International Journal of Applied Resilience and Sustainability, Volume 2, Issue 3, May 2026, pp. 142-175

Published online at Deep Science

International Journal of Applied Resilience and Sustainability

Journal homepage: https://deepscipub.com/ijars

Adoption of artificial intelligence in teaching and teacher professional development: Pedagogical impacts, ethical risks, and challenges

Rabi Bara'u

Federal College of Education, Zaria

Article Info:
Received 02 January 2026
Revised 15 April 2026
Accepted 25 April 2026
Published 07 May 2026

Corresponding Author:
Rabi Bara'u
E-mail: baraurabiat@fcezaria.edu.ng

Abstract

Artificial Intelligence in Education has led to the emergence of the pressing necessity to comprehend the implementation of AI in pedagogy and educator professional growth with references to its effects on pedagogy, ethical issues, as well as systemic concerns. The current work uses the PRISMA framework to conduct a systematic review of the newest literature on the subject of Generative AI in Teaching, AI Adoption in Education, and Teacher Professional Development with an emphasis placed on the emerging trends of AI-supported instruction, personalized learning systems, and educator AI literacy. With an overview indicative of growth in integration of AI in educational settings through technological progression in adaptive learning systems, intelligent tutoring systems and AI-enabled curriculum design as well as rising institutional investment in digital pedagogical change, the review outlines a stark rise in the pace of AI integration in education. The study methodology combine Technology Acceptance Model and Unified Theory of Acceptance and Use of Technology to determine teacher adoption behaviors. The results indicate that AI increases instruction effectiveness, AI-based assessment, and facilitates data-driven teaching with learning analytics, as well as transforms the role of a teacher into an instructor with reduced control and collaboration with AI. Nevertheless, the review suggests key obstacles such as insufficient training and upskilling of the teachers, biased access to professional learning ecosystems, and the gaps in AI governance in schools. The sustainable AI integration should be based on a balance which will integrate technology innovation with the aims of pedagogy, ethical AI in educating and inclusive digital equity in adopting AI.

Keywords: Generative AI, Teaching, Artificial intelligence, Teacher professional development, Technology acceptance model, Personalized learning.

1. Introduction

AI in Education has become one of the most disruptive phenomena in modern settings of teaching and learning. Several prompt developments in Generative AI in Teaching, such as lesson planning, assessment design, personalized feedback, content creation and classroom management, have heightened the uptake of AI in schools, colleges, and universities [1-3]. The schools are increasingly implementing AI-facilitated education, smart tutor tools, adaptive learning, as well as AI-based evaluation to help improve both learning and teaching. Recent trends show that the use of AI in education is now advancing more rapidly than the historic stages of educational technology use, with a large number of educational organizations already incorporating the use of generative AI into their everyday routines and workflows of teachers. Meanwhile, the continued deepening of the role of AI in curriculum design and learning analytics is transforming the conventional way of teachers as content deliverers to facilitators, mentors, and reinventers of learning experiences. This shift in general indicates a general trend towards the digital transformation of pedagogy and points to the increasing significance of addressing the issue of AI as it will influence both the practice of teaching and the overall development of teachers.

https://doi.org/10.70593/deepsci.0203006

The increased topicality of Teacher Professional Development in the era of AI is especially relevant since AI utilization efficiency greatly relies on the level of competence, attitude, and willingness of teachers to interact with new tools. AI literacy among educators is even considered a fundamental skill, alongside data literacy, critical thinking and digital fluency. Human-AI Collaboration in Education, prompt design, AI ethics, and workflow automation are also starting to be trained in professional learning ecosystems to empower teachers in using AI not merely as a technical aid, but as a pedagogical collaborator as well. Yet, technological innovation has frequently exceeded the creation of sufficient teacher training programs that have created a disconnect between the availability of AI and the input of teachers to utilize these technologies effectively and responsibly. Research findings indicate that there are still no well-organized AI-related professional development opportunities to many teachers, despite the growing number of requests and needs of AI education in K-12 and higher education environments. The lack of balance between technological innovation and teacher preparedness has thus come to be one of the most urgent issues in the future of teaching with AI.

In spite of the significant advantages of AI in terms of personalization of instruction, efficiency of administration, and student involvement, the implementation of AI presents some serious pedagogical, ethical, and even institutional risks. Other concerns that made ethical AI in Education a significant issue are algorithmic bias in education, data privacy in educational AI, lack of transparency in AI-generated outputs, and growing concerns about academic integrity and AI [2]. Artificial intelligence that learns on skewed datasets can perpetuate the current imbalances, especially among disadvantaged students and low-resource schools. Likewise, the application of predictive analytics, automated grading systems, and technologies based on surveillance calls into question the issues of fairness, accountability, and teacher agency. Some worries about the possible over-dependence on AI have also also emerged and recent data has indicated that the overuse of AI can also undermine critical thinking, innovation as well as the capacity to solve problems independently. Furthermore, many people have the concern that AI might be a part of the deprofessionalization process where teachers might be heavily reliant on automated tools to make decisions, on planning, and on assessment. Such ethical risks demonstrate the necessity of AI regulation in schools and more efficient systems of responsible and fair AI implementation.

The existing body of literature is indicative of a high level of interest in the field of AI Adoption in Education, but there are also several critical gaps in the literature. Previous literature has been notoriously overly specific on one aspect or the other: on technical uses of AI, or on a single instance of classroom use, whereas less emphasis has been placed on whether such implementation has more or less pedagogical consequences, an expansion in teacher professional growth, or the ethical hazards posed by such implementation, or even better the institutional preparedness to adopt AI. Moreover, numerous works also focus on the short-term impacts instead of long-term effects of AI on teacher identity, teacher agency and AI, and sustainability of digital transformation in education. The research investigating the role of theoretical models that can be utilized to explain the teacher adoption behaviors in various learning settings is also limited with regard to considering the theoretical models like the Technology Acceptance Model and the Unified Theory of Acceptance and Use of Technology. The new body of literature indicate that educators strike intricate conflicts between what feels useful, ethical issues, institutional policy, and professional ethics and decide which and how AI tools should be implemented. This implies that the use of AI is not merely a technology but a socio-technical and pedagogical phenomenon that is influenced by a variety of related factors.

It is against this background that the current literature review aims at exploring the use of Artificial Intelligence in instruction and Teacher Professional Development through the lens of three interrelated perspectives: pedagogical consequences, ethical threats, and obstacles of implementation. The purpose of the review is to provide the synthesis of the emerging evidence on the role of AI-supported instruction, personalized learning systems, AI-enabled curriculum design, and professional learning ecosystems as well as critically discuss the barriers, including digital inequality, the lack of training, absence of policy directives, resistance to change [2,4,5]. Combining the Ethical AI in Education, Human-AI Collaboration in Education, and AI Governance in Schools conversations, the current paper adds to the existing body of literature on the future of AI-assisted instruction and offers an in-depth idea of how schools can design sustainable, fair, and humanistic solutions to the adoption of AI. Further

predictions of the potential response of teachers, policymakers, and institutions to the challenges and opportunities presented by AI technologies that are rapidly developing in the field of education are also provided by the study

2. Methodology

The literature review adhered to the guidelines of Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) 2020 to be transparent, replicable, and rigorous synthesis of the available research on adoption of artificial intelligence in the field of teaching and teacher professional development with particular focus on pedagogical effects, ethical risks, and challenges. Four large academic databases were searched systematically – Scopus, Web of Science, IEEE Xplore and PubMed and included publications since January 2019 up to December 2025, a timeframe chosen to reflect the rapid pace of AI integration in education since the advent of large language models and adaptive learning systems.

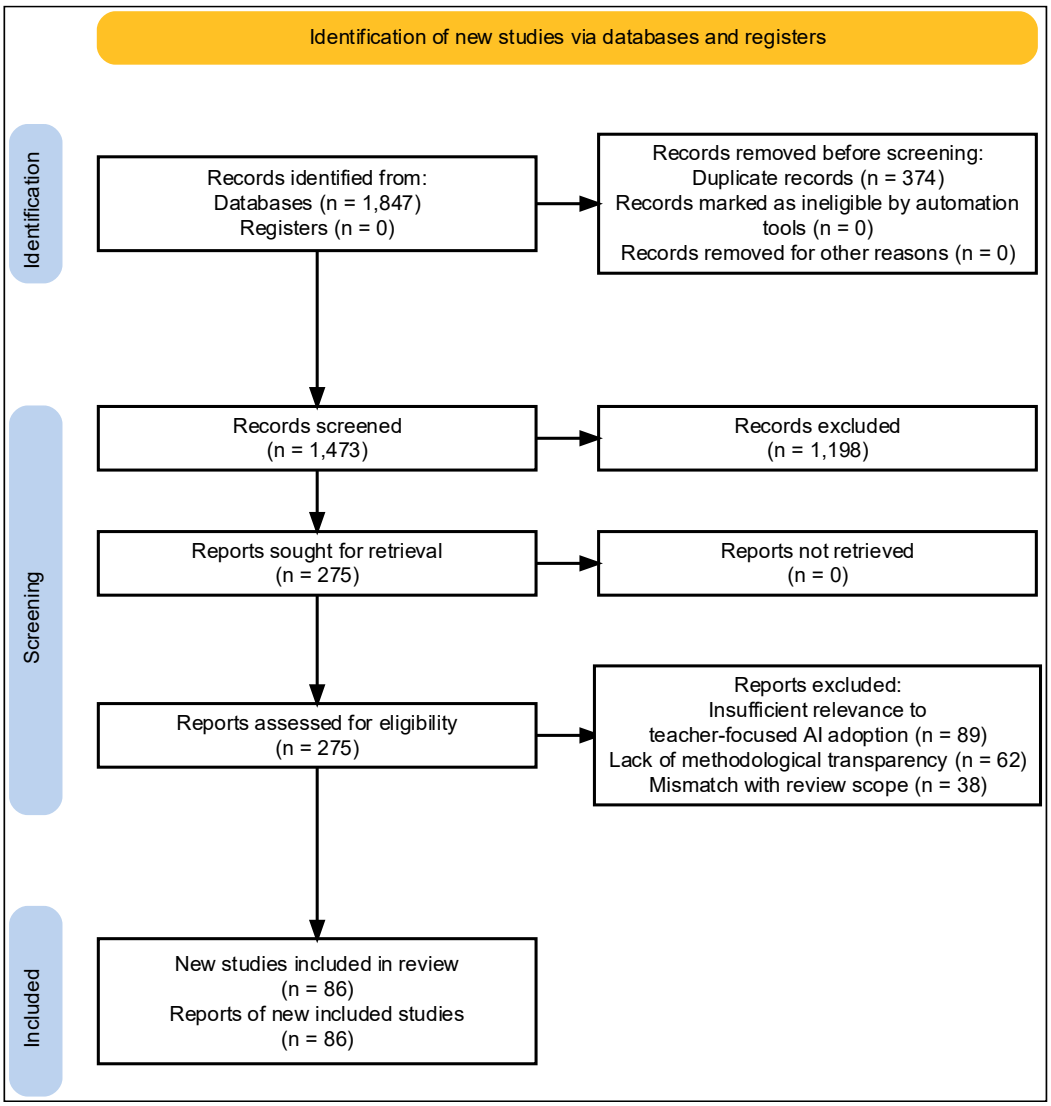

Fig. 1 PRISMA Framework

The Boolean search terms used were formulated with care to maximize recall without significantly reducing the precision to: ("artificial intelligence" OR "AI" OR "machine learning" OR "deep learning" OR "generative AI" OR "large language models" OR "ChatGPT") AND ("teaching" OR "instruction" OR "pedagogy" OR "classroom" OR "higher education" OR "K-12") AND ("teacher professional development" OR "faculty development" OR "teacher training" OR "educator upskilling") AND ("pedagogical impact" OR "learning outcomes" OR "instructional design" OR "teaching practice")

AND ("ethical risks" OR "algorithmic bias" OR "data privacy" OR "digital equity" OR "AI ethics" OR "challenges" OR "barriers"). The studies were dropped when they had worked on student-facing AI tools only but not on teacher roles, were published as editorials, opinion others, or grey literature with lack of methodological rigor, looked at non-educational AI tools, or were duplicated. The original database search provided a total of 1,847 records (Scopus: 612, Web of Science: 498, IEEE Xplore: 431, PubMed: 306), of which 374 of them were duplicate records, leaving 1,473 records to be screened by title and abstract, and 1,198 records that failed to meet the inclusion The rest of the 275 full-text reports were evaluated as eligible, and 189 were eliminated because of a lack of relevance with regard to the topic of teacher-focused AI adoption, lack of methodological clarity, or their irrelevance to the scope of the review, leaving 86 eligible studies that were the subject of thematic synthesis and quality appraisal.

3. Results and discussions

3.1 Artificial intelligence techniques

Machine Learning in Education

Machine Learning in Education is one of the pillar AI methods that aid AI Adoption in Education as well as Teacher Professional Development. Machine learning is the term used to describe algorithms that can recognize the patterns in learning data, provide predictions and, in addition, enhance their performance without specifically being coded to perform every instructional task. In the educational setting, machine learning models have found more applications to study student engagement, provide academic performance forecasts, recognize students at risk, and customize teaching instructions. Supervised learning methods, such as decision trees, random forests, support vector machines, and logistic regression are commonly used in schools to categorize student performance and prescribe measures. Students are grouped in unsupervised learning methods like clustering and association rule mining which group students based on learning behavior, performance patterns and participation patterns. The reinforcement learning is also starting to appear in adaptive learning technology where AI systems repeatedly advance the instructional pathways on the basis of student feedback and behavior.

The application of machine learning to Teacher Professional Development is especially important as it enables educators to make sense of learning analytics and use it to make data-driven pedagogical choices. The machine learning systems can assist the teachers to know the areas where the students lack in their understanding, and to set them unique assignments and identify those students who might need extra help. Professional Learning Ecosystems are also supported by these techniques where teachers are automatically informed on the effectiveness of instruction and classroom performance. Nevertheless, issues of transparency, the overreliance of teachers on predictive systems, and the necessity of Explainable AI in Education are a concern. Lack of proper AI Literacy among Educators means that machine learning tools will be misinterpreted and used improperly, resulting in misjudging the tools and increasing Algorithmic Bias in Education.

Deep Learning in Education

Deep Learning in Education has been gaining more sway with more advanced educational institutions utilizing more advanced types of Artificial Intelligence in Education. Deep learning denotes the class of neural network architectures that are capable of handling complicated and big-sized educational data [6-8]. Such systems come with their own special application in image recognition, speech recognition, automated testing, and content creation. In education, Convolutional Neural Networks are applied to visual visual processing, whereas Recurrent Neural Networks and Transformer-based networks are both common in sequential learning models like language generation and predictive modeling. The advent of deep learning has greatly contributed to Digital Pedagogical Transformation since it allows providing more sophisticated personalization and automation. As an illustration, deep learning systems can implicitly learn the emotional signals in the facial expression, voice recognition in a classroom conversation, and customize learning resources depending on the level of student participation. In Teacher Professional Development, deep learning can facilitate the development of customized teacher training modules, through the analysis of instructional behaviors of educators and proposing

professional learning tools related to them. Although it has potential, deep learning brings up crucial issues of interpretability, data privacy, and ethical responsibility. Numerous deep learning systems can be treated as black boxes, which means that teachers can hardly have access to the information on how choices are produced. The challenge identifies the increasing significance of Explainable AI in Education as well as the necessity of AI Governance in Schools.

Natural Language Processing in Education

Natural Language Processing in Education is one of the fastest growing AI methods as the text-based learning platforms gain popularity, Generative AI in Teaching emerges, and conversational learning environments develop. Natural Language Processing helps AI systems to decode, compose, and react to human language. This method finds more and more applications in essay marking, automatic feedback tools, language learning applications, plagiarism detection, and analysis in classroom discussions. Multilingual education may also be aided by Natural Language Processing translating materials, breaking down challenging content, and increasing the user-friendliness of learning materials to different learners. In the case of teachers, Natural Language Processing has become a useful resource in alleviating workload and enhancing teaching efficiency. Artificial intelligence has the potential to summarize the discussion of students, create lesson plans, scan, and produce assessments, as well as commentary on written pieces. Such tools enable teachers to pay more attention to mentorship and development of critical thinking and individual work with students. In Teacher Professional Development, Natural Language Processing can be used as an aid in reflective teaching to analyze transcripts of lessons, reveal patterns of communication and propose ways to improve the language of teaching results. Nevertheless, with the popularization of Natural Language Processing, the question of Academic Integrity and AI, the credibility of AI-produced feedback, and the potential of producing biased and untruthful material also emerges.

Large Language Models in Education

The Future of Teaching with AI has become one of the most disruptive innovations in the form of Large Language Models in Education. Transformer-inspired models can produce human-like text, respond to questions, create learning materials, and facilitate interactive learning experiences [9,10]. LLMs are being used more and more to make AI Chatbots for Learning, virtual teaching assistants and as productivity tools by teachers. They are able to create lesson plans, create quizzes, discuss complex matters and real-time tutoring assistance. It is also essential that Large Language Models should be adopted into the development of Teachers since they might be used as on-demand coaching systems and teaching aids. Larger Language Models can help teachers brainstorm classroom tasks, create differentiated learning pathways, and have personalized opportunities to learn about professional development. Furthermore, by providing the possibility to co-create instructional resources with the aid of AI instead of only preparing them manually, these models facilitate Human-AI Collaboration in Education. However, the ethical issues are still significant. Large Language Models can generate false information or create references and reinforce negative stereotypes. Their application also creates concerns regarding the Data Privacy in Educational AI, intellectual property and overreliance on automated systems.

Intelligent Tutoring Systems

One of the most well-established AI tools in education settings as well as the focuses of Adaptive Learning Technologies and Personalized Learning Systems are Intelligent Tutoring Systems. IT Systems apply AI algorithms to generate tailored learning and track the advancement of the learner, as well as to modify the material in accordance with the needs of the students. By providing hints, feedback and customized learning activities, these systems mimic the nature of one-to-one tutoring.

Intelligent Tutoring Systems can be used in classroom spaces to allow teachers to support students with various needs by enhancing regular education with additional care. They especially help in mathematics, science and also in learning a language as these systems have the capability to check certain misconceptions and regulate the course of learning [11-13]. Intelligent tutoring systems may also be utilized to train teachers in the case of Teacher Professional Development through simulating classroom

situations, giving performance feedback and even offering performance-based skill development modules. The fact that Intelligent Tutoring Systems are becoming more sophisticated is indicative of more general trends toward AI-based Assessment and Learning Analytics. They are, however, extremely reliant on the quality of the data behind them and the competence of the teachers to read and act on the guidance provided by AI.

Adaptive Learning Technologies

The AITs play a crucial role in AI Adoption in Education since they enable the dynamism of instructional material based on student performance, interests, and their learning speed. These technologies apply machine learning, predictive analytics and behavioral data, which tailors the learning process. Adaptive systems have the potential to adjust question difficulty, personality, and resource recommendations and to deliver real-time assistance to enhance student engagement and performance. The contribution of Adaptive Learning Technologies on the Professional Development of Teachers is becoming more and more prominent since teachers have to possess new skills to work in classrooms to cater to the needs of every student. Teachers should be aware of the functioning mechanisms of adaptive systems, interpretation of the personalized learning data and implementation of the AI suggestions on the classroom plans. Adaptive Learning Technologies support Digital Equity in AI Adoption, as well, as they allow students with varying abilities, backgrounds, and learning styles to have customized support. But there are still questions of equity, privacy of data, and the eventuality of algorithmic personalization inhibiting student agency or supporting status quo disparities.

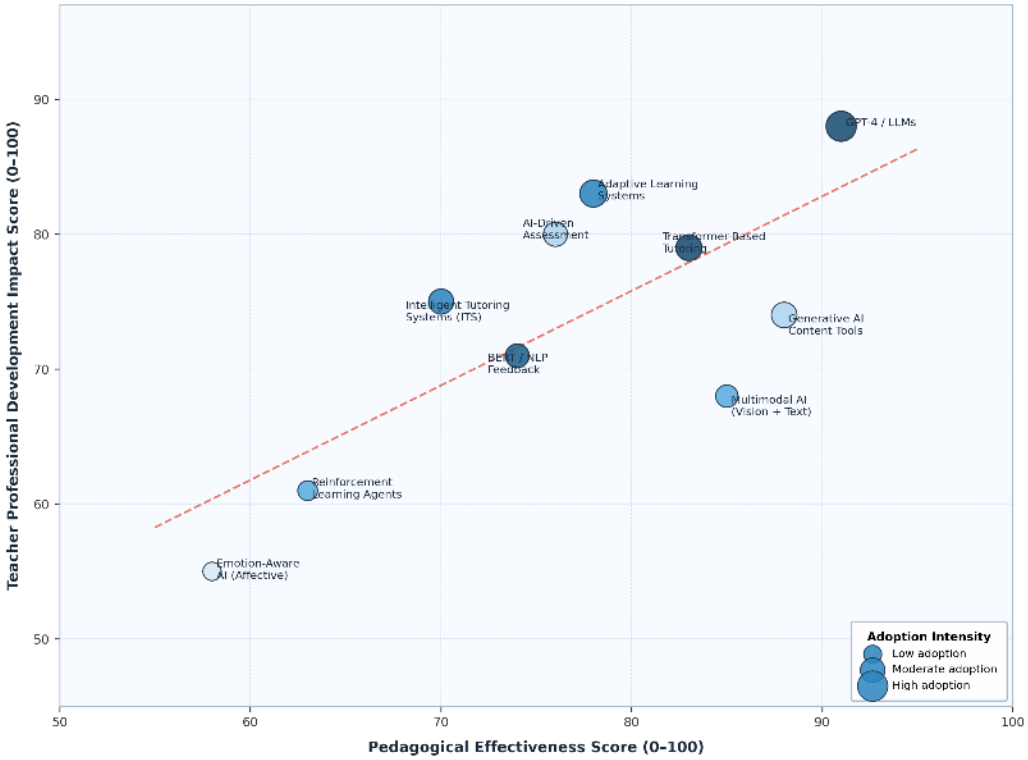

Fig. 2 Pedagogical Effectiveness vs. Teacher Professional Development Impact Across AI Models

Fig. 2 explains a scatter plot maps ten prominent AI models and techniques along two performance dimensions: pedagogical effectiveness score on the horizontal axis and teacher professional development impact score on the vertical axis. Bubble size encodes adoption intensity, providing a third informational layer. GPT-4 and large language models occupy the highest position on both axes, reflecting the literature's growing consensus on their transformative potential in instructional delivery and teacher upskilling. Adaptive learning systems and AI-driven assessment tools cluster in the high-impact quadrant, underscoring their dual utility for personalized pedagogy and continuous professional feedback. Emotion-aware affective AI and reinforcement learning agents appear in the lower-left region,

indicating emerging but not yet mainstream adoption. The dashed red trend line reveals a strong positive correlation between pedagogical effectiveness and teacher development impact, suggesting that AI tools which perform well instructionally also tend to yield stronger gains for educator competency. This visualization is directly relevant to current scholarly debates around selecting appropriate AI tools for dual-purpose deployment in classroom and faculty development contexts.

Learning Analytics and Educational Data Mining

The areas that have been brought into the focus of the AI-based instruction and Teacher Professional Development are Learning Analytics and Educational Data Mining since they can process the systematic study of student behavior, performance, and engagement. Learning analytics refers to the process of collecting and analyzing educational data to enhance decision-making whereas Educational Data Mining is concerned with identifying the hidden patterns and relations in the educational sets of data. They are becoming increasingly popular in identifying students who have educational at risk, using teaching effectiveness, and curriculum development. Dashboards of learning analytics allow teachers to track attendance, participation, completion of assignments and outcomes of assessment. The wider patterns in the behavior of learners can also be extracted by educational Data Mining and it is possible to carry out more effective interventions in the institutions. These tools facilitate evidence-based teaching in Teacher Professional Development and promote reflective decision-making. Nevertheless, the Learning Analytics/Educational Data Mining application poses significant issues concerning surveillance, consent and Data Privacy in the Educational AI. Teachers can also be asked to undergo further training to accurately interpret data and not to rely too much on quantitative indicators.

Learning Analytics and Educational Data Mining

Predictive Analytics in Education is the application of AI models to predict the future using past and live data about education. Predictive systems are capable of estimating the risk of student dropout, making predictions of academic performance, detecting disengagement, and prescribing customized interventions [2,14-17]. These methods are commonplace in higher education, and are becoming more popularly implemented in K-12 settings. In the case of teachers, predictive analytics could enhance the early intervention measures and enable more proactive responses towards struggling students. The predictive systems would as well aid school leaders in forecasting the area of teacher training and also in determining how effective Professional Learning Ecosystems are. Nevertheless, predictive analytics has not been used easily due to poor prediction that tends to stigmatize them and cause self fulfilling prophecies. Predictive algorithms in Education may be considered as the setting where Algorithmic Bias is especially applicable as the biased data may result in discriminatory conclusions. As such, Explainable AI in Education and transparent decision-making frameworks have to be used in conjunction with predictive analytics.

Learning Analytics and Educational Data Mining

Conversational AI in Education and AI Chatbots in Learning are becoming more prominent in office classroom teaching, student services and Teacher Professional Development. These systems are based on the use of Natural Language Processing, Large Language Models, and speech recognition technologies which allow engaging learners in a dialogue [9,18-21]. AI chatbots have the ability to provide responses to questions, give feedback, revising instructions, and simulate tutoring. Teachers are adopting AI Chatbots to Learn as an assistive tool in differentiated instruction, after-hours support, and as a tool to cut down on administrative workload. Conversational AI tools may be applied in Teacher Professional Development as virtual tutors to answer pedagogical questions, to give recommendations on teaching strategies and assist lesson planning. The technologies are particularly useful in situations when teachers are not well equipped with professional assistance. Nevertheless, the quality of chatbot responses, the possible dissemination of false information, and the necessity to retain the level of meaningful human interaction in educational contexts are still of concern.

Computer Vision in Education

Computer Vision in Education is a developing AI method which enables systems to process visual data like images, videos and classroom activity. The use of computer vision technologies in the facial recognition and emotion identification, classroom surveillance and gesture analysis is growing. Such systems can assist in determining the level of engagement, attendance as well as participation among students during online or blended learning. Computer Vision in Education could be applied in Teacher Professional Development to facilitate reflective teaching through analysis of classroom videos and insights on teaching behaviors, interactions with students, and classroom settings. These systems enable the teachers to assess their communication style, movement and the way of engaging the students. However, computer vision presents significant Ethical AI in Education issues as it tends to lead to invasive types of surveillance and biometric data gathering. Consent issues, privacy and psychological impacts of unstopped monitoring are raising more and more questions as increased computer vision technologies become widespread.

Speech Recognition and Voice-Based AI in Education

The use of Speech Recognition in Education is gaining prominence with the rise of voice-based learning platforms and language learning software as well as accessibility features. Speech recognition technologies have the ability to decode verbal communication, analyze pronunciation and feedback on verbal communication skills [22,23]. Such systems are especially useful in language education, special education and inclusive learning. In Speech Recognition in Education, teachers can automate attendance, a classroom conversation, as well as assist students with disabilities. Voice-based AI in Teacher Professional Development Voice-based AI can be used to analyze teacher talk time, questioning strategies and classroom discourse patterns. This may assist the teachers in better communication and control of the classroom. Nonetheless, voice-based systems can be unable to deal with accents, dialects, and multilingual scenarios, which brings up the issues of fairness and inclusivity. These disparities highlight the significance of Digital Equity in the AI Adoption and the necessity of culturally sensitive AI solutions.

Explainable AI in Education

The explanable AI in Education has emerged as a yearning area of concern due to growing demands among teachers, students, and policy makers to have transparency in AI-based decision-making. Explainable AI are methods that involve making AI systems more comprehensible and interpretable [24-26]. Explainable AI can serve in education environments to aid teachers in comprehending why a system produced a given recommendation, forecast, or evaluation finding. The relevance of Explainable AI in the Teacher Professional Development is quite significant as teachers will be more inclined to believe and use AI systems when they know the way these systems work. Teacher Agency and AI are also explainable AI as it makes sure that teachers are active agents and not passive consumers of AI output. Additionally, the threat of Algorithmic Bias in Education can be decreased with the help of Explainable AI, because it becomes easier to discover the unfair, or discriminating patterns. Explainable AI will play a crucial role in promoting responsible, transparent, and human-centered AI Adoption in Education as systems of AI evolve in sophistication.

Recommender Systems in Education

Recommender Systems in Education are being utilized more and more to provide custom learning experiences, to recommend learning materials, and to steer Teacher Professional Development. These systems use the information regarding user preferences, behaviors and performance data to suggest suitable content. Individualized reading lists, practice activities, or even multimedia activities can be given to the students and recommendations on lesson plans, training programs, or classroom techniques may be offered to the teachers. Recommender Systems in Education have a role in Personalized Learning Systems, as they assist students as well as educators in navigating big amounts of digital content. As a teacher, such systems can facilitate further learning as they can find the appropriate workshops, certification, and peer-work possibilities. Nevertheless, the recommender systems can also

serve as sources of filter bubbles that prevent the exposure to a variety of values and teaching games. This points to the necessity of balanced and transparent practices of AI-assisted recommendation.

Multimodal Learning Analytics

Multimodal Learning Analytics is a young discipline that has merged together multiple streams of data, such as text, speech, gestures, eye movements and physiological signals, to come up with a more comprehensive view of the learning processes [27,28]. The method is especially useful in internet, blended and online learning courses where student engagement may be quantified through various means.

In case of Teacher Professional Development Multimodal Learning Analytics will provide possibilities to comprehend classroom interactions, student emotions and effectiveness of instruction better. Multimodal data can help teachers recognize disengagement, assess cooperation, and maintain the teaching strategies. Multimodal Learning Analytics being incorporated into Generative AI in Teaching and Adaptive Learning Technologies forms a rise of one of the most promising places of Future of Teaching with AI. Nevertheless, these methods also contribute to the increase in the concerns of privacy, consent, and ethical management of sensitive educational data. At large, the AI methods that were found in this review show that Artificial Intelligence in Education is changing the mere automation approach to very sophisticated, data-driven and engaging systems. All of these methods help to achieve AI-based education, Teacher Professional growth, and Digital Pedagogical Revolution. Simultaneously, they unveil critical issues of Ethical AI in Education, Data Privacy in Educational AI, Teacher Agency and AI, and Algorithmic Bias in Education. With the ongoing advancement of AI technologies, educational organizations will be required to build a robust overall governance structure, enhance AI Literacy among Teachers, and offer Human-AI Collaboration in Education to establish that these methods are used in a responsible and fair way.

3.2 Artificial intelligence methods

Machine Learning Methods in Education

Machine Learning in Education is considered to be one of the most popular approaches to utilizing AI in education and Teacher Professional Development that allows recognizing the missing patterns in the academic data and facilitating evidentiary decision-making. Supervised machine learning techniques including decision trees, random forests, support vectors machines, Naive Bayes classifiers, and logistic regression are often applied to categorize students in terms of riskiness, engagement rates, performance, and attendance rates. Since they enable educators to discover struggling students, forecast their results, and design interventions uniquely, these methods have grown in importance in Learning Analytics and Educational Data Mining. Clustering, association rule mining, and dimensionality reduction unsupervised learning techniques are also commonly employed to cluster students based on their learning styles, pattern of collaboration or digital engagement history. According to recent research, methodologies of machine learning are becoming fully incorporated into Professional Learning Ecosystems in which educators apply predictive dashboards and AI-enhanced reports to enhance the quality of classroom instruction and teacher management.

Deep Learning Methods in Education

Deep Learning in Education has grown at a tremendous rate due to the increased production of complex data, such as text, speech, video, and logs of interactions, generated in educational systems. Deep learning techniques are based on multilayer neural networks that can handle very complex educational data and make more accurate predictions compared to other machine learning techniques [19,29-31]. Computer Vision Computer Vision Computer Vision Education CNNs are often applied to facial recognition, emotion detection, and monitoring student classroom activity; RNNs and LSTM models are often used to learn sequentially, like predicting student advancement over time. Transformer-based models have gained special relevance in Generative AI in Teaching since they facilitate language generation, content generation, and context analysis. The rising popularity of deep learning processes

in Adaptive Learning Technologies and AI-based Assessment models are linked to the demand to have individually tailored and highly flexible learning settings. Yet, deep learning techniques are typically criticized as being black box, which is hard to learn by teachers as to how output is formed. This has enhanced the relevance of Explainable AI in Education and transparent AI Governance in Schools.

Reinforcement Learning Methods in Education

Reinforcement Learning in Education An early form of AI, Reinforcement Learning in Education is becoming more popular in optimizing Adaptive Learning Technologies and Intelligent Tutoring Systems. Reinforcement learning techniques work by enabling the AI systems to learn through trial-and-error interactions where it is rewarded or punished based on effectiveness of instructional choices. Reinforcement learning can be applied in the educational setting to scale up or down the difficulties in the lesson, prescribe the next-step learning activities, and individualize the order of teaching material. The latter practices are especially effective in Personalized Learning Systems as they help optimize learning trajectories regularly based on the performance of students and their interest. Reinforcement learning also becomes a valuable asset in Teacher Professional Development as it may be used to recreate classroom conditions to expose the teachers to the possible practice of responding to various students and different instructional issues. Though less popular than supervised machine learning, reinforcement learning is starting to be seen as a promising approach to the Future of Teaching with AI because of its ability to facilitate high individualization and responsiveness of the learning process.

Natural Language Processing Methods in Education

NLP in Education has emerged as one of the most revolutionary AI solutions since it enables education systems to learn, create and analyze the human language. Automated Feedback Systems, essay grading, plagiarism software, sentiment analysis, language education, and AI Chatbots used in Learning all heavily use the techniques of NLP [32,33]. The AI systems can analyze classroom speech, student text, and teacher speech using techniques like tokenization, sentiment classification, named entity recognition, semantic similarities, and topic models. In Teacher Professional Development too, natural language processing is taking on an increasing role in a variety of ways, as it may analyze classroom transcripts, determine the patterns of questioning and even gauge the strengths of teacher-student interaction patterns. Systems based on the use of NLP are especially useful in multilingual classes as they may assist in translation, simplify the content and enhance accessibility. Nevertheless, these approaches have problems to do with biasness, misinformation, and Academic Integrity and AI, particularly when the language models produce inaccurate or misguiding results.

Large Language Models in Education

One of the most important areas of development in Generative AI in Teaching and Teacher Professional Development is Large Language Models in Education. They can generate text, summarize content, answer questions, and assist with complex instructional tasks, and are based on transformer architectures that are trained on massive datasets. The LLLMs are finding more applications in lessons, quizzes, rubrics, assessments, and individualized feedback. The systems are also being relied on by teachers to brainstorm instructional strategies, come up with differentiated content, and enhance efficiency in the administrative world. Recent studies indicate that Large Language Models can be of greatest use in independent professional growth as these models can serve as beneficial on-demand coaching assistants and teaching companions. These models are progressively employed by teachers to learn more about pedagogical concepts, to scrutinize pedagogical practices, and to create AI Literacy for Educators. Nonetheless, issues like hallucinated production, misinformation, privacy, and even getting excessively dependent on the automated systems are still of concern. Large Language Models are also challenging Teacher Agency and AI since teachers are likely to become over-dependent on AI-generated recommendations.

Conversational AI and Chatbot Methods

The application of AI Chatbots to Learning, virtual teaching assistants and conversational tutoring systems has broadened the realm of conversational AI in Education. The techniques are a mix of Natural Language Processing, speech recognition, and Large Language Models that facilitate interactive communication between artificial intelligence and students [34-36]. Conversational AI practices have the potential to give instant answers, facilitate revision processes, give individualized explanations, and lessen teacher workload through repetitive tasks. Use of conversational AI Tools in Teacher Professional Development is becoming a common tool in answering pedagogical questions, advice teaching and lesson planning. The systems are especially useful in situations where the teachers lack access to professional mentoring or peer collaboration. Nevertheless, there are also studies that point to the warning that conversational AI can negatively impact teacher-student relationships in cases of excessiveness, leaving less time to interact with humans, and forming an addiction to support mechanisms. Educators thus need good AI Literacy and Human-AI collaboration skills in order to be responsible with conversational AI.

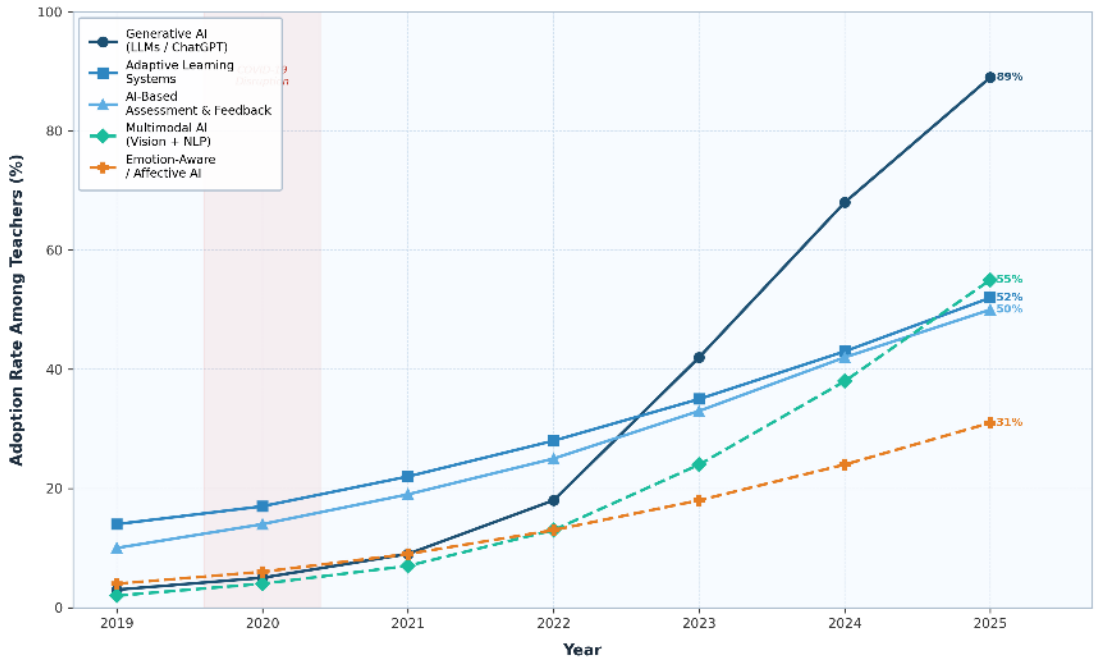

Fig. 3 Perceived Effectiveness of AI Applications Across Higher Education and K-12 Contexts

Fig. 3 visualizes a grouped bar chart contrasts the perceived effectiveness scores of eight AI applications as reported by teachers in higher education versus K-12 settings. Across all categories, higher education consistently records higher perceived effectiveness, with personalized learning paths scoring highest at 81%, followed by AI-generated assessment items at 72% and adaptive learning systems at 68%. K-12 teachers report comparatively lower confidence, particularly for classroom sentiment analysis and teacher professional development recommendation systems, suggesting significant gaps in infrastructure readiness and AI literacy at the primary and secondary levels. AI-augmented lesson planning shows a relatively smaller gap between the two cohorts, hinting at its accessibility and practical applicability across institutional contexts. The visual contrast between the deep and light blue bars across all eight categories communicates not only differences in adoption levels but also potentially divergent pedagogical needs, resource availability, and administrative support structures. These findings align with the emerging literature calling for context-sensitive AI deployment frameworks that account for institutional level and teacher preparedness.

Intelligent Tutoring Systems and Adaptive Learning Methods

Adaptive Learning Technologies and Intelligent Tutoring Systems are some of the most impactful AI-based approaches to education as they facilitate Personalized Learning Systems and instruction based

on an individual. These approaches benefit machine learning, student modeling, and predictive analytics to diagnose the needs of learners and modify teaching only in real time. Intelligent Tutoring Systems can give hints, scaffolding, feedback, and custom exercises depending on the performance of students and adaptive systems can adjust the difficulty of the lesson, the whole lesson pacing, and learning sequences. They are becoming more widely used in both in K-12 and higher education settings since they can assist teachers to deal with diverse classroom settings and varied student ability in the classroom. Another application of intelligent tutoring in Teacher Professional Development is the development of teacher learning resources in customized teacher learning pathways where teachers can receive tailored training leadership opportunities, dependent on their teaching requirements and career objectives.

Intelligent Tutoring Systems and Adaptive Learning Methods

Learning Analytics and Educational Data Mining are both indispensible AI tools to analyze lots of input data in the educational sphere and promote evidence-based education. Learning analytics approaches include data gathering, data processing, and data graphing of student interactions, attendance, performance in assessments, and involvement. Educational Data Mining is an educational data-discovery technique to find patterns, trends, and latent relationships in educational data. These approaches facilitate Predictive Analytics in Education that can assist educators to recognize vulnerable students, assess the teaching performance, and enhance teaching planning. As of recent, there are signs that Machine Learning in Education and Generative AI in Learning Analytics are joining forces to form more sophisticated and dynamic systems able to generate real-time recommendations as well as early-warning operations. The techniques are also finding their way into Teacher Professional Development since they facilitate reflective teaching and data-driven instructional decision-making.

Predictive Analytics Methods in Education

Predictive Analytics in Education is gaining more and more significance as educational facilities are interested in predicting what will happen in the future and setting up boundaries before the occurrence of conflicts. Predictive processes involve machine learning algorithms, statistical modeling and past education data to be used in estimating the risk of dropout, academic performance, disengagement and attendance patterns [37-40]. These strategies enable educators and organizations to conduct screening of learners at risk and offer support in a timely manner. Teacher Professional Development is also beginning to drive the use of predictive analytics to determine any areas that lacked training or support and may require that teacher to seek further assistance. Nevertheless, predictive techniques are linked to significant Ethical AI in Education issues since they can strengthen stereotypes, stigmatize learners or recreate past biases. Explainable and Transparent AI solutions are hence important to allow predictive analytics systems to be fair, trustworthy and supportive as opposed to being punitive.

Computer Vision Methods in Education

Computer Vision in Education is a science that is becoming a dominant AI technique in the classroom setting, on-line learning programs, and educator development. Image recognition, facial recognition, gesture recognition, and object tracking are all computer vision techniques used to assess classroom participation, emotional engagement, and classroom instructional actions. These techniques are especially applicable to blended and online classrooms where educators might not see students as much as they could otherwise. Computer vision is as well finding its application in the Teacher Professional Development to study the classroom videos and give meaningful reflection feedback concerning the style used in teaching, the interaction with the students as well as the pattern of interactive communication. New systems can automatically recognize high engagement situations, classroom disturbances, and suggest how to make instruction better. Nevertheless, Computer Vision in Education also poses significant Data Privacy in Educational AI issues, as since the former is commonly concerned with collecting and monitoring biometric data.

Speech Recognition and Voice-Based AI Methods

The emergence of voice-less learning systems, accessibility software, and language learning applications are transforming Speech Recognition in Education into a more popular topic. Verbal means of speech recognition help to transform the sound into the text and study the speech pronunciation as well as test the competence of verbal communication [41-43]. The techniques are mainly useful in language education, inclusive education and special education as they assist students with disabilities, speech difficulties or in the case of multilingual learners. Teacher Professional Development may also be supported by the voice-based AI based on the realization of Teacher talk time, questioning approach, and classroom dialogues. Speech recognition systems allow teachers to listen and ready-up lessons recorded and where the issues are, where the communication and instruction can be improved. Although these advantages exist, speech recognition techniques are usually adversely affected by accent, dialect and multilingual uses, posing potential inequities to various learners.

Multimodal Learning Analytics Methods

One of the fastest growing AI systems used in education is Multimodal Learning Analytics due to its unification of numerous types of learner data, such as text, speech, gestures, eye tracking, physiological data, and clickstream activity. The methods make a more holistic picture of the learning processes compared to the traditional analytics methods since they will measure both mental and emotional aspects of learning. Recent articles indicate that Multimodal Learning Analytics is being used increasingly with Deep Learning in Education and Generative AI in Teaching to enhance student engagement tracking, collaborative learning, and classroom observation. In Teacher Professional Development, multimodal methods have the ability to offer specific feedback on the quality of instruction, interactions in the classroom, and teacher effectiveness. Technology has now the capacity to scan the tapes of classrooms and can produce very individualized teaching advices based on the best practices in pedagogy.

Explainable AI Methods in Education

The explainable AI in Education has become a necessity due to the growing need among teachers, students and policymakers to have transparency of AI-assisted decision-making. Explainable AI techniques assist users know why an AI system came up with a specific suggestion, anticipation, or judgment finding. These techniques are feature importance analysis, decision trees, visualization, and user-friendly explanatory systems. Particularly important is explainable AI in Predictive Analytics in Education, Adaptive Learning Technologies, and AI-driven Assessment, as these systems may have a powerful impact on education opportunities and teacher choices. Recent trends in Explainable AI include more focused explanations, where the explanations vary depending on the intended audience, such as a teacher, student or administrator. This change is related to the increasing idea of how important the fact that AI systems are not only precise but added to the understandability and mention the trustworthiness of the analyzed system is. Explainable AI also contributes to Teacher Agency and AI by maintaining an active role of the educator in the decisions-making process and not a passive consumer of algorithmic decisions.

3.3 Artificial intelligence technologies

Large Language Models in Education

Learning The concept of Large Language Models in Education has emerged as one of the most impactful technologies in AI that develops the future of teaching and Teacher Professional Development. These systems that require text generation, text summarization, answering questions, designing lesson plans, quiz creation, and classroom communication are all enabled by the use of a transformer [28,44-47]. Their fast growth is changing Generative AI in Teaching as teachers are now adopting these technologies as a way to automate repetitive tasks, customize the learning material, and offer differentiated instruction. Learning institutions are incorporating Large Language Models in digital learning applications, learning management via digital learning applications, and teacher productivity

applications. The popularity of such technologies has been a demonstration of the overarching Digital Pedagogical Transformation that takes place at the institutional level of schools and universities, with a number of institutions implementing generative AI tools at scale. It is reported that currently, education ranks among the top industries in terms of generative AI adoption, meaning that Large Language Models are emerging as a key element of the contemporary Educational Technology Integration.

The importance of Large Language Models to Teacher Professional Development is especially relevant since, in this case, the technologies may be used as virtual instructional coaches, the reflective teaching partners and on-Demand systems of professional help. Educators are turning to writing assistants that are AI-powered even more often, to produce curriculum content, streamline learning goals, and reformulate assessment schedules. Meanwhile, there is a threat of hallucinated outputs, wrongful content generation, and IP problems as well as overreliance on automated systems. This increasing focus on the idea of Human-AI Collaboration in Education implies that Large Language Models can be viewed as assistive but not a substitute to teacher judgment, creativity, and pedagogical knowledge.

Natural Language Processing Technologies

One of the basic AI technologies facilitating the automated communication between learners, teachers and intelligent system is Natural Language Processing in Education. NLP technologies help in grading essays, plagiarism, sentiment analysis, automatic feedback, or classroom discourse analysis [48,49]. These technologies are becoming an inseparable part of the education system as it is able to study written tasks, identify misunderstandings, and give individual recommendations to students. NLP is also taking center stage in the multilingual education since it allows translation, simplification of study materials and adapting languages in teaching students with varying student profile. In the case of Teacher Professional Development, Natural Language Processing technologies can be used to analyze classroom transcripts and patterns of teacher questioning and the quality of communication during classroom instruction. These systems have the ability of giving reflective information to teachers regarding their teaching styles, classroom discourse, and teaching language. The application of the NLP technologies, however, also implies the problem of Academic Integrity and AI, when students rely on the text-generating technologies to create the essays or or assignments without showing any signs of authentic learning. Growing AI literacy initiatives are more focused on educators needing to be trained on how to differentiate valid AI-assisted writing support and the abuse of AI-created content.

Intelligent Tutoring Systems

One of the best-developed and the most common AI applications in education is Intelligent Tutoring Systems. Such systems offer personalized learning, automatic feedback and adaptive study by studying performance of these learners and modifying the content dynamically [3,50-52]. The Intelligent Tutoring Systems are especially useful in the areas of mathematics, science, and learning languages since they will be able to recognize the misconceptions and knowledge gaps and provide specific interventions. Intelligent Tutoring Systems Intelligent Tutoring Systems are increasingly playing a significant role in the Teacher Professional Development due to their ability to train teachers as well. New systems now model classroom situations, offer feedback on teacher choices and develop custom teacher learning journeys. One of the most significant educational AI innovations are dynamic tutoring technologies that launch real-time feedback and practical insights. These technologies are now growing as being tools to reinforce instruction quality as well as promote student learning and teacher development.

Adaptive Learning Technologies

The core of AI Adoption in Education is Adaptive Learning Technologies that allow Personalized Learning Systems in which instructional content is tailored based on the student needs, preferences, performance. These technologies rely on predictive models and profile of the learner and behavioral analytics to determine the optimal level of difficulty, pace, and sequence of learning materials. Adaptive learning systems are able to prescribe learning materials, modify examinations, and offer specific guidance according to student achievement.

Adaptive Learning Technologies are relevant to Teacher Professional Development because teachers need to be taught to use learning data on an individual basis and how to apply adaptive recommendations in the classroom. The technologies are also capable of assisting teachers to run diverse classrooms more efficiently through encouraging differentiated instruction and inclusive learning approaches. Learning institutions are starting to take advantage of AI in order to assist with individualized learning opportunities that assist students in recognizing gaps in their skills and apply competencies to fulfilling those gaps more effectively.

Learning Analytics Platforms

Learning Analytics has become one of the most powerful AI technologies in any educational decision-making process due to the ability of the technology to collect, process, and interpret big data about students. LAA systems are able to track attendance, participation, grades, levels of participation, and patterns of digital activity [53-57]. The technologies assist educators to detect struggling students, assess teaching performance, and make evidence-based lessons. The rising role of Learning Analytics in Professional Learning Ecosystems indicates the rising significance of the use of data in the teaching practice. Analytics dashboards allow educators to track student progress and reveal the trends that are otherwise not visible. Simultaneously, Data Privacy in Educational AI, surveillance, and ethical data governance are the issues of Learning Analytics technologies. The accelerated development of educational data systems emphasizes the necessity of AI Governance in Schools and enhanced protection over student data.

Conversational AI and Chatbots

Conversational AI in Education is the new technology that becomes increasingly shaping the interactions between students and teachers and technology. Learning Chatbots Malfunctioning AI Chatbots can respond to questions, provide explanations, assist in the revision process, and can offer immediate feedback to learners. Natural Language Processing, Large Language Models, and speech recognition are combined in these technologies to develop more interactive and responsive learning environments. Among teachers, conversational AI technologies help in the decreasing of administrative burdens, in the provision of after-hours learning support, and enhance access to teaching resources. AI chatbots can act as virtual mentors in Teacher Professional Development through advice on pedagogies, suggestions on how to teach, and aiding in lesson planning. Over the recent years, conversational AI has shifted off of the general purpose, question-answering systems to more specialized, subject-specific, and teacher-centered tools that are designed to stimulate critical thought, instead of retrieving passive answers passively. Even faculty-created AI systems are being marketed as a means to challenge, provoke discussion, and make students learn more rather than to provide the easy solutions.

Computer Vision Technologies

Computer Vision in Education is a new AI tool that helps systems analyze content (images, video, gestures, facial expression) with a high level of accuracy. Classroom monitoring, attendance tracking, engagement detection and emotion analysis of technologies are increasingly being applied in the classroom [58,59]. Computer vision system will be able to assist teachers in determining the presence of disengagement, confusion, or gaps in participation through visual behavior patterns in online and blended learning settings. The Teacher Professional Development is also embracing Computer Vision technologies since the teacher can access the classroom records and obtain the feedback on the communication patterns, movement, classroom management and interaction with the students. The technologies, however, raise critical issues concerning Ethical AI in Education since in most cases they are linked with surveillance and collection of biometric data. With more AI being integrated into the classroom, institutions are finding themselves being questioned to come up with safeguards that would secure the privacy of teachers and students.

Speech Recognition Technologies

The growing popularity of voice-enabled learning systems, applications for language learning, and accessibility technologies are making Speech Recognition in Education more significant. The

technology of speech recognition gradually transforms the spoken word into a written one, examines speech patterns, and offers some speech assessment. Such systems are particularly useful in language education, inclusive education, and special education since they assist learners with disabilities, multilingual as well as those with speech challenges. In the case of the teachers, the speech recognition technologies may mechanize the attendance, record lessons and interpret the conversations in the classroom. They are also coming into play in Teacher Professional Development in that teachers can check their teaching language, questioning styles and their communication patterns through them. Nonetheless, voice systems can be limited to accents, dialects, and cultural differences, which could decrease accuracy and strengthen inequalities. These difficulties demonstrate the significance of designing AI inclusively and Digital Equity in AI Adoption.

Recommender Systems in Education

The importance of Recommender Systems in Education is growing due to the overwhelming amount of digital content, courses, assessments and learning resources that teachers and students encounter. Recommender systems process the data on user preferences, user behaviors, and user performance to recommends personalized content, instructional material, and professional development options. As a student, recommender systems are able to recommend the relevant learning materials, videos, assignments, and revision materials. In the case of teachers, these systems have the capability of suggesting lesson plans, teaching methods, workshops, and AI literacy materials. In Teacher Professional Development, particularly, places are becoming especially significant, as recommender technologies are designed to guide educators to find the opportunities of this specific training and customized learning paths. With the increased data-driven nature of education systems, the importance of recommender systems in informing lifelong professional learning and ongoing pedagogical enhancement can be expected to grow.

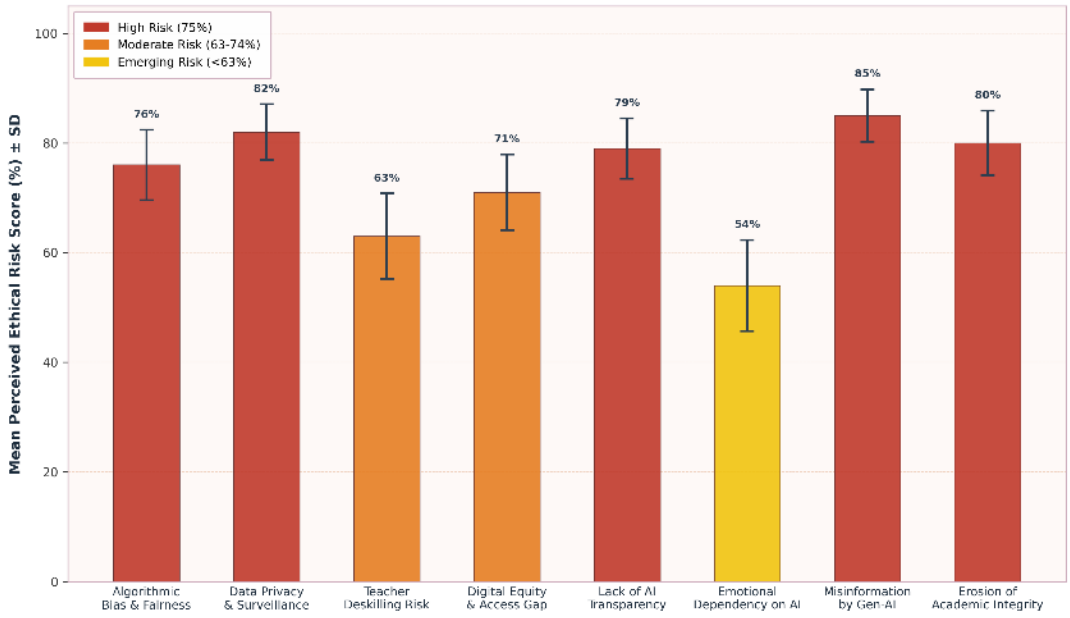

Fig. 4 Mean Perceived Ethical Risk Scores of AI Adoption in Teaching with Standard Deviation

Fig. 4 is a error bar chart quantifies the perceived severity and variability of eight ethical risk categories associated with AI adoption in educational settings. Misinformation generated by generative AI is perceived as the highest-risk concern at 85%, followed closely by data privacy and surveillance at 82%, and erosion of academic integrity at 80%, all rendered in deep red to indicate high-risk classification. Algorithmic bias and fairness, and lack of AI transparency also fall within the high-risk band, reflecting heightened scholarly and regulatory attention to these issues in post-2022 AI ethics discourse. Error bars representing standard deviation reveal that emotional dependency on AI and teacher deskilling risk carry the greatest variability, indicating heterogeneity in teacher perceptions likely influenced by institutional culture, subject discipline, and prior AI experience. The risk severity classification scheme using color-

coded bars provides an immediate visual risk hierarchy, making this figure suitable for policy-oriented sections of systematic reviews addressing the ethical governance of AI in education.

Virtual Reality, Augmented Reality, and Extended Reality

AR and VR are increasingly integrated with AI technology to form immersive and experiential learning settings as Virtual Reality in Education, Augmented Reality in Education and Extended Reality in Education. Such technologies enable students to communicate with simulations, virtual laboratories, historical reconstructions and three-dimensional learning environments [3,60,61]. By personalizing content, adapting scenarios, and by giving smart positive feedback, AI works to improve these systems. In the case of Teacher Professional Development, simulated classroom training using immersive technologies creates new opportunities of virtual peer observation as well as reflective classroom practice. The teachers will be able to engage in virtual contexts that will replicate classroom situations, students and how decisions related to instruction are made. These technologies are becoming well regarded as potent tools towards experiential learning and teacher training due to their ability to enable teachers to train the skills in low-risk, but real-world settings. Trends in education indicate that the role of immersive technologies is about to expand with schools demanding more interactive, and hands-on ways of learning.

Robotics and Internet of Things Technologies

The field of robotics in Education and Internet of Things in Education is becoming more and more significant as schools implement smart classes, devices connected and interacting, and practical STEM learning environments. Coding, problem-solving, computational thinking, and collaborative learning can be assisted by educational robots. IoT technologies enable devices, sensors and classroom systems to gather data, track environmental conditions and enhance classroom efficiency. Teacher Professional Development is also incorporating these technologies as teachers are more and more required to train in robotics, coding, smart classroom management, and in computational thinking. According to recent educative movements, it is important to introduce AI, computational thinking and digital literacy earlier in the academic process to equip students to the future work environment. Increased adoption of AI and computational thinking in schools denotes that robotics and IoT technologies will become the focus of classroom instruction and education of educators.

Explainable AI Technologies

Explainable AI in Education is one of the essential emerging technologies, as the transparency of AI-driven decisions becomes more and more sought after by teachers, students, and policymakers. Explainable AI technologies allow users to know why an AI system has produced the given recommendation, prediction or assessment [62-64]. Such technologies are significantly valued in predictive analytics, adaptive learning systems, and automated grading since they have impact on the critical decisions in education. Explainable AI is of great relevance to Teacher Professional Development since teachers will tend to trust and integrate AI technologies more when they are aware how these systems work. Explainable AI also makes Teacher Agency and AI possible because it makes sure that educators do not become inactive consumers of AI-generated recommendations. Explainability is progressively seen as a fundamental part of the development of trust, accountability, and ethical integration of AI systems in the educational domain as they are becoming more complex.

Cloud-Based AI Platforms and Agentic Workflows

Cloud-based AI Platforms are also allowing schools and universities to utilize AI technologies without necessarily spending large sums of money on the local infrastructure. The platforms offer scalable support on Large Language Models, analytics dashboards, adaptive learning systems, and content creation tools [65-67]. The AI platforms based on clouds enable teachers to make presentations, automate workflows, generate assessment and conduct work with colleagues in other institutions. Among the first and foremost recent ones is the emergence of the so-called agentic workflows, defined as an interplay of several AI tools that collaborate in order to accomplish complex educational tasks without human intervention. To illustrate the point, teachers have the opportunity to create lesson

content with AI systems, convert it into presentations, create assessments and deliver through learning management systems. These technologies are gaining more and more relevance since they ease the burden on teachers and enhance efficiency. They do need better AI Literacy among Educators and more liberal governance frameworks to make sure that automation does not put quality and teacher autonomy at risk.

3.4 Artificial intelligence models

Machine Learning Models in Education

Machine Learning models in Education are the core of Artificial Intelligence in Education and are the focus of both AI Adoption in Education and Teacher Professional Development. These models consist of supervised learning models, which are logistic regression, decision trees, support voltage machines and ensemble models, which have extensive use in classification and prediction of educational applications. They have wide use in Learning Analytics and Predictive Analytics in Education to expose at-risk students, predict academic performance and optimize how instructions are formed. There are also unsupervised models like clustering and dimensionality reduction which reveal hidden learning patterns and classify students according to their engagement and cognitive patterns. The growth in the utilization of Machine Learning Models is associated with the broader Digital Pedagogical Transformation in which teaching activities are turning data-driven and evidence-based. But the increasing use of predictive models also has issues concerning Algorithmic Bias in Education, as well as Data Privacy in Educational AI, especially when models receive incomplete or biased data.

Deep Learning Models in Education

Deep Learning Models in Education is an important development in the field of AI Models because these models have been designed to handle large, multimodal and complex educational data in large amounts. Artificial neural networks with more than one hidden layer are used in constructing these models, which are able to learn the hierarchical representations of the data. Computer Vision Convolutional Neural Networks are popular in Computer Vision in Education, and Recurrent Neural Networks and Long Short-Term Memory models are used in sequences learning tasks like predicting student performance. In recent years, Deep Learning Models built off of Transformers have been on the forefront, especially in Generative AI Models and Natural Language Processing in Education. Such models accommodate automated feedback, adaptive assessments, learning analytics, and real-time. In spite of their efficiency, Deep Learning Models are prone to criticism due to their lack of transparency, which lends more credence to Explainable AI Models in Education and AI Governance in Schools.

Transformer Models and Large Language Models in Education

Education The most revolutionary AI models over the last several years include transformer Models in Education, especially Large Language Models in Education. These models are based on attention mechanisms which makes them able to process massive amounts of textual data and also form human like responses [68,69]. Generative AI in Teaching has become increasingly popular as Large Language Models are used in the process of lesson planning, content generation, lesson assessment design, and conversational tutoring. The quick pace of adoption of these models since the onset of generative AI tools has transformed the education practice and teacher practice. More sophisticated systems, such as reasoning-based architectures, are now able to solve problems step-by-step and perform intricate reasoning, and can now be much more extensively exploited in pedagogy.

Transformer Models are now used in Teacher Professional Development as virtual learning tutors that facilitate reflective teaching, curriculum design, and AI Literacy for Educators. Nevertheless, the issues about hallucinations, misinformation, and dependency beg the question about Ethical AI Models in Education and Human-AI Collaboration Models that keep teacher agency intact.

Intelligent Tutoring System Models

One of the oldest AI Models in education is Intelligent Tutoring System Models which are extensively utilized to deliver a rich and individualized learning process. These models incorporate several AI processes, such as Machine Learning Models, Knowledge Tracing Models, and Natural Language Processing, to mimic one-to-one tutoring [20,70-72]. The use of Intelligent Tutoring Systems is based on the learner models, domain models and pedagogical models to provide a customized instruction and feedback. Studies indicate that these systems facilitate adaptive learning, personalization, and real-time feedback of students and are quite effective in enhancing student outcomes. Recent research has proposed hybrid ITS models to integrate Large Language Models with classical rule-based systems to provide more flexible and context-sensitive tutoring experiences. Such hybrid models constitute a move to the more interactive and conversational learning process despite having the pedagogical instructions.

Knowledge Tracing Models

Knowledge Tracing Models are also special AI Models which are used to trace and predict the knowledge of students in real-time. These models approximates the mastery of a particular learner in certain concepts through the interaction of the learner with content of education. Bayesian Knowledge Tracing, a traditional technique, has also been extensively applied in Intelligent Tutoring System applications, but newer Deep Learning based techniques, like Deep Knowledge Tracing and Transformer based models offer more precise and scaleable predictions. Knowledge Tracing Models: Knowledge Tracing Models are especially significant to Personalized Learning Systems and Adaptive Learning Technologies since they allow adjusting the instructional material in real-time. Another major application of these models to Teacher Professional Development is their success in providing information on the student learning process and enabling teachers to realize how they can offer more support. Nevertheless, there are still problems with making sure whether these models reflect the intricate learning processes and are not simple student cognition representations.

Reinforcement Learning Models in Education

Reinforcement Learning Models in Education: Reimbursement Learning Models are starting to be employed in maximizing teaching courses and Adaptive Learning Systems. These models acquire knowledge through their exposure to the environment and obtaining feedback through rewards or penalties [73-75]. Within the educational environments, the reinforcement learning can be applied to define the most successful order of educational activities, modify the level of difficulty, and customize the learning events. In Intelligent Tutoring Systems and Personalized Learning Models, reinforcement Learning Models are especially useful as they are constantly being enhanced by responses of the students. They are also being simulated in Teacher Professional Development simulations, where teachers can train on how to make decisions during a dynamic classroom environment. Reinforcement learning models are expensive because of the large quantities of data and need precise design to be effectively implemented without resorting to unethical methods.

Conversational AI Models

The AI Models of Conversation in Education are created to aid and guide the interactive communication among learning, teaching, and AI. These are models that use Natural Language Processing and Large Language Models with dialogue management systems to develop AI Chatbots to use in the Learning and virtual teaching assistants. The use of conversational models is on the rise in order to offer real-time feedback and questions as well as assist students in their activities.

In Teacher Professional Development conversational AI models can be used as virtual mentors, providing tips on pedagogy, classroom management, and instructional design. These models are especially useful in situations with the lack of opportunities to receive expert guidance. Nonetheless, the integrity of responses has been an issue of concern as well as misinformation that may be disseminated and also the necessity to maintain healthy interaction among humans in learning institutions.

Predictive Models in Education

Predictive Models in Education has extensive applications in terms of predicting student performance, to detect those at risk, and to guide intervention plans. The models are based on statistical processing and Machine Learning to process past and live data [38,76-78]. Learning Analytics Models include predictive models that are becoming increasingly found in educational dashboards and decision-support systems. Predictive models are available to teachers as action-driven insights to encourage personalized instruction and early intervening. These models can also be used to determine aspects that may require extra training or support of educators in Teacher Professional Development. Nevertheless, predictive models also bring important Ethical AI in Education issues, especially in terms of bias, equality, and risk of self-fulfilling prophecies.

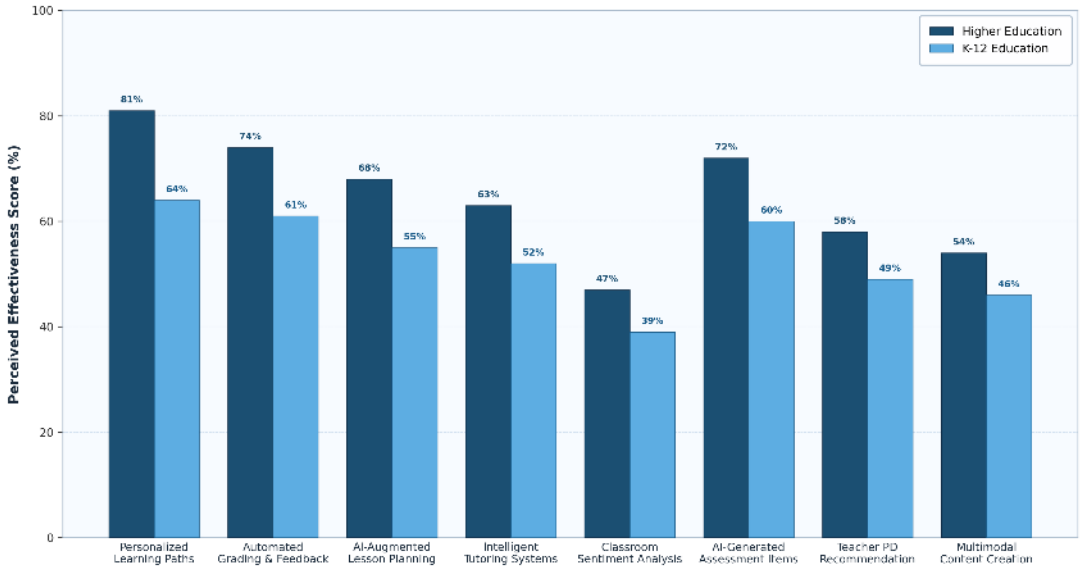

Fig. 5 Perceived Effectiveness of AI Applications Across Higher Education and K-12 Contexts

Fig. 5 shows grouped bar chart contrasts the perceived effectiveness scores of eight AI applications as reported by teachers in higher education versus K-12 settings. Across all categories, higher education consistently records higher perceived effectiveness, with personalized learning paths scoring highest at 81%, followed by AI-generated assessment items at 72% and adaptive learning systems at 68%. K-12 teachers report comparatively lower confidence, particularly for classroom sentiment analysis and teacher professional development recommendation systems, suggesting significant gaps in infrastructure readiness and AI literacy at the primary and secondary levels. AI-augmented lesson planning shows a relatively smaller gap between the two cohorts, hinting at its accessibility and practical applicability across institutional contexts. The visual contrast between the deep and light blue bars across all eight categories communicates not only differences in adoption levels but also potentially divergent pedagogical needs, resource availability, and administrative support structures. These findings align with the emerging literature calling for context-sensitive AI deployment frameworks that account for institutional level and teacher preparedness.

Multimodal AI Models

Multimodal AI Models in Education is a significant development in the field of AI Models since it includes a combination of datasets (text, audio, video, sensors data, and more). These models can facilitate the analysis of intricate learning settings and can give a more detailed insight into student actions and involvement. Computer Vision in Education Multimodal models are becoming more common in Speech Recognition in Education, and Learning Analytics. Multimodal AI Models in Teacher Professional Development are powerful tools that offer specific insights into classroom interactions, teaching practices, and student engagement. These models are capable of analyzing recordings in the classrooms, detect trends in communicating, and give feedback on the effectiveness

of instruction. Multimodal data and their integration is one of the most promising areas of Future of Teaching with AI, but it also poses a privacy-data security issue.

Explainable AI Models in Education

Explainable AI Models in Education is aimed to enhance transparency and trust in AI-based decision-making. These algorithms describe how to give predictions, suggestions, and results so that teachers and learners can learn how AI technologies work [79-81]. Explainable AI was specifically significant in Predictive Analytics, Adaptive Learning Systems, and AI-based Assessment. Explainable AI Models are used in Teacher Professional Development to assist in AI Literacy Among Educators to help teachers understand and act on AI responses. Such models are also instrumental in dealing with Algorithmic Bias in Education as it becomes simpler to diagnose and eliminate any unpleasant or prejudiced trends. Explainability is gaining momentum as a mandatory condition to ethical and responsible adoption of AI systems as the systems become more intricate.

Hybrid and Ensemble Models in Education

Hybrid and Ensemble Models in Education: Hybrid and Ensemble Models implement a combination of AI Models to enhance their performance, robustness, and adaptability. Machine Learning, Deep Learning and rule-based systems are just several techniques used in these models to form more holistic and flexible educational solutions. Predictive analytics typically use ensemble methods e.g. random forests, boosting algorithms, whereas hybrid models are becoming more popular in Intelligent Tutoring Systems. In recent studies, there is a growing focus on hybrid models, which integrate Large Language Models with Knowledge Tracing and Learning Analytics and enforce more powerful and context-aware learning systems. The models can provide the benefits of customized learning at the same time preserving pedagogical order and precision. Human-AI Collaboration in Education is also centered around hybrid models since they facilitate a more successful integration of the human expertise and the capabilities of AI.

Foundation Models and Generative AI Models

The most recent direction of Artificial Intelligence in Education is Foundation Models and Generative AI Models. These models are trained with large scale datasets and can be scaled to numerous educational tasks such as content generation, assessment, tutoring and curriculum design [82,83]. Many Generative AI applications, such as Large Language Models and multimodal systems, are based on their foundation models. The emergence of Generative AI Models has greatly catalyzed the Digital Pedagogical Transformation, through providing scalable, personalized, and interactive learning experiences. New studies note that generative AI and multi-modal models of AI in Education are the main innovations in AI, along with human-AI collaboration and learning analytics. These models offer new chances of custom-designed training, reflective practice, and learning in Teacher Professional Development. However, their large dissemination also comes with the drawbacks of improper use, intellectual property and robust governance structures.

3.5 Artificial intelligence applications

AI Applications in Lesson Planning and Curriculum Design

Lesson planning, and AI-enabled curriculum design, is one of the most popular AI Applications in Education. Generative AI in Teaching is becoming more popular with teachers, who are able to write lesson plans and instructional objectives, differentiated activities, quizzes, and classroom resources in a fraction of the time normally taken. Languages large models (LLM) in education show special effectiveness in the production of age-related examples, the contextualization of the topic, and compliance with learning requirements. Lesson planning that uses AI has become one of the main points of entry into AI Adoption in Education since it has direct positive effects on a reduction of the workload of the teacher and the increase of efficiency. The emerging evidence indicates that pre-service and in-service educators find AI beneficial to the lesson planning, resource development, and alleviating administration load in mathematics, language learning, and interdisciplinary education. Digitization of

curriculum design is also more indicative of Digital Pedagogical Transformation in the sense that the responsibilities of educators turn more towards the curator and facilitator of content rather than content creation. Intelligent lesson plans have the potential to assist the teachers tailor learning resources to each student, to change lessons to suit varying learners, to redesign learning activities rapidly to support learning at online, hybrid, or inclusive learning settings. But new fears are that excessive reliance on AI-generated content can diminish the artfulness and critical pedagogical thinking of teaching and professional autonomy. This substantiates the significance of Teacher Agency and AI and the necessity to carefully assess and refine AI-generated materials prior to teaching them to students.

AI Applications in Personalized Learning Systems

Personalized Learning Systems are the most powerful AI Applications to Education as they enable instruction content to be tailored to performance, preferences, speed, and cognitive requirements of the students. Adaptive Learning Technologies are based on machine learning, predictive analytics, and learner profiles to personalize education [28,84-86]. These systems have the capability to suggest content, modify the challenge of exercises, and give targeted support as it happens. Personalized learning apps are especially beneficial in multiple-classrooms, as they can be used by instructors to deal with differences in learning style, language competency, and background knowledge. Motivated by AI-enhanced personalization, K-12 and higher education are beginning to adopt a more individualized approach to education, as this will enhance service delivery to students and enable teachers to better handle a bigger cohort. The existing tendencies indicate that AI-based personalization will keep growing at an alarming rate as learning institutions will target more effective and scalable methods of differentiated instruction. An expanding AI education market indicates a greater need and use of more advanced assessment tools, content delivery based on users, and the collaboration facilitated by AI.

AI Applications in Intelligent Tutoring Systems

Intelligent Tutoring Systems are also one of the oldest application of Artificial Intelligence to Education since it offers personalized education and feedback that is analogous to human tutoring. They employ student modeling, adaptive algorithms, and knowledge tracing methods that help these systems detect learning gaps and dynamically adapt the content [87,88]. ITS are particularly effective in the fields of mathematics, science, and language teaching due to the ability to identify misunderstandings, as well as prescribe specific remedies. Intelligent Tutoring Systems have a pedagogical benefit in that they can be used to directly offer real-time assistance during internationally classroom time, effectively increasing the teacher presence and minimizing the disparities in access to personalized teaching. New AI-driven schools are creating an increase in dependence on AI tutors to teach core subject material as teachers work on life skills, creativity, emotional, mentorship. Meanwhile, the uncontrolled nature of AI tutoring systems and their potential influence on student-teacher relationships or ongoing collaborative learning are also of concern.

AI Applications in Assessment and Automated Feedback

Assessment and Automated Feedback Systems powered by AI have emerged as one of the key AI Applications in Education since they enable the teacher to assess student performance more effectively and consistently. AI systems have the ability to both automatically grade quizzes, essays, short answers and assignments as well as provide real time feedback to learners. The use of Natural Language Processing in Education is gradually gaining popularity as a way of analyzing the student writing, detecting misconceptions, and offering formative assessment based on structure, coherence, grammar and critical thinking. They are particularly vital in Teacher Professional Development since less administrative work goes into grading and teachers have time to devote to instructional planning and student support. Continues formative assessment through automated feedback becomes a possibility as well. Nonetheless, there are still issues about the reliability of automated marking, cultural and linguistic bias and the danger that teachers will place undue confidence in AI-generated assessment. The rising popularity of AI-based grading systems have consequently led to the growing impetus to seek Explainable AI in Education and more open assessment methods.

AI Applications in Teacher Professional Development

One of the most recent and rapidly expanding uses of Artificial Intelligence in Education lies in Professional Development of Teachers. Professional learning platforms powered by AI now offer personalized learning journeys, self-paced courses and adaptive suggestions, based on the needs, interests, and contexts of the classroom, of the teacher. AI has the potential to suggest workshops, detect skill gaps, and create customized learning plans in accordance with licensure avenues and career aspirations of teachers. On current trends, teacher training in AI is increasing at an exceptionally high rate and significantly, a greater number of educators are getting at least one session of professional development in AI over the past few years than before. The theme of AI Literacy and Educators seeks to deepen knowledge of AI Literacy in professional development, ethical use of AI, workflow automation, and strategies to integrate AI into classrooms [89-91]. There is also an emerging evidence that teachers are applying generative AI both to professional development that is self-directed, reflective, and instructional experimentation. These trends suggest that AI is impacting not just the classroom instruction, but how educational professionals learn, upscale, and pursue a life-long professional education as well.

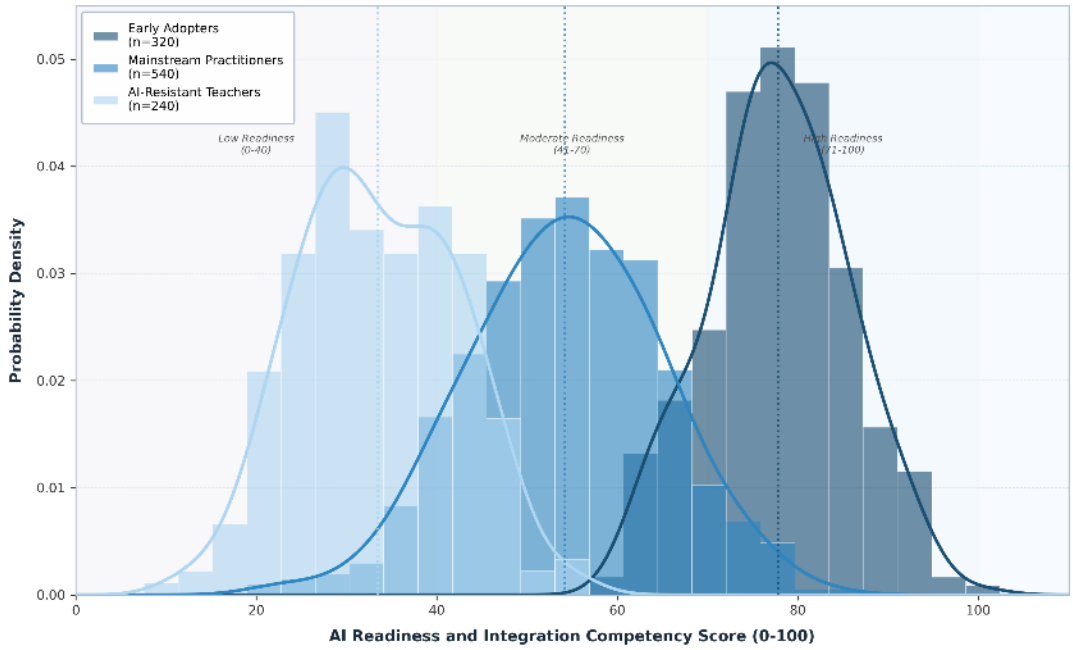

Fig. 6 Distribution of AI Readiness and Integration Competency Scores Across Teacher Cohorts

Fig. 6 represents a overlapping histogram with superimposed kernel density estimation curves profiles the distribution of AI readiness and integration competency scores across three empirically meaningful teacher cohorts: early adopters, mainstream practitioners, and AI-resistant teachers. The trimodal structure of the combined distribution reflects a stratified teaching workforce, where each group clusters around a distinct readiness centroid. Early adopters peak near a score of 78, displaying a relatively tight distribution consistent with a self-selected, highly motivated subgroup. Mainstream practitioners center around 55 with broader dispersion, capturing the heterogeneous majority navigating institutional expectations and limited training support. AI-resistant teachers cluster at approximately 33, with their distribution extending into the low-readiness zone, underscoring the persistence of adoption barriers rooted in pedagogical skepticism, digital anxiety, and ethical concern. The background shading delineates three readiness zones, offering an interpretive scaffold for policymakers designing professional development interventions. The KDE curves smooth over sampling noise to reveal underlying distributional patterns, while the dotted mean lines anchor each group's central tendency. This figure is especially pertinent to research on differentiated professional development strategies and the human factors moderating AI integration in education.

AI Applications in Learning Analytics and Predictive Analytics

The use of Learning Analytics and Predictive Analytics in Education is common to trace student engagement, at-risk learners, and assist in making data-informed decisions. They are used to gather and process student information on attendance, attendance, assessment results, and online learning activity. The predictive models can help pinpoint students who might be likely to fail, drop in interest or drop out, and teach them early to prevent them. To teachers, such analytics programs can be helpful to understand the effectiveness of instruction and classroom performance. Learning analytics dashboards are becoming a common feature in educational institutions as they strive to visualize the advancement of students and implement focused interventions based on the view [36,92-94]. Simultaneously, predictive analytics applications also feature significant problems with regard to surveillance, labeling, and Algorithmic Bias in Education. Unless predictive systems are trained using complete and unbiased datasets, they can stigmatize some students unfairly or support the status status quo. This supports the necessity to have Ethical AI in Education and explicit data governance policies.

AI Applications in Conversational AI and Chatbots

The use of conversational AI in Education and AI Chatbots to learn is increasingly gaining applications in assisting students, tutoring, and teacher productivity. AI chatbots are able to provide response to student questions, respond to and explain, to guide revision, and to support homework. These systems rely on Natural Language Processing and Large Language Models to generate two-way dialogue which can replicate one-to-one support. Conversational AI is also being used by teachers to do administrative work, including writing emails, creating classroom announcements, creating handouts, and responding to frequently asked student questions. AI chatbots may also be used in Teacher Professional Development as virtual mentors, which offer pedagogical support, offer teaching techniques, and assist the educator with troubleshooting classroom issues. Nevertheless, some worry that excessive use of chatbots can decrease the instances of genuine interaction and diminish the ability of students in critical thinking. According to surveys, there is a concern among a lot of teachers that students are overrelying on AI to write, think, and solve problems.

AI Applications in Classroom Management

The use of AI in classroom management is gaining considerable significance due to the increasing number of requirements of teachers connected with the attendance tracking, behavioral monitoring, communication, and overload management. Facial recognition, speech recognition, and records of the logs can be automated by AI-based systems and apply to attendance. They are also able to track classroom interactions, detect gaps of participation and create behavior reports on students. Educators are also trying AI tools to better deal with routine duties of the administration, facilitate the communication process, and better plan classroom processes. AI systems are useful in the scheduling of activities, provision of reminders, maintaining records of grading activities, and generate personalised learning plans. Increasing focus in emerging teacher training programs on the use of AI tools being used to enhance efficiency and decrease burnout includes productivity assistants and document automation systems. But the classroom management applications also cause an issue of surveillance, confidentiality and gathering of sensitive student information.

AI Applications in Inclusive and Special Education

Artificial AI in the field of Education can be potentially very helpful in enhancing access and inclusion to students with disabilities and in students with different learning needs. Natural Language Processing, Speech Recognition in Education and adaptive learning systems are more commonly being utilized in order to assist learners with hearing impairments, speech difficulties, learning disabilities and with multilingual needs [95-97]. AI technology can create captions, text-to-speech and speech-to-text features, translation, and reading difficulty levels. Such apps are especially significant in the sense that they will allow a more equal distribution of access to education and assist teachers in managing in heterogeneous classrooms. AI-assisted accessibility can enable students to be more engaged in classroom activities and minimize impediments to learning. Nevertheless, as well, it is feared that schools with low resources will not have access to high-level assistive technologies, which supports

Digital Equity in AI Adoption dilemmas. The affordability, cultural responsiveness, and inclusion of AI-supported tools can be viewed as a promising area of future development.

AI Applications in STEM Education and Educational Robotics

One of the most vibrant fields of AI Adoption in Education is STEM education as increasingly, AI tools are used to aid in coding, robotics, computational thinking, and problem-solving. Education Robotics/AI-driven STEM solutions enable students to have practical learning opportunities, that develop creativity, and collaboration, as well as digital literacy. Such applications are particularly valuable in the sciences and mathematics as they enable students to access simulations, code labs and virtual laboratories. AI is also being utilized by teachers in STEM classrooms to create coding problems, offer automatic feedback, and customize learning. Scholarship indicates that Intelligent Tutoring Systems, learning analytics, computer vision, robotics, and AI-enhanced extended reality are emerging as a more significant focus in elementary and secondary STEM education. Simultaneously, there is a concern of barriers in infrastructure, privacy, and disproportionate roll out of enhanced technologies in the various schools and regions.

AI Applications in Teacher-AI Co-Design and Collaboration

Teacher-AI co-design is one of the youngest fields of AI Applications in Education, in which teachers and AI systems jointly design instructional materials, assessments and learning experiences. However, instead of seeing AI as an adversary of teachers, most educators are beginning to consider AI as an instructional companion that expands its teaching capabilities without usurping the human judgment and control [97-99]. The results of new pilots run in classrooms indicate that educators engage AI in co-designing tasks, facilitating student inquiry, analyzing growth trends, and providing feedback. The teachers are at the centre of the decision process and AI is seen as an assistant that facilitates handling the complexity and enhancing responsiveness. This model of Human-AI Collaboration in Education is an emerging shift to a bigger code of hybrids in intelligence where human expertise and AI capabilities complete each other. The use of such methods is becoming more sustainable and ethically responsible than complete automation since they do not eliminate Teacher Agency or AI and exploit the efficiency of intelligent systems.

AI Applications in AI Literacy and Responsible Use Education

Basic AI Literacy among Educators and students has emerged as one of the most crucial areas of use due to the growing importance to educators and students on how to not only use AI but also judge, critically think, and responsibly act regarding it. Some applications of AI literacy involve training on prompt engineering, critical analysis of AI outputs, ethical decision-making, data privacy, and responsible use policies.

Schools are actively creating AI literacy courses, educator training initiatives and policy models to enable teachers to responsibly introduce AI in the classroom. There is a growing demand and necessity to develop stricter regulatory frameworks and professional guidance when many teachers are utilizing AI in practice despite a lack of formal policies at the school level [6,100-103]. The trend of AI literacy programs insists more on the importance of educators being generally familiar with how AI functions, when to employ it, and where the weaknesses and dangers are thresholded. The Future of AI Adoption in Education, thus, will probably be conditional on both access to technology, as well as the capacity of teachers and students to apply AI in a critical, ethical, and responsible way.

4. Discussion

The results of this extensive literature review about Artificial Intelligence in Education demonstrate the speed of the changes that are happening and the rapidly increasing rates of using AI in Education, especially in teaching activities and Teacher Professional Development. Recent developments suggest that the invasion of Generative AI into Teaching is reaching an unparalleled level, with a high percentage of educational establishments actively introducing AI tools into the instructional design, evaluation, and administration processes. There is evidence that as many as 86 per cent of learning institutions are

actively utilizing technologies of generative AI, with the greater dynamics of technology uptake in the education sector than at any previous time. Such a fast spreading highlights the potential of AI Applications in Education that could dramatically transform the Personalized Learning Systems, routine teaching jobs, and data-driven decision-making based on Learning Analytics. Meanwhile, the growing adoption of AI indicates a significant paradigm shift in wanting teachers to stop as knowledge transmitters and become Human-AI Collaboration in Education facilitators. Nonetheless, such change is not evenly distributed as the inequality in access, infrastructure, and AI Literacy from the Educator Perspective still influence the uptake pattern among various educational settings.

One key point that comes out in the literature is the disproportion between AI Applications in teaching and its use in Teacher Professional Development. Whereas most works concentrate on in-classroom based implementations like Intelligent Tutoring Systems, AI-based Assessment and Adaptive Learning Technologies, much less literature is found on how teachers should be trained to successfully implement the systems. This is a worrying imbalance considering teacher competency is one of the main factors in determining AI integration success. Empirical data show that despite the growth of teacher training in AI, with about half of the teachers undergoing some type of AI-related professional training, there are still considerable gaps in the depth, quality, and access of AI training. This implies that Professional Learning Ecosystems are at the infancy of their course and need more context-specific, scalable, structured approaches. Moreover, the increasing pressure on AI Literacy among Educators, as well as the ability to promptly engineer, interpret data and/or conduct ethically, demonstrates that the current paradigm of professional development will not be adequate when forming the professional requirements of the AI-driven educational setting.

The other important aspect of the discussion is associated with the pedagogical implications of AI Models in Education and AI Technologies in Education. It is clearly shown throughout the literature that AI-based teaching promotes efficiency, provides opportunities to get immediate feedback, and makes the learning process more personalized [104-106]. Learning Analytics platforms and Predictive Analytics in Education are some examples of AI-based systems that enable educators to track the progress of students more efficiently and take proactive measures to do so. But the pedagogical implications are intricate and manifold. Though AI may boost the interest among students and nurture differentiated instruction, it is becoming increasingly evident that dependence on AI tools can weaken critical thinking, creativity, and autonomy in learning. Recent research results show that a considerable part of the teaching population feels like student cognitive interest has been lowered as a result of more intensive use of AI tools, posing critical concerns regarding the future effects of AI on the learning process in the long run. This is to underscore the necessity of balance in pedagogical practice that incorporate AI without sacrificing the main ideals of human-centered education.

Table 1: AI Applications, Techniques, and Technologies in Education

Sr. No.	Application	Techniques	Technologies	Models
1	Lesson Planning	NLP, Generative AI	LLMs	Transformer Models
2	Assessment	NLP, ML	Automated Grading Systems	Predictive Models
3	Personalized Learning	ML, RL	Adaptive Platforms	Recommendation Models
4	Tutoring	Knowledge Tracing	ITS	Hybrid Models
5	Feedback	NLP	Feedback Engines	Deep Learning Models
6	Analytics	Data Mining	Dashboards	Predictive Models
7	Classroom Management	CV, Speech AI	Monitoring Systems	ML Models
8	Language Learning	NLP	Translation Systems	LLMs
9	STEM Education	Robotics, ML	Simulations	Reinforcement Models
10	PD Systems	ML	AI Platforms	Recommendation Models
11	Chatbots	NLP	Conversational Systems	LLMs
12	Inclusion	Speech AI	Assistive Tools	Multimodal Models
13	VR/AR Learning	XR	Immersive Systems	Simulation Models
14	Content Creation	Generative AI	Content Tools	Foundation Models
15	Collaboration	AI Agents	Cloud Platforms	Hybrid Models
16	Evaluation	Analytics	Monitoring Tools	ML Models
17	Engagement Tracking	CV	Sensors	Deep Learning
18	Curriculum Design	AI Planning	LMS	Transformer Models

19	Knowledge Mapping	Data Mining	Analytics Tools	Bayesian Models
20	Policy Support	Analytics	Governance Systems	Explainable Models

Ethical aspect of AI Adoption in Education is one of the most vital issues discovered in the literature. Ethical AI in Education deals with such issues as Algorithmic Bias in Education, Data Privacy in Educational AI, transparency, accountability, and fairness. The trend of using AI-based systems in assessment, prediction, and decision-making makes one unworried about the probability of bias and discrimination. Predictive models, e.g., can unintentionally improve existing distributive differences when trained on biased data, automated evaluation systems can neglect cultural and linguistic differences. In addition, there is a notable security issue with the wide range of student data gathered and analyzed in Learning Analytics and Educational Data Mining. The literature highlights the fact that the AI Governance in Schools is an underdeveloped area, and most of the institutions do not have clear policies and guidelines, or regulatory frameworks regarding the implementation of AI. Such an imbalance between technological innovation and policy formulation highlights why it is crucial to create strong governance frameworks that will ensure a transparent, ethical, and responsible deployment of AI.

The role of Human-AI Collaboration in Education is yet another theme of the discussion, but it is currently being proposed as the core of Future of Teaching with AI. Instead of ousting teachers, AI is becoming more and more of an augmentation that augments teacher abilities and adds to collaborative decision making [107-109]. Increasingly popular are hybrid approaches to teaching, in which teachers and AI work together to design educational content, interpolate student data, and provide feedback. This change signifies a transition to hybrid intelligence systems where human knowledge functions and machine effectiveness are effectively used. Nonetheless, Teacher Agency and AI is a burning issue, which is essential because substantial use of AI tools can trigger the process of the deprofessionalization of teaching. Sustainable and ethical integration of AI is that pedagogical choices cannot be controlled by the authors of the learning process or by AI, but it should be central to the process.

Table 2: Challenges, Opportunities, and Future Directions of AI in Education

Sr. No.	Challenge	Opportunity	Future Direction
1	Algorithmic Bias	Fair AI systems	Bias mitigation frameworks
2	Data Privacy	Secure analytics	Privacy-preserving AI
3	Teacher Training Gaps	AI Literacy Programs	Scalable PD models
4	Overreliance on AI	Balanced pedagogy	Human-AI synergy
5	Infrastructure Limitations	Cloud AI platforms	Global access expansion
6	Ethical Concerns	Responsible AI	Governance policies
7	Lack of Transparency	Explainable AI	Interpretable models
8	Student Dependency	Critical thinking focus	AI-assisted cognition
9	Unequal Access	Inclusive AI tools	Digital equity initiatives
10	Resistance to Change	Awareness programs	Change management
11	Policy Gaps	Regulation frameworks	Global AI standards
12	Skill Gaps	Upskilling programs	Lifelong learning ecosystems
13	Cost Barriers	Open-source AI	Affordable solutions
14	Data Misuse	Ethical guidelines	Secure infrastructures
15	Teacher Workload	Automation tools	Smart workflows
16	Assessment Bias	Fair evaluation	Adaptive assessment
17	Limited Research	Interdisciplinary studies	Longitudinal research
18	Fragmented Systems	Integrated platforms	Unified ecosystems
19	Low Trust	Transparency tools	Trustworthy AI
20	Rapid Change	Continuous learning	Adaptive education systems

Besides the issues related to pedagogy and ethics, the literature also singles out the number of systemic issues that affect the AI Adoption in Education. They are infrastructure constraints, insufficiency of funding, change resistance and digital access inequity. Digital Equity in AI Adoption has continued to pose a major challenge especially among low-resource environments characterized by a drawback of

access to sophisticated AI technologies and training access. Moreover, the speed of AI is growing faster than the education institutions, which creates discrepancies in technology and how institutions are prepared to meet the changes. The literature also points to the need to work interdisciplinarily between educators, technologists, policymakers, and researchers to deal with these issues and create holistic solutions. Summing up, it is possible to note that the process of Artificial Intelligence implementation in Education is both overwhelming and sophisticated, as it has outstanding prospects of improving the teaching and Teacher Professional Development but introduces serious issues that one will have to address with special care. Whether AI will thrive in education will be determined by how the stakeholders can walk both the side of innovation and ethical responsibility, promote equitable access, and create Human-AI Collaboration in Education that will improve instead of hinder the function of teachers.

5. Conclusion

This integrative PRISMA-oriented literature review on utilization of Artificial Intelligence in Learning shows that the implementation of Generative AI in Teaching and Teacher Professional Development is not only a technological change but an extensive change of pedagogical ecosystem, teaching identity and institutional organization. The synthesis of recent research materials indicates that AI Adoption in Education is materially faster than ever before and that a significant portion of teachers have implemented AI-enhanced instruction, intelligent tutoring, and AI-enhanced evaluation into their day to day lives. This adoption pace is supported by the fact that most educators are actively taking the AI tools to lesson planning, content creation, and personal learning platforms, which is reflective of a larger scale shift towards digital pedagogy change and the use of data in optimal ways to inform teaching practices.

The results also highlight the fact that Teacher Professional Development is becoming a key factor of successful AI implementation, and AI-powered professional learning environments provide context-sensitive, tailored solutions to the needs and aims of the educators and the institution. Nonetheless, even with such changes, the review notes that there have remained disparities in AI literacy among educators, unequal access to training materials, a lack of correspondence between the professional development programs and classroom implementations. This disequilibrium shows the continuing applicability of theory like the Technology Acceptance Model and Unified Theory of Acceptance and Use of Technology in elucidating differences in patterns of adoption and resistance to technology among teachers. Further, the Human-AI Collaboration in Education is an emerging concept that implies changes in tool-based use and forming a partnership with AI where teachers and AI systems co-build knowledge, make better decisions, and differentiate instruction.

Simultaneously, the paper indicates that Ethical AI in Education has been an urgent issue, and the presence of an algorithmic bias in education, data privacy in educational AI, as well as academic integrity and AI threatens to undermine fair and responsible implementation. The recently emerging evidence suggests that the extensive use of AI can reinforce the existing inequality and lessen the trust in the educational systems unless the involved schools adopt AI governance and specific policy frameworks. Moreover, fears of AI tools overuse and rationality loss highlight the need to balance integrating the human aspect of teaching and learning.

The future of AI in education and teacher education is the creation of all-encompassing, multidisciplinary approaches that combine technological innovation, pedagogical theory, and ethical protection and considerate design practices. Future studies need to concentrate on longitudinal studies on a long-term alteration in AI-developed curriculum design, implementation of adaptive learning technologies with widespread applicability, and applicability of AI-based professional advancement models in a range of educational situations. Moreover, the urgency of examining policy based strategies that can inform digital equity in the adoption of AI and promote teacher agency and autonomy also exists. Finally, sustainable AI development in the educational context will be heavily reliant on how the stakeholder groups will accordingly balance the innovation and duty factor, such that AI can become an agent of transformational, equitable, and human-centered educational futures.

Conflict of interest

The authors declare no conflicts of interest.

References

[1] Law L. Application of generative artificial intelligence (GenAI) in language teaching and learning: A scoping literature review. Computers and Education Open. 2024 Jun 1;6:100174. https://doi.org/10.1016/j.caeo.2024.100174

[2] Barrett A, Pack A. Not quite eye to AI: Student and teacher perspectives on the use of generative artificial intelligence in the writing process. International Journal of Educational Technology in Higher Education. 2023 Nov 10;20(1):59. https://doi.org/10.1186/s41239-023-00427-0

[3] Sauder M, Tritsch T, Rajput V, Schwartz G, Shoja MM. Exploring generative artificial intelligence-assisted medical education: assessing case-based learning for medical students. Cureus. 2024 Jan 9;16(1). https://doi.org/10.7759/cureus.51961

[4] Li KC, Wong BT. Artificial intelligence in personalised learning: a bibliometric analysis. Interactive Technology and Smart Education. 2023 Sep 1;20(3):422-45. https://doi.org/10.1108/ITSE-01-2023-0007

[5] Lin H, Chen Q. Artificial intelligence (AI)-integrated educational applications and college students' creativity and academic emotions: students and teachers' perceptions and attitudes. BMC psychology. 2024 Sep 16;12(1):487. https://doi.org/10.1186/s40359-024-01979-0

[6] Chiu TK, Meng H, Chai CS, King I, Wong S, Yam Y. Creation and evaluation of a pretertiary artificial intelligence (AI) curriculum. IEEE Transactions on Education. 2021 Jun 15;65(1):30-9. https://doi.org/10.1109/TE.2021.3085878

[7] Maghsudi S, Lan A, Xu J, van Der Schaar M. Personalized education in the artificial intelligence era: what to expect next. IEEE Signal Processing Magazine. 2021 Apr 28;38(3):37-50. https://doi.org/10.1109/MSP.2021.3055032

[8] Ahmad K, Iqbal W, El-Hassan A, Qadir J, Benhaddou D, Ayyash M, Al-Fuqaha A. Data-driven artificial intelligence in education: A comprehensive review. IEEE Transactions on Learning Technologies. 2023 Sep 12;17:12-31. https://doi.org/10.1109/TLT.2023.3314610

[9] Lee GG, Mun S, Shin MK, Zhai X. Collaborative learning with artificial intelligence speakers: pre-service elementary science teachers' responses to the prototype. Science & Education. 2025 Apr;34(2):847-75. https://doi.org/10.1007/s11191-024-00526-y

[10] An X, Chai CS, Li Y, Zhou Y, Yang B. Modeling students' perceptions of artificial intelligence assisted language learning. Computer Assisted Language Learning. 2025 Jul 4;38(5-6):987-1008. https://doi.org/10.1080/09588221.2023.2246519

[11] Leal Filho W, Ribeiro PC, Mazutti J, Lange Salvia A, Bonato Marcolin C, Lima Silva Borsatto JM, Sharifi A, Sierra J, Luetz J, Pretorius R, Viera Trevisan L. Using artificial intelligence to implement the UN sustainable development goals at higher education institutions. International Journal of Sustainable Development & World Ecology. 2024 Aug 17;31(6):726-45. https://doi.org/10.1080/13504509.2024.2327584

[12] Gardner J, O'Leary M, Yuan L. Artificial intelligence in educational assessment:'Breakthrough? Or buncombe and ballyhoo?'. Journal of Computer Assisted Learning. 2021 Oct;37(5):1207-16. https://doi.org/10.1111/jcal.12577

[13] Slimi Z, Carballido BV. Navigating the Ethical Challenges of Artificial Intelligence in Higher Education: An Analysis of Seven Global AI Ethics Policies. TEM journal. 2023 May 1;12(2). https://doi.org/10.18421/TEM122-02

[14] Alam A, Mohanty A. Business models, business strategies, and innovations in EdTech companies: integration of learning analytics and artificial intelligence in higher education. In2022 IEEE 6th Conference on Information and Communication Technology (CICT) 2022 Nov 18 (pp. 1-6). IEEE. https://doi.org/10.1109/CICT56698.2022.9997887

[15] Alam A, Mohanty A. Foundation for the future of higher education or 'misplaced optimism'? Being human in the age of artificial intelligence. InInternational Conference on Innovations in Intelligent Computing and Communications 2022 Dec 16 (pp. 17-29). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-23233-6_2

[16] Salas-Pilco SZ, Xiao K, Hu X. Artificial intelligence and learning analytics in teacher education: A systematic review. Education sciences. 2022 Aug 20;12(8):569. https://doi.org/10.3390/educsci12080569

[17] King MR, ChatGPT. A conversation on artificial intelligence, chatbots, and plagiarism in higher education. Cellular and molecular bioengineering. 2023 Feb;16(1):1-2. https://doi.org/10.1007/s12195-022-00754-8

[18] Drach I, Petroye O, Borodiyenko O, Reheilo I, Bazeliuk O, Bazeliuk N, Slobodianiuk O. The use of artificial intelligence in higher education. International Scientific Journal of Universities and Leadership. 2023 Jun 30(15):66-82. https://doi.org/10.31874/2520-6702-2023-15-66-82

[19] Liang JC, Hwang GJ, Chen MR, Darmawansah D. Roles and research foci of artificial intelligence in language education: An integrated bibliographic analysis and systematic review approach. Interactive Learning Environments. 2023 Oct 3;31(7):4270-96. https://doi.org/10.1080/10494820.2021.1958348

[20] Memarian B, Doleck T. Fairness, Accountability, Transparency, and Ethics (FATE) in Artificial Intelligence (AI) and higher education: A systematic review. Computers and Education: Artificial Intelligence. 2023 Jan 1;5:100152. https://doi.org/10.1016/j.caeai.2023.100152

[21] Munir H, Vogel B, Jacobsson A. Artificial intelligence and machine learning approaches in digital education: A systematic revision. Information. 2022 Apr 17;13(4):203. https://doi.org/10.3390/info13040203

[22] Ayanwale MA, Frimpong EK, Opesemowo OA, Sanusi IT. Exploring factors that support pre-service teachers' engagement in learning artificial intelligence. Journal for STEM Education Research. 2025 Apr;8(2):199-229. https://doi.org/10.1007/s41979-024-00121-4

[23] Ruiz Viruel S, Sánchez Rivas E, Ruiz Palmero J. The role of artificial intelligence in project-based learning: Teacher perceptions and pedagogical implications. Education Sciences. 2025 Jan 26;15(2):150. https://doi.org/10.3390/educsci15020150

[24] Hanna MG, Pantanowitz L, Dash R, Harrison JH, Deebajah M, Pantanowitz J, Rashidi HH. Future of artificial intelligence (AI)-machine learning (ML) trends in pathology and medicine. Modern Pathology. 2025 Jan 4:100705. https://doi.org/10.1016/j.modpat.2025.100705

[25] Alier M, Pereira J, Garcia-Penalvo FJ, Casan MJ, Cabre J. LAMB: An open-source software framework to create artificial intelligence assistants deployed and integrated into learning management systems. Computer Standards & Interfaces. 2025 Mar 1;92:103940. https://doi.org/10.1016/j.csi.2024.103940

[26] Yuan L, Liu X. The effect of artificial intelligence tools on EFL learners' engagement, enjoyment, and motivation. Computers in Human Behavior. 2025 Jan 1;162:108474. https://doi.org/10.1016/j.chb.2024.108474

[27] Karataş F, Eriçok B, Tanrikulu L. Reshaping curriculum adaptation in the age of artificial intelligence: Mapping teachers' AI-driven curriculum adaptation patterns. British Educational Research Journal. 2025 Feb;51(1):154-80. https://doi.org/10.1002/berj.4068

[28] Ahuja AS, Polascik BW, Doddapaneni D, Byrnes ES, Sridhar J. The digital metaverse: Applications in artificial intelligence, medical education, and integrative health. Integrative Medicine Research. 2023 Mar 1;12(1):100917. https://doi.org/10.1016/j.imr.2022.100917

[29] Sperling K, Stenberg CJ, McGrath C, Åkerfeldt A, Heintz F, Stenliden L. In search of artificial intelligence (AI) literacy in teacher education: A scoping review. Computers and Education Open. 2024 Jun 1;6:100169. https://doi.org/10.1016/j.caeo.2024.100169

[30] Sabri H, Saleh MH, Hazrati P, Merchant K, Misch J, Kumar PS, Wang HL, Barootchi S. Performance of three artificial intelligence (AI)-based large language models in standardized testing; implications for AI-assisted dental education. Journal of periodontal research. 2025 Feb;60(2):121-33. https://doi.org/10.1111/jre.13323

[31] Kamila MK, Jasrotia SS. Ethical issues in the development of artificial intelligence: recognizing the risks. International Journal of Ethics and Systems. 2025 Jan 30;41(1):45-63. https://doi.org/10.1108/IJOES-05-2023-0107

[32] Nemorin S, Vlachidis A, Ayerakwa HM, Andriotis P. AI hyped? A horizon scan of discourse on artificial intelligence in education (AIED) and development. Learning, Media and Technology. 2023 Jan 2;48(1):38-51. https://doi.org/10.1080/17439884.2022.2095568

[33] Su J, Yang W. Artificial intelligence in early childhood education: A scoping review. Computers and Education: Artificial Intelligence. 2022 Jan 1;3:100049. https://doi.org/10.1016/j.caeai.2022.100049

[34] Alqahtani N, Wafula Z. Artificial intelligence integration: Pedagogical strategies and policies at leading universities. Innovative Higher Education. 2025 Apr;50(2):665-84. https://doi.org/10.1007/s10755-024-09749-x

[35] Hardaker G, Glenn LE. Artificial intelligence for personalized learning: a systematic literature review. The International Journal of Information and Learning Technology. 2025 Jan 13;42(1):1-4. https://doi.org/10.1108/IJILT-07-2024-0160

[36] Tuygunov N, Samaranayake L, Khurshid Z, Rewthamrongsris P, Schwendicke F, Osathanon T, Yahya NA. The transformative role of artificial intelligence in dentistry: a comprehensive overview part 2: the promise and perils, and the international dental federation communique. International Dental Journal. 2025 Feb 25. https://doi.org/10.1016/j.identj.2025.02.006

[37] Wang C, Wang H, Li Y, Dai J, Gu X, Yu T. Factors influencing university students' behavioral intention to use generative artificial intelligence: Integrating the theory of planned behavior and AI literacy. International Journal of Human-Computer Interaction. 2025 Jun 3;41(11):6649-71. https://doi.org/10.1080/10447318.2024.2383033

[38] Han X, Xiao S, Sheng J, Zhang G. Enhancing efficiency and decision-making in higher education through intelligent commercial integration: Leveraging artificial intelligence. Journal of the Knowledge Economy. 2025 Mar;16(1):1546-82. https://doi.org/10.1007/s13132-024-01868-2

[39] Cheung KK, Long Y, Liu Q, Chan HY. Unpacking epistemic insights of artificial intelligence (AI) in science education: A systematic review. Science & Education. 2025 Apr;34(2):747-77. https://doi.org/10.1007/s11191-024-00511-5

[40] Alier M, Peñalvo FJ, Camba JD. Generative Artificial Intelligence in Education: From Deceptive to Disruptive. International Journal of interactive multimedia and artificial intelligence. 2024 Mar 1;8(5):5-14. https://doi.org/10.9781/ijimai.2024.02.011

[41] Choudhary OP, Infant SS, Chopra H, Manuta N. Exploring the potential and limitations of artificial intelligence in animal anatomy. Annals of Anatomy-Anatomischer Anzeiger. 2025 Feb 1;258:152366. https://doi.org/10.1016/j.aanat.2024.152366

[42] Kong SC, Korte SM, Burton S, Keskitalo P, Turunen T, Smith D, Wang L, Lee JC, Beaton MC. Artificial Intelligence (AI) literacy-an argument for AI literacy in education. Innovations in education and teaching international. 2025 Mar 4;62(2):477-83. https://doi.org/10.1080/14703297.2024.2332744

[43] Mao J, Chen B, Liu JC. Generative artificial intelligence in education and its implications for assessment. TechTrends. 2024 Jan;68(1):58-66. https://doi.org/10.1007/s11528-023-00911-4

[44] Vieriu AM, Petrea G. The impact of artificial intelligence (AI) on students' academic development. Education Sciences. 2025 Mar 11;15(3):343. https://doi.org/10.3390/educsci15030343

[45] Topaz M, Peltonen LM, Michalowski M, Stiglic G, Ronquillo C, Pruinelli L, Song J, O'connor S, Miyagawa S, Fukahori H. The ChatGPT effect: nursing education and generative artificial intelligence. Journal of Nursing Education. 2025 Jun 1;64(6):e40-3. https://doi.org/10.3928/01484834-20240126-01

[46] Shahzad MF, Xu S, Asif M. Factors affecting generative artificial intelligence, such as ChatGPT, use in higher education: An application of technology acceptance model. British Educational Research Journal. 2025 Apr;51(2):489-513. https://doi.org/10.1002/berj.4084

[47] Bewersdorff A, Hartmann C, Hornberger M, Seßler K, Bannert M, Kasneci E, Kasneci G, Zhai X, Nerdel C. Taking the next step with generative artificial intelligence: The transformative role of multimodal large language models in science education. Learning and Individual Differences. 2025 Feb 1;118:102601. https://doi.org/10.1016/j.lindif.2024.102601

[48] Malik AR, Pratiwi Y, Andajani K, Numertayasa IW, Suharti S, Darwis A. Exploring artificial intelligence in academic essay: higher education student's perspective. International Journal of Educational Research Open. 2023 Dec 1;5:100296. https://doi.org/10.1016/j.ijedro.2023.100296

[49] Baidoo-Anu D, Ansah LO. Education in the era of generative artificial intelligence (AI): Understanding the potential benefits of ChatGPT in promoting teaching and learning. Journal of AI. 2023 Dec 31;7(1):52-62. https://doi.org/10.61969/jai.1337500

[50] Chiu TK, Xia Q, Zhou X, Chai CS, Cheng M. Systematic literature review on opportunities, challenges, and future research recommendations of artificial intelligence in education. Computers and Education: Artificial Intelligence. 2023 Jan 1;4:100118. https://doi.org/10.1016/j.caeai.2022.100118

[51] Akgun S, Greenhow C. Artificial intelligence in education: Addressing ethical challenges in K-12 settings. AI and Ethics. 2022 Aug;2(3):431-40. https://doi.org/10.1007/s43681-021-00096-7

[52] Pratama MP, Sampelolo R, Lura H. Revolutionizing education: harnessing the power of artificial intelligence for personalized learning. Klasikal: Journal of education, language teaching and science. 2023 Aug 10;5(2):350-7. https://doi.org/10.52208/klasikal.v5i2.877

[53] Tan X, Cheng G, Ling MH. Artificial intelligence in teaching and teacher professional development: A systematic review. Computers and Education: Artificial Intelligence. 2025 Jun 1;8:100355. https://doi.org/10.1016/j.caeai.2024.100355

[54] Abbasi BN, Wu Y, Luo Z. Exploring the impact of artificial intelligence on curriculum development in global higher education institutions. Education and Information Technologies. 2025 Jan;30(1):547-81. https://doi.org/10.1007/s10639-024-13113-z

[55] Topali P, Ortega-Arranz A, Rodríguez-Triana MJ, Er E, Khalil M, Akçapınar G. Designing human-centered learning analytics and artificial intelligence in education solutions: a systematic literature review. Behaviour & Information Technology. 2025 Mar 16;44(5):1071-98. https://doi.org/10.1080/0144929X.2024.2345295

[56] Huang X. Aims for cultivating students' key competencies based on artificial intelligence education in China. Education and Information Technologies. 2021 Sep;26(5):5127-47. https://doi.org/10.1007/s10639-021-10530-2

[57] Lampou R. The integration of artificial intelligence in education: Opportunities and challenges. Review of Artificial Intelligence in Education. 2023 Aug 18;4:e15-. https://doi.org/10.37497/rev.artif.intell.educ.v4i00.15

[58] Pham ST, Sampson PM. The development of artificial intelligence in education: A review in context. Journal of Computer Assisted Learning. 2022 Oct;38(5):1408-21. https://doi.org/10.1111/jcal.12687

[59] Chen X, Zou D, Xie H, Cheng G, Liu C. Two decades of artificial intelligence in education. Educational Technology & Society. 2022 Jan 1;25(1):28-47.

[60] Ouyang F, Jiao P. Artificial intelligence in education: The three paradigms. Computers and Education: Artificial Intelligence. 2021 Jan 1;2:100020. https://doi.org/10.1016/j.caeai.2021.100020

[61] Bhutoria A. 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. 2022 Jan 1;3:100068. https://doi.org/10.1016/j.caeai.2022.100068

[62] Okunlaya RO, Syed Abdullah N, Alias RA. Artificial intelligence (AI) library services innovative conceptual framework for the digital transformation of university education. Library Hi Tech. 2022 Dec 8;40(6):1869-92. https://doi.org/10.1108/LHT-07-2021-0242

[63] Gordon M, Daniel M, Ajiboye A, Uraiby H, Xu NY, Bartlett R, Hanson J, Haas M, Spadafore M, Grafton-Clarke C, Gasiea RY. A scoping review of artificial intelligence in medical education: BEME Guide No. 84. Medical Teacher. 2024 Apr 2;46(4):446-70. https://doi.org/10.1080/0142159X.2024.2314198

[64] Alam A. A digital game based learning approach for effective curriculum transaction for teaching-learning of artificial intelligence and machine learning. In2022 international conference on sustainable computing and data communication systems (ICSCDS) 2022 Apr 7 (pp. 69-74). IEEE. https://doi.org/10.1109/ICSCDS53736.2022.9760932

[65] Kuleto V, Ilić M, Dumangiu M, Ranković M, Martins OM, Păun D, Mihoreanu L. Exploring opportunities and challenges of artificial intelligence and machine learning in higher education institutions. Sustainability. 2021 Sep 18;13(18):10424. https://doi.org/10.3390/su131810424

[66] Eysenbach G. The role of ChatGPT, generative language models, and artificial intelligence in medical education: a conversation with ChatGPT and a call for papers. JMIR medical education. 2023 Mar 6;9(1):e46885. https://doi.org/10.2196/46885

[67] Lee J, Wu AS, Li D, Kulasegaram KM. Artificial intelligence in undergraduate medical education: a scoping review. Academic Medicine. 2021 Nov 1;96(11S):S62-70. https://doi.org/10.1097/ACM.0000000000004291

[68] Pavlik JV. Collaborating with ChatGPT: Considering the implications of generative artificial intelligence for journalism and media education. Journalism & mass communication educator. 2023 Mar;78(1):84-93. https://doi.org/10.1177/10776958221149577

[69] Hooda M, Rana C, Dahiya O, Rizwan A, Hossain MS. Artificial intelligence for assessment and feedback to enhance student success in higher education. Mathematical Problems in Engineering. 2022;2022(1):5215722. https://doi.org/10.1155/2022/5215722

[70] Ramirez EA, Esparrell JA. Artificial Intelligence (AI) in Education: Unlocking the Perfect Synergy for Learning. Educational Process: International Journal. 2024;13(1):35-51. https://doi.org/10.22521/edupij.2024.131.3

[71] Liu R, Zenke C, Liu C, Holmes A, Thornton P, Malan DJ. Teaching CS50 with AI: leveraging generative artificial intelligence in computer science education. InProceedings of the 55th ACM technical symposium on computer science education V. 1 2024 Mar 7 (pp. 750-756). https://doi.org/10.1145/3626252.3630938

[72] Linderoth C, Hultén M, Stenliden L. Competing visions of artificial intelligence in education-A heuristic analysis on sociotechnical imaginaries and problematizations in policy guidelines. Policy Futures in Education. 2024 Nov 13;22(8):1662-78. https://doi.org/10.1177/14782103241228900

[73] Erduran S, Levrini O. The impact of artificial intelligence on scientific practices: an emergent area of research for science education. International Journal of Science Education. 2024 Dec 11;46(18):1982-9. https://doi.org/10.1080/09500693.2024.2306604

[74] Borger JG, Ng AP, Anderton H, Ashdown GW, Auld M, Blewitt ME, Brown DV, Call MJ, Collins P, Freytag S, Harrison LC. Artificial intelligence takes center stage: exploring the capabilities and implications of ChatGPT and other AI-assisted technologies in scientific research and education. Immunology and cell biology. 2023 Nov;101(10):923-35. https://doi.org/10.1111/imcb.12689

[75] Winkler C, Hammoda B, Noyes E, Van Gelderen M. Entrepreneurship education at the dawn of generative artificial intelligence. Entrepreneurship Education and Pedagogy. 2023 Oct 26;6(4):579-89. https://doi.org/10.1177/25151274231198799

[76] Bozkurt A. Generative artificial intelligence (AI) powered conversational educational agents: The inevitable paradigm shift. Asian Journal of Distance Education. 2023 Mar 31;18(1).

[77] Wang T, Lund BD, Marengo A, Pagano A, Mannuru NR, Teel ZA, Pange J. Exploring the potential impact of artificial intelligence (AI) on international students in higher education: Generative AI, chatbots, analytics, and international student success. Applied Sciences. 2023 May 31;13(11):6716. https://doi.org/10.3390/app13116716

[78] Venter J, Coetzee SA, Schmulian A. Exploring the use of artificial intelligence (AI) in the delivery of effective feedback. Assessment & Evaluation in Higher Education. 2025 May 19;50(4):516-36. https://doi.org/10.1080/02602938.2024.2415649

[79] Rahayu S. The impact of artificial intelligence on education: Opportunities and challenges. Jurnal Educatio FKIP UNMA. 2023 Nov 30;9(4):2132-40.

[80] Yu L, Yu Z. Qualitative and quantitative analyses of artificial intelligence ethics in education using VOSviewer and CitNetExplorer. Frontiers in Psychology. 2023 Mar 9;14:1061778. https://doi.org/10.3389/fpsyg.2023.1061778

[81] Fuchs K, Aguilos V. Integrating artificial intelligence in higher education: Empirical insights from students about using ChatGPT. International Journal of Information and Education Technology. 2023 Sep;13(9):1365-71. https://doi.org/10.18178/ijiet.2023.13.9.1939

[82] Gao P, Li J, Liu S. An introduction to key technology in artificial intelligence and big data driven e-learning and e-education. Mobile Networks and Applications. 2021 Oct;26(5):2123-6. https://doi.org/10.1007/s11036-021-01777-7

[83] Bender SM. Coexistence and creativity: Screen media education in the age of artificial intelligence content generators. Media Practice and Education. 2023 Oct 2;24(4):351-66. https://doi.org/10.1080/25741136.2023.2204203

[84] Sun Z, Anbarasan M, Praveen Kumar DJ. Design of online intelligent English teaching platform based on artificial intelligence techniques. Computational Intelligence. 2021 Aug;37(3):1166-80. https://doi.org/10.1111/coin.12351

[85] An X, Chai CS, Li Y, Zhou Y, Shen X, Zheng C, Chen M. Modeling English teachers' behavioral intention to use artificial intelligence in middle schools. Education and Information Technologies. 2023 May;28(5):5187-208. https://doi.org/10.1007/s10639-022-11286-z

[86] Zhang C, Schießl J, Plößl L, Hofmann F, Gläser-Zikuda M. Acceptance of artificial intelligence among pre-service teachers: a multigroup analysis. International Journal of Educational Technology in Higher Education. 2023 Sep 4;20(1):49. https://doi.org/10.1186/s41239-023-00420-7

[87] Jaiswal A, Arun CJ. Potential of Artificial Intelligence for transformation of the education system in India. International Journal of Education and Development using Information and Communication Technology. 2021;17(1):142-58.

[88] Al Darayseh A. Acceptance of artificial intelligence in teaching science: Science teachers' perspective. Computers and Education: Artificial Intelligence. 2023 Jan 1;4:100132. https://doi.org/10.1016/j.caeai.2023.100132

[89] García-Martínez I, Fernández-Batanero JM, Fernández-Cerero J, León SP. Analysing the impact of artificial intelligence and computational sciences on student performance: Systematic review and meta-analysis. Journal of New Approaches in Educational Research. 2023 Jan;12(1):171-97. https://doi.org/10.7821/naer.2023.1.1240

[90] Fatima A, Shafique MA, Alam K, Ahmed TK, Mustafa MS. ChatGPT in medicine: A cross-disciplinary systematic review of ChatGPT's (artificial intelligence) role in research, clinical practice, education, and patient interaction. Medicine. 2024 Aug 9;103(32):e39250. https://doi.org/10.1097/MD.0000000000039250

[91] Celik I, Dindar M, Muukkonen H, Järvelä S. The promises and challenges of artificial intelligence for teachers: A systematic review of research. TechTrends. 2022 Jul;66(4):616-30. https://doi.org/10.1007/s11528-022-00715-y

[92] Xu JJ, Babaian T. Artificial intelligence in business curriculum: The pedagogy and learning outcomes. The International Journal of Management Education. 2021 Nov 1;19(3):100550. https://doi.org/10.1016/j.ijme.2021.100550

[93] Cope B, Kalantzis M, Searsmith D. Artificial intelligence for education: Knowledge and its assessment in AI-enabled learning ecologies. Educational philosophy and theory. 2021 Oct 15;53(12):1229-45. https://doi.org/10.1080/00131857.2020.1728732

[94] Lee HS, Lee J. Applying artificial intelligence in physical education and future perspectives. Sustainability. 2021 Jan 2;13(1):351. https://doi.org/10.3390/su13010351

[95] Järvelä S, Nguyen A, Hadwin A. Human and artificial intelligence collaboration for socially shared regulation in learning. British Journal of Educational Technology. 2023 Sep;54(5):1057-76. https://doi.org/10.1111/bjet.13325

[96] Habib S, Vogel T, Anli X, Thorne E. How does generative artificial intelligence impact student creativity?. Journal of Creativity. 2024 Apr 1;34(1):100072. https://doi.org/10.1016/j.yjoc.2023.100072

[97] Bearman M, Ajjawi R. Learning to work with the black box: Pedagogy for a world with artificial intelligence. British Journal of Educational Technology. 2023 Sep;54(5):1160-73. https://doi.org/10.1111/bjet.13337

[98] Wei L. Artificial intelligence in language instruction: impact on English learning achievement, L2 motivation, and self-regulated learning. Frontiers in psychology. 2023 Nov 6;14:1261955. https://doi.org/10.3389/fpsyg.2023.1261955

[99] Kong SC, Yang Y, Hou C. Examining teachers' behavioural intention of using generative artificial intelligence tools for teaching and learning based on the extended technology acceptance model. Computers and Education: Artificial Intelligence. 2024 Dec 1;7:100328. https://doi.org/10.1016/j.caeai.2024.100328

[100] Morales-García WC, Sairitupa-Sanchez LZ, Morales-García SB, Morales-García M. Development and validation of a scale for dependence on artificial intelligence in university students. InFrontiers in Education 2024 Mar 12 (Vol. 9, p. 1323898). Frontiers Media SA. https://doi.org/10.3389/feduc.2024.1323898

[101] Singh SV, Hiran KK. The impact of AI on teaching and learning in higher education technology. Journal of Higher Education Theory & Practice. 2022 Oct 1;12(13). https://doi.org/10.33423/jhetp.v22i13.5514

[102] Wang C, Boerman SC, Kroon AC, Möller J, H de Vreese C. The artificial intelligence divide: Who is the most vulnerable?. New Media & Society. 2025 Jul;27(7):3867-89. https://doi.org/10.1177/14614448241232345

[103] Belkina M, Daniel S, Nikolic S, Haque R, Lyden S, Neal P, Grundy S, Hassan GM. Implementing generative AI (GenAI) in higher education: A systematic review of case studies. Computers and Education: Artificial Intelligence. 2025 Apr 10:100407. https://doi.org/10.1016/j.caeai.2025.100407

[104] Russell RG, Novak LL, Patel M, Garvey KV, Craig KJ, Jackson GP, Moore D, Miller BM. Competencies for the use of artificial intelligence-based tools by health care professionals. Academic medicine. 2023 Mar 1;98(3):348-56. https://doi.org/10.1097/ACM.0000000000004963

[105] Halagatti M, Gadag S, Mahantshetti S, Hiremath CV, Tharkude D, Banakar V. Artificial intelligence: the new tool of disruption in educational performance assessment. InSmart analytics, artificial intelligence and sustainable performance management in a global digitalised economy 2023 May 29 (Vol. 110, pp. 261-287). Emerald Publishing Limited. https://doi.org/10.1108/S1569-37592023000110A014

[106] Ng DT, Chan EK, Lo CK. Opportunities, challenges and school strategies for integrating generative AI in education. Computers and Education: Artificial Intelligence. 2025 Jan 25:100373. https://doi.org/10.1016/j.caeai.2025.100373

[107] Hwang GJ, Tu YF. Roles and research trends of artificial intelligence in mathematics education: A bibliometric mapping analysis and systematic review. Mathematics. 2021 Mar 10;9(6):584. https://doi.org/10.3390/math9060584

[108] Bilgic E, Gorgy A, Yang A, Cwintal M, Ranjbar H, Kahla K, Reddy D, Li K, Ozturk H, Zimmermann E, Quaiattini A. Exploring the roles of artificial intelligence in surgical education: a scoping review. The American Journal of Surgery. 2022 Jul 1;224(1):205-16. https://doi.org/10.1016/j.amjsurg.2021.11.023

[109] Stretton B, Kovoor J, Arnold M, Bacchi S. ChatGPT-based learning: generative artificial intelligence in medical education. Medical Science Educator. 2024 Feb;34(1):215-7. https://doi.org/10.1007/s40670-023-01934-5