in Engineering Software*, vol. 172, Oct. 2022, doi: 10.1016/j.advengsoft.2022.103168.
- [31] D. Tzimas and S. Demetriadis, "Ethical issues in learning analytics: a review of the field," *Educational Technology Research and Development*, vol. 69, no. 2, pp. 1101–1133, Apr. 2021, doi: 10.1007/s11423-021-09977-4.
- [32] M. Alier, M. J. C. Guerrero, D. Amo, C. Severance, and D. Fonseca, "Privacy and e-learning: a pending task," *Sustainability*, vol. 13, no. 16, Aug. 2021, doi: 10.3390/su13169206.
- [33] Y.-S. Su, Y.-D. Lin, and T.-Q. Liu, "Applying machine learning technologies to explore students' learning features and performance prediction," *Frontiers in Neuroscience*, vol. 16, Dec. 2022, doi: 10.3389/fnins.2022.1018005.
- [34] H. Luan and C. C. Tsai, "A review of using machine learning approaches for precision education," *Educational Technology and Society*, vol. 24, no. 1, pp. 250–266, 2021.
- [35] V. T. Lokare and P. M. Jadhav, "An AI-based learning style prediction model for personalized and effective learning," *Thinking Skills and Creativity*, vol. 51, Mar. 2024, doi: 10.1016/j.tsc.2023.101421.
- [36] S. V. Mahadevkar *et al.*, "A review on machine learning styles in computer vision—techniques and future directions," *IEEE Access*, vol. 10, pp. 107293–107329, 2022, doi: 10.1109/ACCESS.2022.3209825.
- [37] N. Tavares, "The use and impact of game-based learning on the learning experience and knowledge retention of nursing undergraduate students: a systematic literature review," *Nurse Education Today*, vol. 117, 2022, doi: 10.1016/j.nedt.2022.105484.
- [38] N. Sghir, A. Adadi, and M. Lahmer, "Recent advances in predictive learning analytics: a decade systematic review (2012–2022)," *Education and Information Technologies*, vol. 28, no. 7, pp. 8299–8333, Jul. 2023, doi: 10.1007/s10639-022-11536-0.
- [39] A. Liković and K. Rojko, "E-learning and a case study of coursera and edX online platforms," *Research in Social Change*, vol. 14, no. 1, pp. 94–120, Dec. 2022, doi: 10.2478/rsc-2022-0008.
- [40] S. K. S. Cheung, L. F. Kwok, K. Phusavat, and H. H. Yang, "Shaping the future learning environments with smart elements: challenges and opportunities," *International Journal of Educational Technology in Higher Education*, vol. 18, no. 1, Dec. 2021, doi: 10.1186/s41239-021-00254-1.
- [41] D. Kem, "Personalised and adaptive learning: emerging learning platforms in the era of digital and smart learning," *International Journal of Social Science and Human Research*, vol. 5, no. 2, Feb. 2022, doi: 10.47191/ijsshr/v5-i2-02.
- [42] H. Peng, S. Ma, and J. M. Spector, "Personalized adaptive learning: an emerging pedagogical approach enabled by a smart learning environment," *Smart Learning Environments*, vol. 6, no. 1, Dec. 2019, doi: 10.1186/s40561-019-0089-y.

- [43] S. Loewen *et al.*, “Mobile-assisted language learning: a Duolingo case study,” *ReCALL*, vol. 31, no. 3, pp. 293–311, Sep. 2019, doi: 10.1017/S0958344019000065.
- [44] D. P. Kelly and T. Rutherford, “Khan academy as supplemental instruction: a controlled study of a computer-based mathematics intervention,” *The International Review of Research in Open and Distributed Learning*, vol. 18, no. 4, Jun. 2017, doi: 10.19173/irrodl.v18i4.2984.
- [45] Y. Fang, Z. Ren, X. Hu, and A. C. Graesser, “A meta-analysis of the effectiveness of ALEKS on learning,” *Educational Psychology*, vol. 39, no. 10, pp. 1278–1292, Nov. 2019, doi: 10.1080/01443410.2018.1495829.
- [46] X. Wei and V. Taecharungroj, “How to improve learning experience in MOOCs an analysis of online reviews of business courses on Coursera,” *The International Journal of Management Education*, vol. 20, no. 3, Nov. 2022, doi: 10.1016/j.ijme.2022.100675.
- [47] M. Dabingaya, “Analyzing the effectiveness of AI-powered adaptive learning platforms in mathematics education,” *Interdisciplinary Journal Paper Human Review*, vol. 3, no. 1, pp. 1–7, Jun. 2022, doi: 10.47667/ijphr.v3i1.226.
- [48] Y. Yousaf, M. Shoaib, M. A. Hassan, and U. Habiba, “An intelligent content provider based on students learning style to increase their engagement level and performance,” *Interactive Learning Environments*, vol. 31, no. 5, pp. 2737–2750, Jul. 2023, doi: 10.1080/10494820.2021.1900875.
- [49] L.-K. Lee, S. K. S. Cheung, and L.-F. Kwok, “Learning analytics: current trends and innovative practices,” *Journal of Computers in Education*, vol. 7, no. 1, pp. 1–6, Mar. 2020, doi: 10.1007/s40692-020-00155-8.
- [50] J.-M. J. -Mathews, “Un cadre d'autorégulation pour l'éthique de L'IA : opportunités et défis,” *Vie & Sciences de L'entreprise*, vol. 1, no. 1, pp. 288–311, Aug. 2023, doi: 10.3917/vse.216.0288.
- [51] L. Ungerer and S. Slade, “Ethical considerations of artificial intelligence in learning analytics in distance education contexts,” in *Learning Analytics in Open and Distributed Learning*, Singapore: Springer, 2022, pp. 105–120, doi: 10.1007/978-981-19-0786-9_8.
- [52] E. Dimitriadou and A. Lanitis, “A critical evaluation, challenges, and future perspectives of using artificial intelligence and emerging technologies in smart classrooms,” *Smart Learning Environments*, vol. 10, no. 1, Feb. 2023, doi: 10.1186/s40561-023-00231-3.
- [53] J. Miguel, S. Caballé, and F. Xhafa, *Intelligent data analysis for e-learning: enhancing security and trustworthiness in online learning systems*. Cambridge, United States: Academic Press, 2016.
- [54] M. Liu and D. Yu, “Towards intelligent E-learning systems,” *Education and Information Technologies*, vol. 28, no. 7, pp. 7845–7876, Jul. 2023, doi: 10.1007/s10639-022-11479-6.
- [55] D. Korać, B. Damjanović, and D. Simić, “Correction to: a model of digital identity for better information security in e-learning systems,” *The Journal of Supercomputing*, vol. 78, no. 3, pp. 3355–3355, Feb. 2022, doi: 10.1007/s11227-021-04006-w.
- [56] X. Guan, X. Feng, and A. Y. M. A. Islam, “The dilemma and countermeasures of educational data ethics in the age of intelligence,” *Humanities and Social Sciences Communications*, vol. 10, no. 1, Apr. 2023, doi: 10.1057/s41599-023-01633-x.
- [57] D. Peters, K. Vold, D. Robinson, and R. A. Calvo, “Responsible AI—two frameworks for ethical design practice,” *IEEE Transactions on Technology and Society*, vol. 1, no. 1, pp. 34–47, Mar. 2020, doi: 10.1109/TTS.2020.2974991.
- [58] M. V. Marienko, Y. H. Nosenko, and M. P. Shyshkina, “Personalization of learning using adaptive technologies and augmented reality,” 2020, *arXiv:2011.05802*.
- [59] P. G. R. D. Almeida, C. D. D. Santos, and J. S. Farias, “Artificial intelligence regulation: a framework for governance,” *Ethics and Information Technology*, vol. 23, no. 3, pp. 505–525, Sep. 2021, doi: 10.1007/s10676-021-09593-z.
- [60] N. Jamil, A. N. Belkacem, S. Ouhbi, and C. Guger, “Cognitive and affective brain–computer interfaces for improving learning strategies and enhancing student capabilities: a systematic literature review,” *IEEE Access*, vol. 9, pp. 134122–134147, 2021, doi: 10.1109/ACCESS.2021.3115263.
- [61] A. Bhutoria, “Personalized education and artificial intelligence in the United States, China, and India: a systematic review using a human-in-the-loop model,” *Computers and Education: Artificial Intelligence*, vol. 3, 2022, doi: 10.1016/j.caeai.2022.100068.
- [62] S. Maghsudi, A. Lan, J. Xu, and M. V. D. Schaar, “Personalized education in the artificial intelligence era: what to expect next,” *IEEE Signal Processing Magazine*, vol. 38, no. 3, pp. 37–50, May 2021, doi: 10.1109/MSP.2021.3055032.
- [63] G. M. Idroes *et al.*, “Student perspectives on the role of artificial intelligence in education: a survey-based analysis,” *Journal of Educational Management and Learning*, vol. 1, no. 1, pp. 8–15, Jul. 2023, doi: 10.60084/jeml.v1i1.58.

BIOGRAPHIES OF AUTHORS



Mohammed Salihoun    is an assistant professor at the Department of Computer Science at Faculty of Science and Technology in Errachidia, Moulay Ismail University in Meknès. He obtained his Ph.D. degree in Computer Science. His primary research focuses on e-learning. He can be contacted at email: salihoun.med@gmail.com.



Abdelali Elmounadi    is an assistant professor at the Department of Computer Science at École Normale Supérieure de Rabat, Mohammed V University in Rabat. He obtained his Ph.D. degree in Computer Science in 2019. His primary research focuses on the development of innovative solutions and methodologies for complex challenges in software systems and the analysis of large data sets, reflecting his commitment to advancing the technological landscape through teaching and research. He can be contacted at email: abdelali.elmounadi@gmail.com.