International Journal of Applied Resilience and Sustainability, Volume 2, Issue 3, May 2026, pp. 49-83

Published online at Deep Science

International Journal of Applied Resilience and Sustainability

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

Adoption of generative artificial intelligence in K-12 education: Teacher preparedness, ethical concerns, and implementation challenges

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Article Info:
Received 24 February 2026
Revised 25 April 2026
Accepted 27 April 2026
Published 04 May 2026

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Abstract

The recent acceleration of the inspiratory use of generative artificial intelligence in K-12 education has presented considerable possibilities of personalized learning, instructional innovation, and teacher efficiency, at the same time raising important concerns in the manner of teacher preparedness, ethical oversight, and implementation difficulties. Although the numbers of large language models are rising, there are more multimodal learning systems, and AI-driven educational systems are getting popular, various schools still have to struggle with obstacles linked to the lack of teacher preparation, insufficient AI knowledge, ineffective policies, and inequitable access to online resources. The emergence of new trends also provides evidence of increasing anxiety around the topics of algorithmic bias, data privacy, academic integrity, digital equity, and teacher agency. This literature review has synthesized recent research on the adoption of generative artificial intelligence in K-12 education within PRISMA, specifically, focusing on teacher preparedness as well as ethical issues and implementation barriers. The key themes mentioned in the analysis are AI literacy, professional development, digital pedagogy, technology acceptance, curriculum integration, responsible AI practices, and human-AI collaboration. It has been seen that teachers are becoming increasingly aware of the opportunities that generative AI can offer them through personalized learning, automated administrative work, differentiated instruction, and student engagement. Nevertheless, there are still continuing problems regarding ethical risks, little institutional back-up, inadequate training and unequal technological accessibility among schools and regions. New research indicates also that the key to successful adoption is a sustained professional development in teachers, explainable AI systems, effective school leadership and inclusive policy design.

Keywords: Generative artificial intelligence, Digital equity, Academic integrity, Adaptive learning, Data privacy, Digital transformation.

1. Introduction

The fast development of generative artificial intelligence has changed the educational frame of the world, especially in the area of K-12 education where educational institutions, educators, and academic policymakers begin to explore the opportunities of large language models, intelligent tutoring systems, adaptive learning platforms, and multimodal learning applications. Generative artificial intelligence, also known as GenAI, has been coined as offering new prospects of individualized learning, automated feedback, lesson planning, instructional design, assessment generation, as well as student engagement [1]. Now educators can access a tool like ChatGPT and other AI-based education software to produce differentiated learning content, clarify complicated concepts, offer personalized learning, and lessen the workload on administrations. Meanwhile, the growing popularity of AI in K-12 classrooms has sparked discussions about the readiness of teachers, the problem of ethics and issues related to digital pedagogy, and the future impact of technology-mediated educational transformation. As of late, there is an indication that schools are no longer on the experimental phase of AI implementation to a more widespread institutionwide adoption, meaning that it is rapidly becoming necessary to study how

https://doi.org/10.70593/deepsci.0203003

teachers are reacting to these new technologies and whether they are well-prepared to utilize them effectively and responsibly.

The urgency of this problem is increased by the rate at which generative artificial intelligence is being introduced to K-12 classrooms, and tends to surpass teacher preparation, school administration forms, and policy systems, in most instances. Although AI literacy and educator training become more and more viewed as the necessary part of the modern education system, there are a lot of teachers who do not have the technical knowledge, pedagogical confidence, supporting institutions to integrate AI into the classroom in a meaningful way. The available sources show that educators tend to view generative AI as a possibility and a danger at the same time. On the one hand, these tools can contribute to personalized learning, adaptive learning and inclusive learning and human-AI collaboration. In contrast, educators are also worried about being overly dependent on AI, lack of critical thinking skills, loss of agency in teachers, and the future elimination of necessary human interaction in the learning platforms. Newer debates also indicate educational systems should cease AI literacy structures in favor of more global awareness of AI, teachers, students are knowledgeable of when, why, and how AI ought to be applied in a responsible manner within the classroom setting.

The current situation concerning the use of generative artificial intelligence in K-12 education demonstrates both opportunities and considerable issues. The contemporary research indicates that nowadays, teachers utilize AI tools in planning lessons, generating content, formative assessment, providing feedback, differentiating, and managing classroom activities [1-2]. Educational leaders also start implementing the policy framework, endorsed AI platforms, and teacher professional development programs to facilitate the responsible use of AI. Yet, the adoption is a highly unequal process among the educational settings and is dependent on the differences in digital infrastructures, funding of schools, educator hub, and access to the professional development. Low-resource schools, rural schools, underserved communities, and rural institutions tend to have more obstacles to educational technology adoption that consequently augment digital inequity and restrict the benefits of AI-driven educational innovation. Moreover, the fast growth of the generative AI has brought forth new socio-technical issues regarding the institutional preparedness, curriculum integration, cybersecurity, and long-term sustainability.

One of the most important aspects of generative artificial intelligence in K-12 education has become ethical issues. The present discourse revolves around the risks of algorithmic bias, inaccurate content generation, misinformation, surveillance of students, data privacy, intellectual property and student inequalities based on race. These issues are especially significant since younger learners can be more susceptible to misleading artificial intelligence-generated information, biased products and overdependence on automated systems. It is also becoming increasingly feared that upon being used without proper monitoring or pedagogical protection, generative AI could compromise students in terms of critical thinking, creativity, writing skill, and the capacity to express oneself. Moreover, no clear AI governance, explainable AI systems, and definition of institutional guidelines have provided ambiguity in the minds of teachers as to the limits of ethical issues, responsibility, and acceptable classroom usage. Therefore, responsible AI and AI ethics are now the central topics in the modern discourse of educational technology and school reform.

Even though research on generative artificial intelligence in the field of education has increased, some significant research gaps still exist. The current literature is biased in either understanding the technological advantages of AI or along the lines of individual ethical concerns, and there is a lack of studies on how all three interactions relate to one another, meaning the preparation levels of teachers, the ethical management system, the barriers to implementation, and the long-term institution preparedness [3-5]. The knowledge on the influence of teacher professional development, school leadership, policy frameworks, and AI competency on successful classroom adoption overall is also poorly investigated. Moreover, the contemporary learning is strongly limited to one country and region, and there are significant gaps in the knowledge regarding how generative AI is embraced in various educational systems, socioeconomic settings, and in diverse cultural contexts. Most of the work is still discovery and short research and a necessity to do more thorough reviews to summarise the recent

findings, reveal where new tendencies appear and explain the key contexts affecting the process of sustainable AI implementation in K-12 environments.

To address these gaps, this literature review will attempt to offer a thorough analysis of the introduction of generated artificial intelligence into K-12 education with particular emphasis on teacher preparedness, ethical issues, and challenges in the process of implementation. The review aims to understand teacher perceptions of and practice related to generative AI, the major obstacles influencing classroom adoption, understand ethical issues of AI-linked teaching and learning, and discuss the guidance of teacher training, AI literacy, school administration, and policy formulation in responsible adoption. The synthesis of newly emerging findings in various research studies makes the paper part of the growing field of knowledge about the digital transformation of education and forms a basis on which future studies, educational policy and practice in institutions will be founded. Finally, the review mentions the necessity of coming up with human-centered, equitable, and sustainable generative artificial intelligence in K-12 learning so that the technological innovation could reinforce the pedagogical practice and professional judgment of the teacher, rather than substituting them..

2. Methodology

The literature review presented here was undertaken based on the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) 2020 model in favor of transparency, rigor, and reproducibility in the identification and selection of academic materials that are interesting in the topic of adopting generative artificial intelligence in K-12 education, in particular, with respect to teacher preparedness, ethical concerns, and challenges Four major academic databases, including Scopus, Web of Science, IEEE Xplore, and PubMed, were searched systematically in the range of January 2019 to December 2025, with a range being chosen to locate both literature on pre-generative AI baseline and the current boom of publications following widespread adoption and deployment of large language model-based tools in education. The Boolean search strings applied across Scopus and Web of Science included: ("generative artificial intelligence" OR "generative AI" OR "large language model" OR "LLM" OR "ChatGPT" OR "GPT-4") AND ("K-12" OR "primary education" OR "secondary education" OR "elementary school" OR "high school") AND ("teacher preparedness" OR "teacher readiness" OR "professional development" OR "teacher training"); ("generative AI" OR "ChatGPT" OR "LLM") AND ("ethical concerns" OR "AI ethics" OR "bias" OR "privacy" OR "academic integrity") AND ("K-12" OR "school education"); and ("generative artificial intelligence" OR "AI tools") AND ("implementation challenges" OR "barriers" OR "adoption" OR "integration") AND ("K-12 education" OR "classroom" OR "educators"). The primary search in the databases resulted in 1,247 records (Scopus: 487; Web of Science: 374; IEEE Xplore: 261; PubMed: 125), which were further supplemented by 18 records found using citation search and screening reference lists. After deduplication (213 records were removed), 1,052 records were sorted at the title and abstract stage, and 748 records got filtered due to their being out of the scope of K-12 generative AI education research. The rest of the 304 reports were requested to be checked to full-text and 21 of those were not retrievable, leaving 283 reports that were examined to be eligible to databases; and 16 reports that were checked to be eligible to other sources. The amount of full-text exclusions was 262 records, with many being rejected on the basis of lack of focus on K-12 education (n=89), lack of connection to generative AI (n=74), lack of focus on teacher preparedness or ethical aspects (n=58), and lack of any empirical or peer-reviewed basis (n=41). To be its inclusion criteria, the studies had to be peer-reviewed empirical or conceptual articles published in English that covered the use of generative AI tools in formal K-12 learning settings and discussed one of the three areas of focus. Excluded were those that were opinion pieces not backed by empirical evidence as well as studies that only dealt with the higher education. The evidential basis of the synthesis provided in further parts of the review was comprised of a final corpus of 37 studies.

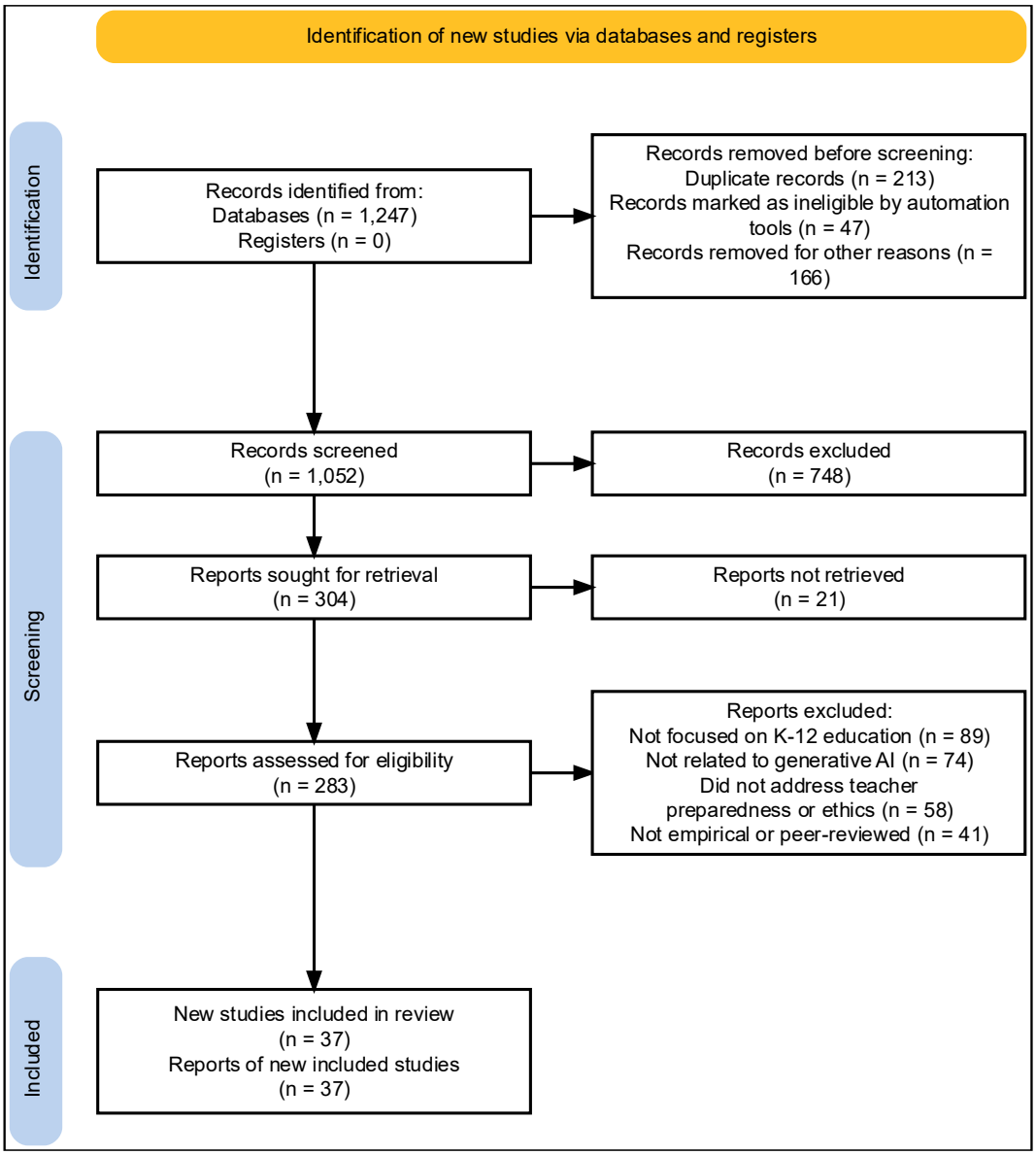

Fig. 1 PRISMA Framework

3. Result

3.1 Artificial intelligence techniques

Large Language Models in K-12 Education

Large language models have become the most prevalent approach to generating artificial intelligence in K-12 education due to their capability to produce human-generated text, give contextual answers, aiding lesson planning, as well as creating adaptive teaching content. Chatbots and other conversational AIs, including ChatGPT, are also used by educators to write lesson plans, quizzes, simplify reading resources, offer differentiated explanations, and facilitate multilingual education [6-8]. Such systems are based on transformer architecture, deep learning and natural language processing to understand teacher prompts and create coherent outputs that could be tailored to grade levels and subject domains. According to the literature, big language models have become particularly distinctive in English language teaching, social sciences, mathematics education, and science education due to their ability to provide individualised learning routes, as well as, create learning content at a rate that is easy to sustain. Nevertheless, teacher readiness is an important issue since the performance of the large language models is defined by the capacity of the educators to confirm the information provided by AI, recognize the

hallucinations, and modify answers to suit the needs of the students. Recent data show that although there has been a growing awareness among teachers of the efficiency benefits of large language models, the issue of inaccuracy, misinformation, and overdependence on automatic content generation remains a concern to many educators.

Multimodal Large Language Models and Multimodal Learning

Multimodal large language models are also considered as another significant improvement of text-based generative artificial intelligence since they can input and generate data in text form, pictures, audio, video and even visual diagrams. In schooling, multimodal learning proves to be a more crucial element since students tend to learn better by using different sensory experience and interactive material. Multimodal large language models are capable of supporting science experiments, visual interpretations, image understanding, speech-based tutoring, and real-time translation, which increases access and inclusive learning. These methods are effective especially among younger students and also those with disabilities as they offer learners a variety of ways of working with content. Multimodal systems are capable of processing diagrams, laboratory images, and visual evidence and at the same time produce explanatory narratives in science and STEM education. Multimodal learning tools are also viewed by teachers as useful in assisting differentiated instruction and classroom integration since they allow more meaningful and interesting learning processes. Nevertheless, the growing sophistication of multimodal systems brings in more issues associated with teacher preparedness, AI literacy, privacy, and ethical governance since teachers need to be informed about how these systems handle student information, and the ways outputs can vary based on the type of modality.

Intelligent Tutoring Systems and Adaptive Learning

Intelligent tutoring system is still among the best-established artificial intelligent methods in education and is actively being integrated with generative AI features. They are based on machine learning, learner modeling, and predictive analytics that are used to deliver personalized instruction, detect learning gaps, and prescribe specific interventions [9]. Intelligent tutoring systems assist with adaptive learning in K-12 learning environments by continuously modifying difficulty, pace, and content of learning tasks based on student performance. Intelligent tutoring systems have been enhanced seriously by incorporating generative artificial intelligence since they are now able to create custom examples, expound hard concepts in multifarious ways, and give real time feedback. They are highly applicable in mathematics, language studies, and STEM classes where students typically need ongoing scaffolding and one-on-one assistance. The literature states that the intelligent tutoring systems have the potential to enhance student engagement, teacher workload, and learning outcomes, but to be successful, it should be implemented through the capacity of the teachers to interpret the AI task in accordance with the pedagogical goals. Moreover, the issue of data privacy, algorithmic bias, and over-reliance on automated guidance are also a significant impediment to the wider use.

Retrieval-Augmented Generation for Educational Accuracy

Retrieval-augmented generation has gained significant relevance as an AI method due to its focus on a significant shortcoming of the large language models, i.e., hallucination and factual error. Retrieval-augmented generation is a technique that uses AI-based tools that combine generative models with external systems that retrieve knowledge, such as trusted databases, school-vetted materials, textbooks, or curriculum materials and then generate answers. Retrieval-augmented generation can be applied in K-12 education to enhance the credibility of lesson plans, explanations of facts, content of quizzes, and educational chatbots by basing them on validated knowledge. The method is especially useful in such subjects as science, history, and civics when a precision is critical and any misinformation has a negative impact on the learning processes. AI assistants in schools, online libraries, and subject-specific tutoring systems also have potential in future due to Retrieval-augmented generation since it provides teachers the ability to regulate the information sources utilized by the AI models. Retrieval-augmented generation as one of the possible strategies to enhance responsible AI behavior and reduce mistakes is taken as a chance in the growing number of educational institutions that are interested in making AI governance, explainability, and trust in schools.

Prompt Engineering and Teacher AI Competency

The art of prompt engineering has become a fundamental skill of teachers who apply generative artificial intelligence since the quality of the AI-generated products is strongly associated with prompt design. Prompt engineering entails producing domain-specific instructions that are clear, specific, and richly contextual and steer the use of AI systems to make relevant and pedagogically suitable responses [7,9-10]. When teachers have high level of prompt engineering, they have better chances of producing effective lesson plans, differentiated assignments, template of feedback and assessment materials. Timely engineering as a subset of AI literacy and teacher development is becoming more and more prevalent in K-12 education since it provides an educator with the channels to control classroom content but minimizes the probability of erroneous or biased outputs. Teachers are becoming acquainted with structured prompts which include grade level, subject area, learning objectives, tone and complexity in efforts to make AI responses more meaningful. Nevertheless, the literature indicates that up to now, a lot of teachers are not knowledgeable about advanced prompt engineering methods, which holds them back. Consequently, teacher preparedness curricula, curriculum integration approaches, and digital pedagogy efforts have begun emphasizing prompt engineering as one of their priorities.

Learning Analytics and Predictive Analytics

Learning analytics and predictive analytics are among significant artificial intelligence methods, which can be used to track the performance of students, identify at-risk students, and aid making evidence-based decisions in K-12 schools. The methods are based on educational data mining, machine learning, and statistical modeling to interpret the tendencies in attendance, assessment scores, engagement rates, and online learning patterns. Learning analytics dashboards that are AI-powered may assist educators with visualizing the progress of students, identifying learning challenges, and tailoring interventions depending on the needs of a particular student. Recent advances reveal a growing number of learning analytics and generative artificial intelligence, allowing the systems to generate feedbacks, recommendations, and tailored learning plans automatically. Predictive analytics allow teachers to detect students who might need extra assistance and modify the teaching process. However, ethical issues involving learning analytics usage include surveillance, privacy, transparency and fairness in that predictive systems can only support underlying disparities when trained on unbalanced or incomplete data. Naive learning analytics usage thus needs authoritative institutional frameworks, exposable AI methods, and educator supervision to make sure that forecasts are applied ethically and positively.

Explainable AI and Transparent Decision-Making

The idea of explainable AI has grown in significance in K-12 education since educators, learners, and school leaders must learn how AI systems formulate suggestions and judgment. Most classical deep learning models are typically black box and users might have difficulty ascertaining the reason why some outputs are obtained [1,11-14]. Explainable AI methods strive to enhance transparency through being able to offer comprehensible explanations on AI-generated works, forecastive models and suggestion systems. In elementary and secondary instruction, explainable AI can allow teachers to assess how a system has labeled somebody as at risk, why a chatbot has come up with a specific response, or why an adaptive learning platform has suggested a certain activity. An increased amount of transparency will benefit the agency of teachers, make ethical choices, and establish trust in AI-assisted teaching. It also contributes to decreasing doubts about the bias of algorithms and caused unfair treatment since educators are able to check the mechanisms of decision-making. With the spread of AI-based systems in schools, explainable AI will inevitably emerge as a key demand behind responsible AI governance, especially applying to the issues of data privacy, academic honesty, and equitable educational access.

Automated Assessment and Generative Feedback

Automated assessment systems are based on machine learning, natural language processing, and generative AI to assess student work, give students immediate feedback, and lessen teacher workload on grading. These systems are capable of evaluating multiple choices, short-answer questions, essays, and coding as well as the activities in the spoken language. Automated assessment is especially useful

in K-12 education where teachers can deliver timely feedback and track the progress of students more effectively. The generative feedback methods are capable of providing individualized comments, recommending edits, and providing specific guidance based on the performance of the students. Nonetheless, fairness, reliability, and validity are still of concern as an automated system might not be capable of interpreting creativity, cultural background, and subtle student reactions. Another concern of teachers is that excessive use of automated assessment can decrease the real interaction between teachers and students and impair critical thinking in case of providing student with the opportunity to follow only AI-generated standards. The most promising evidence is based on the argument that using a combination of automated assessment and teacher supervision approach is the best way as it allows educators to implement fairness, and retain a human aspect of learning and assessment (Rodriguez 2007).

Conversational AI and Virtual Teaching Assistants

Virtual teaching assistants and conversational AI become more and more prevalent in the K-12 education sector since they offer 24-hour support to both students and teachers during the hours beyond their classroom sessions. Such systems may respond to commonly asked questions, clarify concepts, catalog and lead students through assignments as well as offer emotional or motivational assistance [13,15-17]. To provide human-like interaction, virtual teaching assistants frequently use natural language processing, chatbots technology and big language models. These tools have particularly been very effective in K-12 institutions in homework support, language practice, and one on one tutoring. Virtual assistants can also be used by teachers to automatically perform administrative roles like reminder about attendance, assignments, and announcements to a classroom. In spite of these advantages, there are still fears regarding the accuracy, reliability and the ethical implications of conversational AI due to the fact that the students can have trust in the answers provided by AI without question their validity. It is further feared that overreliance on virtual assistants could lead to the removal of peer interaction, teacher-student interaction and process of learning. The implementation directions in the future are more likely to be centered on the hybrid approach in which conversational AI will assist without substituting teacher-directed work and classroom discussion.

Computer Vision and Image-Based AI Systems

The use of computer vision methods is becoming more popular in K-12 education as they are applied to image recognition, the construction of visual content, classroom monitoring, and augmented reality. Computer vision can be used to examine images, charts, handwriting, facial expressions and gesture patterns to come up with information regarding learner engagement and learning. Computer vision can help in laboratory experiments, visual problem solving and object recognition exercises in STEM education. Language learning and special education are also using these systems to understand visual cues and assist learners with disabilities respectively. Nevertheless, computer vision brings significant issues on privacy, consent and surveillance and student safety due to the fact that image-based AI systems capture highly sensitive visual content. The dangers of deepfake technologies, manipulated student imagery, and the inappropriate content production have been also addressed recently. Consequently, school administrators are putting a greater focus on the importance of strong AI controls, cybersecurity measures, and explicit ethical principles prior to applying computer vision technology in schools.

Speech Recognition and Natural Language Processing

Natural language processing and speech recognition are key artificial intelligence applications that help in facilitating accessibility, language acquisition and inclusive education in the K-12 classrooms. Speech recognition can also identify speech and transcription of spoken words, assess pronunciation and real time captions, which are very useful especially to students with impaired hearing abilities and language barriers or when literary skills are challenged [18-20]. NLP can also help AI systems read writings and spoken language to comprehend and engage it in sentiment analysis. These solutions allow teachers to track student attendance, assess the oral presentation, and facilitate teaching in multiple languages. Speech recognition systems can be used to offer immediate pronunciation and fluency feedback in language education, and natural language processing can be used to guide reading resources to the level

of different abilities. Nevertheless, speech-based AI systems can recreate linguistic prejudices and fail to match accents, dialect, and multilingual speech patterns, despite the mentioned advantages. Teacher preparedness is thus a necessity since it is necessary that teachers be aware of the abilities and weaknesses of speech recognition technologies in the various classroom situations.

Recommendation Systems and Personalized Learning Pathways

Recommendation systems are becoming more and more popular in K-12 education to recommend learning materials, homework, video and activities according to student interests, performance and engagement patterns. Such systems are based on machine learning, collaborative and predictive analytics to customise educational experiences and enhance student outcomes. Adaptive learning can be supported with the help of recommendation systems that help students choose materials that are relevant to their current interests and abilities. They will be specifically applicable to the field of online and blended learning when a student is likely to need extra instructions and support in using digital tools. The recommendation systems are helpful to teachers as they give some idea about the students who could be in need of additional help and the resources which could contribute the most to various learners. But there are still fears about filter bubbles, algorithmic bias and decreased agency of students on behalf of having the algorithm reinforce existing preferences and restricting exposure to a variety of learning experiences. The novelties of the future are probably concerned with the explainable recommendation systems to provide the teachers with increased control over the arrangement and monitoring of the learning pathways.

Human-AI Collaboration and Teacher-Centered AI

Human-AI partnership has become the most sustainable and ethically appropriate paradigm of implementing generative artificial intelligence in K-12 education. Instead of substituting teachers, existing studies focus on teacher-centered AI systems that complement human knowledge, innovativeness and professional judgment [19,21-22]. Human-AI collaboration means that with AI tools, teachers can plan lessons, assessments, differentiate and do administration without losing ultimate influence on pedagogical decision making. It is a strategy that acknowledges the fact that educators have a contextual knowledge, emotions and interpersonal skills which are impossible to improve with the help of AI systems. Ethical decision-making is also encouraged by teacher-centered AI since educators can review the work of AI, fix mistakes, and make sure that technology is congruent to classroom objectives. The trend in the literature shows a more cautious approach to overreliance on generative AI since over-dependence can lead to diminished teacher agency, loss of professional knowledge, and overall creation of fake mastery among the students. Possible future directions thus focus more on balanced integration approaches on the basis of which generative artificial intelligence performs as a cooperative partner but not as a unilateral teaching agent.

3.2 Artificial intelligence methods

Transformer Models and Large Language Models

Transformer models are now considered the basic artificial intelligence technique in generative artificial intelligence systems applied in K-12 education due to the ability to process language in a highly contextual and scalable way. Transformer architectures are based on attentiveness machinery, which enables systems to examine connections among words, expressions, and whole pieces of text in parallel instead of sequence. Such a feature of transformer-based systems has made them quite useful in classroom integration since a discrete lesson planning, synthesizing of instructional resources, creation of quizzes, and one-on-one explanation can be produced. Transformer architecture-based large language models have become common in K-12 education to enhance adaptive learning, digital pedagogy, automated tutoring, and differentiated instruction. The use of transformer-based instructions by teachers to make intricate material easier to understand, create versions of learning material and content of varying complexity depending on the ability of different students and grade levels are becoming more prevalent. Nonetheless, any implementation of transformer models also creates an issue of hallucination, factual bias, algorithm bias, and overreliance on AI-reliant answers. The literature is

consistent with the idea that teacher preparedness and AI literacy are the key to making sure that transformer-based systems are exploited in responsible manners and teachers still have control of the quality of content and ethical integration in a classroom. The increased popularity of open-source large language models and multilingual transformer systems further indicates that educational applications of this nature will be further customizable, more transparent, and more accessible to various school settings in future.

Supervised Learning Methods in Educational AI

One of the most commonly used applications of the artificial intelligence theory in K-12 educational technology has been supervised learning as it enables the system to learn patterns in responses to labeled data and predict the results in the future. Supervised learning, as a method of automated grading, predictive analytics, attendance prediction and forecasting, student performance monitoring, and earlier-than-standard identification of at-risk learners, has generally been applied in K-12 education [11,23-25]. These systems are being trained using past data on education which include test scores, level of participation, percentage of completing assignment and attendance records. Learning models can be supervised to conclude on the kind of students who might need more help, the best modes of instruction and the most relevant learning materials to a particular learner profile. Combining supervised learning with generative artificial intelligence has increased the functionality of learning platforms since prediction models currently can be integrated with large language models to create individualized interventions, personalized feedback, and study plans automatically. Nevertheless, the ethical concerns regarding supervised learning are also noted in literature since predictive models can support the predominance of the existing disparities in case the support data used is historical or less representative of a diverse student body. With learning systems of supervision increasingly being implemented in schools, explainable AI and transparency are becoming the issues of justice, confidence, and teacher agency.

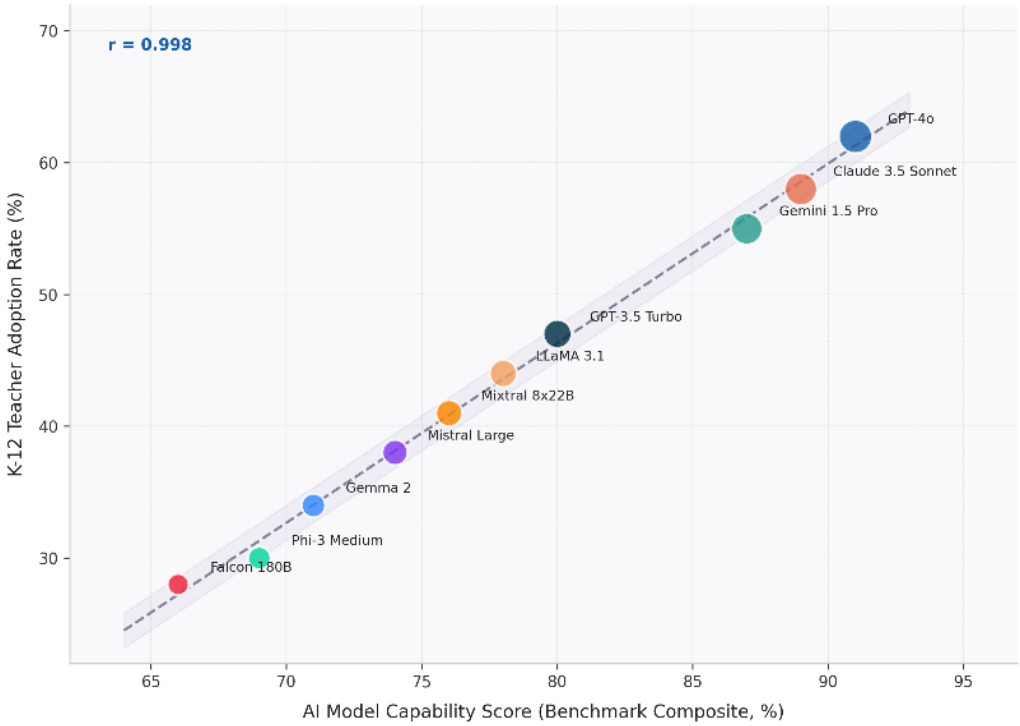

Fig. 2 AI Model Capability vs. K-12 Teacher Adoption Rate

Fig. 2 show a scatter plot examines the relationship between the composite benchmark capability scores of ten prominent generative AI models and their corresponding K-12 teacher adoption rates. Each data point represents a distinct large language model, including GPT-4o, Gemini 1.5 Pro, Claude 3.5 Sonnet, LLaMA 3.1, Mistral Large, Gemma 2, Phi-3 Medium, Falcon 180B, Mixtral 8x22B, and GPT-3.5 Turbo, with marker size scaled proportionally to relative deployment frequency in educational contexts. A

linear regression line with a 95% confidence interval band visually conveys the positive directional relationship between model capability and adoption uptake among K-12 practitioners. The Pearson correlation coefficient is displayed on the plot, reinforcing the statistical strength of this association. Frontier models such as GPT-4o and Claude 3.5 Sonnet cluster in the upper-right quadrant, indicating both high capability and relatively stronger adoption, while open-source alternatives such as Phi-3 Medium and Gemma 2 occupy the lower-left zone, reflecting the gap between technical performance and real-world classroom implementation. This visualization highlights a critical finding: teacher adoption is not solely driven by model performance, suggesting that usability, cost, and institutional policy also moderate uptake.

Unsupervised Learning and Pattern Discovery

One of the roles played by unsupervised learning techniques in educational data mining is the ability to enable artificial intelligence systems to discover obscure patterns, clusters and relationships that are not pre-labeled using known data sets. Unsupervised learning is also common in K-12 education to cluster students based on their learning styles, determine which misconceptions most individuals share, determine patterns in classroom interaction, and investigate trends in digital learning habits. The clustering algorithms, topic modeling, and dimensionality reduction algorithms will help schools to learn more about how students communicate with the learning platforms and what teaching practices are most effective with diverse classes of learners. Unsupervised learning can be of specific importance in adaptive learning situations since it assists in forming observations regarding the student behavior that might not be seen directly by an educator. These techniques are becoming more intertwined with the generative artificial intelligence systems that generate more reacting and information-based educational experiences. As an illustration, unsupervised learning can recognize student question or writing style patterns, which may then be used to create an individualized feedback and specific instructional content. Nevertheless, unsupervised learning is also hard to interpret due to the absence of explicit labels, which poses a challenge on teacher preparedness and explainable AI. Educators must have adequate AI competence to be aware of how such models can be used to recognize patterns and how they ought to be applied to facilitate fair and ethical learning determinations.

Reinforcement Learning for Adaptive Educational Systems

The reinforced learning is a new form of artificial intelligence that is being utilized to achieve the adaptive learning and intelligent tutoring systems in learning of the K-12. Reinforcement learning, unlike supervised learning, learns by the successive engagement with an environment, and by successfully performing and instead, is rewarded [26-28]. In learning modules, the system of reinforcement learning can modify the learning activities in terms of speed, difficulty, and sequencing based on the response of learners and performance. Math and sciences, as well as learning of languages, may be assessed with these systems as they enable students to obtain customized exercises and timely feedback which later transforms along with their progress as they acquire new abilities. Reinforcement learning is also useful in gamification and educational simulations where a student is provided with a dynamic learning experience which responds to the student in real time. Recent advancements show that reinforcement learning is also getting integrated with generative artificial intelligence to make more adaptable and interactive education tools that can generate individually tailored explanations, fluidic questions, and smart hints. Nevertheless, there are still questions about the clarity of the reinforcement learning systems as there is a possibility that the teachers are not completely aware of the justification behind certain instruction decisions. This gives explainable AI, teacher professional development and human-AI collaboration urgent necessity to make adaptive systems responsive to the educational purposes and realities in the classroom.

Retrieval-Augmented Generation Methods

Two key artificial intelligence techniques that have become significant in enhancing the accuracy, reliability, and contextuality of generative artificial intelligence systems in the educational process include retrieval-augmented and generative artificial intelligence systems. The outdated information, hallucinations, and limitations on knowledge cutoffs tend to be more problematic with their traditional large language models since they are mostly trained on a limited set of data that is usually outdated. The

Retrieval-augmented generation approach resolves this issue by using generative models together with other knowledge sources like textbooks, curriculum documents, digital libraries, and school-approved materials. The system uses credible sources to access the necessary information when a teacher or a student makes a query and then produces a response. Retrieval-augmented generation has found such uses in K-12 education lesson planning, curriculum integration, educational chatbots, automated assessment, and subject-specific tutoring since it enhances accuracy of facts and minimizes chances of misinformation. New research studies also reveal that there is the development of multimodal retrieval-augmented generation methods which integrate text, images, audio, and video in educational responses that result in a more enriched and engaging learning which is being developed. Moreover, retrieval augmented generation is becoming a critical approach to responsible AI as it enhances the transparency, verifiability, and trust in the educational systems.

Prompt Engineering and Contextual Optimization

Prompt engineering is an ultrasonic AI technique since it directly impact the quality and relevance of the output of generative AI tools. Prompt engineering can be defined as the task to create useful instructions that can steer large language models towards preferred responses [29-32]. Prompt engineering in K-12 education is becoming a more known aspect of teacher preparedness and AI literacy since teachers must know how to design prompts that can produce content of age, correct, and pedagogically valuable. Good timely engineering typically contains information on grade level, academic discipline, learning objectives, reading level, classroom setting, and assessment. The teachers with high prompt engineering capabilities can better apply AI systems to lesson planning, quiz generation, differentiated instruction as well as student feedback. Other more recent development approaches in advanced prompt engineering are chain-of-thought prompting, role prompting, few-shot prompting and scaffold prompting they enhance stability and reliability of AI-generated responses. According to the recent research, prompt engineering is bound to become a significant educational competency due to the fact that the upcoming generations of generative artificial intelligence will still require human directions to be accurate, just, and in accordance with the curriculum.

Multimodal Learning Methods

The use of multimodal learning approaches in K-12 education has become even more pertinent due to the ability of artificial intelligence systems to process and produce multimedia information in various forms (text, images, video, speech, and interactive media). Multimodal large language models, which integrate natural language processing, computer vision, and audio recognition are used to provide more immersive and accessible educational experiences. These systems are particularly helpful to younger learners, multilingual students and students with disabilities as they contribute to the variety of learning preferences and enhance inclusive education. Multimodal methods may decode diagrams, create an explanation visually, analyze laboratory photos, and offer interactive demonstrations in the teaching of sciences and mathematics. In the direction of language learning, multimodal systems have the means of speech recognition combined with visual cues and text cues as a method to enhance understanding and connection. Emerging studies also point out the possibility of generation based on multimodal retrieval-augmentation in which systems will retrieve and combine information using various sources and modalities in order to generate more precise and context relevant information. Although these benefits exist, multimodal approaches also create some other ethical issues associated with privacy, surveillance, and data protection since they usually imply a visual, audio, and behavioral data gathering of students. Knowledge Tracing and Predictive Modelingtechnologies are utilised in a sustainable manner.

Explainable AI and Interpretable Methods

Explainable AI has been a significant approach to methodological concern since lots of educational systems of artificial intelligence are black boxes that reveal minimal data on how the outputs and predictions are created. Explainable AI practices are designed to make the transparency more comprehensible, so that teachers, students, and school leaders are in a better position to understand how a model arrived at a specific recommendation or decision [31,33-35]. Explainable AI is of particular significance in K-12 education in the fields of predictive analytics, adaptive learning systems, recommendation engines, and automated assessment since these systems have a direct effect on the

educational outcomes and the choices made by teachers. Explainable AI techniques can be visualizations, feature-importance score, confidence score, natural language descriptions, and interactive dashboards where the user can investigate the decision-making process. Open systems assist teachers to uncover mistakes, detect bias, and exercise control over AI-powered teaching. Another emerging trend is the growing popularity of multimodal explainable AI, whereby the explanations are tailored based on the roles of users, student requirements, and educational situations. It is believed that these approaches will grow more essential, as the responsibility of AI governance requires transparency, fairness and accountability.

Knowledge Tracing and Predictive Modeling

Knowledge tracing is an artificial intelligence technique, which simulates the evolution over time of student knowledge based on learning interactions, assessment outcomes and patterns of engagement. Adaptive learning systems often apply knowledge tracing system, as it assists in predicting what concepts are already acquired by a student and what area of knowledge needs further practice. The classical knowledge tracing methods frequently utilized probabilistic models, however, in the recent past, there has been strong inclination towards the use of deep learning, neural networks and transformers based techniques to enhance prediction accuracy. Knowledge tracing is particularly applicable in K-12 education where mathematics, science, and language learning have significant use in that this area typically entails progressive acquisition of skills and knowledge prerequisites. Generative artificial intelligence may also be used to further improve understanding of knowledge tracking, by generating personalized reading resources, practice problems and explanatory feedbacks informed by learning gaps that are predicted. Still, there is an issue of predictive model reliability and fairness as predictions that are made at a bad rate can influence student confidence, teacher expectations and educational opportunities. Consequently, the future applications of knowledge tracing will tend to focus on explainable AI, supervision of teachers, and continuous verification of whether predictive methods prove to be helpful but not harmful to student advancement.

Recommendation Systems and Personalized Learning

Recommendation systems are becoming more significant, artificial intelligence techniques, as they are used to make the learning process more personal, offering relevant resources, assignments, videos, activities, and instructional materials. These systems are commonly based on collaborative and content based filtering and predictive analytics to find the student an educational content that suits his/her interests and levels of learning as well as learning preferences [36-38]. Recommendation systems are especially useful in K-12 education in online and blended learning processes where students can be offered extra guidance based on their requirements to access vast amounts of online content. The recommendation systems also help teachers since they can gain information on which materials in learning can be the most effective to various learners. The generative artificial intelligence integration has added to the potential of recommendation systems since now they are able to produce a customized explanation, a personalized learning plan and an adaptive study pathway. Nonetheless, recommendation systems have also reasoned to raise issues of algorithmic bias, digital equity, and filter bubbles since students can be exposed to the same type of content instead of wide access to educational experiences. To use recommendation systems responsibly, then, teacher supervision, open algorithms, and design inclusivity is necessary.

Smart Language Processing and Conversational AI

It makes natural language processing one of the most significant artificial intelligence techniques in K-12 education since it allows systems to explain, understand, and produce the human language. The natural language processing serves many applications such as conversational AI, automated essay score, chatbot tutoring, sentiment analysis, translation, speech recognition, and feedback generation. The use of conversational AI systems in schools has become more frequent as they make students have access to on-demand support, insert dialogues, clarify ideas and concepts, and assist students in doing homework. Such systems have the potential to enhance the involvement of students and their accessibility, especially those students that need further assistance beyond the usual working hours in classrooms. An analysis of classroom conversations, student self-reflection, and written work is also

performed with the use of natural language processing to detect misconceptions, affective states, and response rates. Although these advantages exist, conversational AI systems can give biased or misleading answers, and teacher supervision is necessary. The next generation of natural language processing trends should be multilingual support, emotion-sensitive tutoring, and more context-sensitive interactions, more characteristic of classroom communication.

Computer Vision and Visual Recognition Methods

The computer vision techniques enable artificial intelligence systems to perceive and recognize photographs, diagrams, videos, handwriting and facial expression. Applications of computer vision in K-12 education include classroom surveillance, automatic attendance, handwriting recognition, generation of visual content, and science laboratory tasks [1,39-41]. Inclusive education can also be aided by computer vision to assist students with visual impairment to interpret images and gesture-based interaction to support students with communication issues. Recent advances indicate that computer vision is increasingly becoming more deeply coupled with multimodal large language models, and systems can produce explanations in the form of diagrams, recognize patterns in drawings by students, and can support interactive visual learning. The application of computer vision methods, however, is also associated with serious ethical concerns as it also presupposes the use of surveillance technology and student-sensitive information. Facial recognition, behavioral tracking, and image Scanning can pose privacy threats, bias and imbalance in case they are not correctly controlled. As a result, ethical AI governance, informed consent, and data protection as the key to the successful implementation of computer vision methods in K-12 education are being increasingly valued by school leaders and policymakers.

Human-in-the-Loop Methods and Teacher-Centered AI

Human-in-the-loop approaches are increasingly being seen as fundamental to the needs of making sure that generative artificial intelligence systems remain consistent with educational aims, moral ideals and classroom realities. The human-in-the-loop models include the participation of teachers in AI generated work in design, evaluation, monitoring, and improvement. Instead of letting artificial intelligence systems, as though self-driven, teacher-centered AI models focus on co-operation between educators and technology. Lesson plans that teachers have created can be reviewed, generate assessments that can be edited by the teacher, it can be checked on recommendations and can correct errors, until content can be utilized in the classroom. This will maintain control over the teacher, ensure more confidence in artificial intelligence tools, and minimize the existence of destructive and misinformed results. Recent researchers have also opined that human-in-the-loop systems enhance explainability, accountability, and acceptance in that teachers are consistently at the core of the decision in AI-assisted teaching. The typical direction taken by future research is the incorporation of hybrid systems that would provide the efficiency of an artificial intelligence that is generative with the situational experience, emotional intelligence, and pedagogical judgment of a human teacher.

3.3 Artificial intelligence technologies

Large Language Models and Transformer Architectures

Large language models have become the most influential artificial intelligence technologies in K-12 education because they provide the computational foundation for text generation, question answering, lesson planning, differentiated instruction, and automated feedback. These technologies are built on transformer architectures that use attention mechanisms to analyze relationships between words, sentences, and concepts in highly sophisticated ways [42-44]. In K-12 settings, large language models are increasingly integrated into digital pedagogy because they enable teachers to generate quizzes, summarize textbooks, create reading passages, design assessments, and support multilingual instruction. The growing popularity of systems such as ChatGPT reflects the broader shift toward conversational and generative technologies that can function as virtual teaching assistants, classroom aides, and personalized tutors. Recent studies suggest that large language models are increasingly being customized for school environments through curriculum-specific fine-tuning, domain adaptation, and

school-approved content filtering. However, these technologies also introduce concerns related to hallucination, misinformation, bias, and overreliance on AI-generated content, making teacher preparedness and AI literacy essential for responsible classroom integration. Emerging trends indicate that future transformer architectures will become more energy efficient, multimodal, and context-aware, allowing educational AI systems to provide richer and more personalized learning experiences.

Multimodal Large Language Models and Multimodal AI

Multimodal large language models represent a major technological evolution because they can process and generate information across multiple formats including text, images, audio, video, and diagrams. In K-12 education, multimodal AI technologies are increasingly used to support inclusive education, personalized learning, and interactive teaching strategies. These systems are especially valuable for younger learners because they provide more engaging and accessible forms of instruction that combine verbal explanations with visual and auditory content. Multimodal AI can support science education by analyzing diagrams, interpreting laboratory images, and generating explanations from visual evidence. In language learning, multimodal systems can combine speech recognition, translation, and visual prompts to improve comprehension and communication. Emerging educational technologies also integrate multimodal retrieval systems that allow students to search across video lectures, images, audio clips, and text-based materials simultaneously. The rapid growth of multimodal AI suggests that future classrooms will increasingly rely on systems capable of interpreting multiple forms of student interaction, thereby supporting more comprehensive and adaptive learning experiences. However, these technologies also raise additional concerns regarding data privacy, surveillance, and equitable access because multimodal systems often require extensive processing of sensitive visual and audio data.

Intelligent Tutoring Systems and Adaptive Learning Platforms

Intelligent tutoring systems and adaptive learning platforms are among the most established artificial intelligence technologies in K-12 education because they provide individualized support based on student performance, engagement, and learning preferences. These technologies use machine learning, predictive analytics, and learner modeling to adjust instructional content according to each student's needs [45-46]. Modern intelligent tutoring systems are increasingly enhanced by generative artificial intelligence, allowing them to create personalized explanations, adaptive quizzes, and targeted feedback in real time. Adaptive learning platforms are particularly useful in mathematics, science, and language learning because they continuously monitor student progress and recommend appropriate learning pathways. Teachers benefit from these technologies because they reduce grading burdens, provide actionable insights into student performance, and support differentiated instruction. Nevertheless, the literature indicates that teacher trust and preparedness are essential because educators may hesitate to rely on intelligent tutoring systems if they do not fully understand how recommendations are generated or whether they align with pedagogical objectives. Future developments are likely to focus on emotionally responsive tutoring systems that adapt not only to cognitive performance but also to student motivation, frustration, and engagement.

Retrieval-Augmented Generation Technologies

Retrieval-augmented generation technologies have emerged as an important advancement because they improve the factual reliability and contextual relevance of generative artificial intelligence systems. Traditional large language models often produce inaccurate or outdated responses because they rely on static training data. Retrieval-augmented generation addresses this limitation by connecting generative models with external databases, textbooks, curriculum standards, and school-approved resources. In K-12 education, these technologies are increasingly used in educational chatbots, lesson planning systems, digital libraries, and AI-powered search tools. Teachers can use retrieval-augmented generation to ensure that AI-generated content aligns with curricular goals and reflects verified educational information. These systems are particularly valuable in subjects such as science, history, and civics where factual accuracy is essential. Recent innovations also include multimodal retrieval-augmented generation, where systems retrieve relevant images, videos, and audio alongside text-based information. As educational institutions seek to strengthen responsible AI practices, retrieval-augmented generation

is likely to become a core component of future AI governance frameworks because it improves transparency, trust, and explainability.

Conversational AI and Educational Chatbots

Conversational AI technologies are increasingly common in K-12 education because they enable students and teachers to interact with AI systems using natural language. Educational chatbots, virtual assistants, and AI-powered help desks can answer questions, explain concepts, provide homework support, and guide students through assignments [18,47-49]. These technologies are especially valuable in blended learning and remote education environments because they offer continuous support outside classroom hours. Teachers also use conversational AI to automate routine communication tasks such as reminders, announcements, and responses to frequently asked questions. Recent developments show that conversational AI systems are becoming more context-aware, emotionally responsive, and capable of supporting longer and more meaningful educational dialogues. However, concerns remain regarding the reliability and trustworthiness of conversational AI because students may accept inaccurate responses without verification. There is also concern that excessive use of educational chatbots may reduce opportunities for peer interaction, teacher engagement, and critical thinking. As a result, future conversational AI technologies are likely to emphasize hybrid human-AI collaboration models where teachers remain central to the learning process.

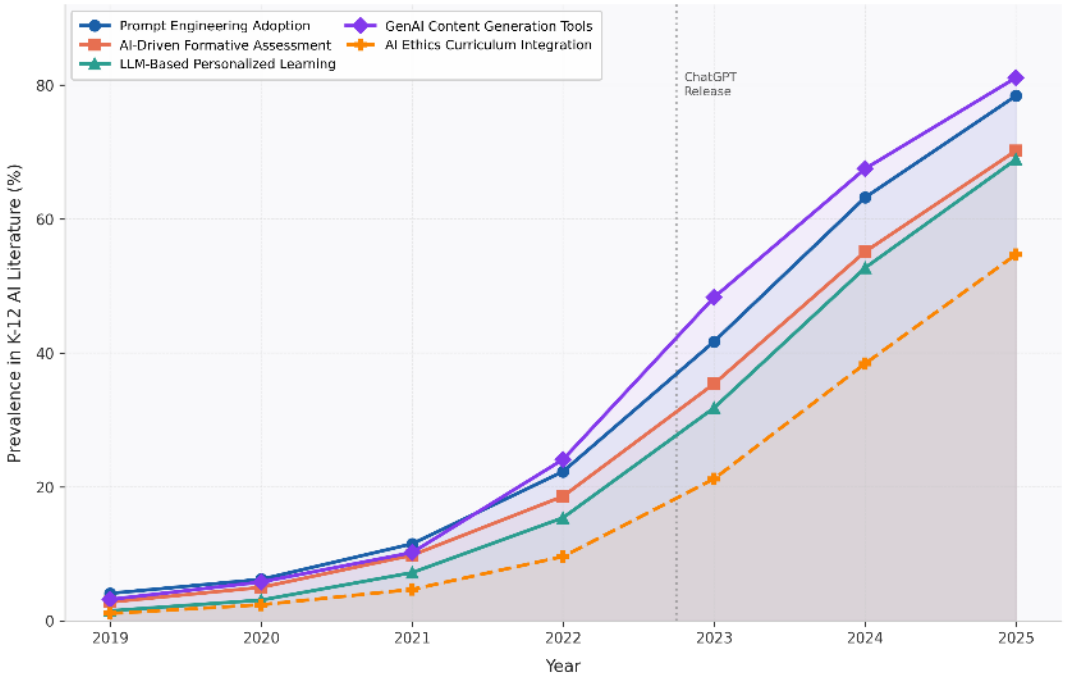

Fig. 3 Temporal Trends in Generative AI Techniques in K-12 Literature (2019-2025)

Fig. 3 explains multi-series line plot traces the longitudinal evolution of five key generative AI techniques and applications as reflected in K-12 educational research literature from 2019 to 2025. The techniques tracked include prompt engineering adoption, AI-driven formative assessment, LLM-based personalized learning, generative AI content generation tools, and AI ethics curriculum integration. A vertical reference line marks the release of ChatGPT in late 2022, which serves as a structural inflection point across nearly all series, illustrating a sharp acceleration in scholarly and practical attention following this milestone. The generative AI content generation tools series exhibits the steepest growth trajectory, peaking above 80% prevalence by 2025, while AI ethics curriculum integration, though lower in absolute prevalence, shows a sustained upward trend that underscores the field's growing consciousness around responsible deployment. The dashed line style applied to the ethics series visually distinguishes normative and pedagogical discourse from technical adoption metrics. The plot demonstrates the compound and mutually reinforcing nature of these trends, providing a temporal

narrative of how generative AI has transitioned from peripheral interest to central concern in K-12 education research.

Automated Assessment Technologies and Generative Feedback Systems

Automated assessment technologies have become increasingly important in K-12 education because they allow teachers to evaluate student performance more efficiently and provide timely feedback. These systems use natural language processing, machine learning, and generative artificial intelligence to assess essays, quizzes, short answers, coding tasks, and even spoken language activities. Generative feedback systems can produce personalized comments, recommend revisions, and suggest additional learning resources based on student performance. In K-12 settings, automated assessment technologies are particularly valuable because they reduce teacher workload and provide students with faster feedback cycles. However, teachers remain concerned about the fairness and reliability of automated assessment because AI systems may struggle to interpret creativity, cultural context, and complex reasoning. The growing popularity of AI-generated content has also intensified concerns regarding academic integrity, plagiarism, and cheating. Recent evidence suggests that schools are increasingly redesigning assessments by emphasizing oral presentations, project-based learning, reflective writing, and classroom discussion in order to reduce misuse of generative AI technologies.

Learning Analytics and Predictive Analytics Technologies

Learning analytics and predictive analytics technologies are increasingly integrated into K-12 education because they allow schools to monitor student performance, identify at-risk learners, and personalize educational interventions. These technologies analyze large amounts of educational data including attendance, test scores, assignment completion, participation levels, and digital learning behaviors. AI-powered dashboards can help teachers visualize student progress, detect learning gaps, and develop evidence-based instructional strategies. Predictive analytics systems are especially useful for identifying students who may require additional support before academic problems become severe. Generative artificial intelligence is now being combined with learning analytics technologies to automatically generate recommendations, progress reports, and personalized learning plans. However, the increasing use of predictive analytics also raises concerns regarding surveillance, bias, transparency, and student privacy because predictive systems may reinforce existing inequalities if they rely on incomplete or biased data. Responsible use of learning analytics therefore requires clear governance structures, teacher oversight, and explainable AI techniques.

Computer Vision Technologies and Image-Based AI

Computer vision technologies are increasingly being adopted in K-12 education to support image recognition, classroom monitoring, augmented reality experiences, and visual content analysis. These technologies can analyze diagrams, laboratory images, student handwriting, facial expressions, and classroom activities in order to generate educational insights [50-52]. In science and STEM education, computer vision can help students interpret visual data, conduct virtual experiments, and solve image-based problems. In special education, computer vision technologies can support gesture recognition, accessibility tools, and alternative communication methods. However, the use of image-based AI technologies raises significant ethical concerns because they often involve surveillance, facial recognition, and sensitive student data collection. Recent discussions have highlighted risks associated with deepfake content, inappropriate image generation, and the misuse of AI to create harmful materials involving teachers and students. Schools are therefore increasingly being encouraged to adopt strict AI governance frameworks, cybersecurity protections, and consent policies before implementing computer vision technologies in educational settings.

Speech Recognition and Natural Language Technologies

Speech recognition and natural language technologies are essential components of educational AI because they improve accessibility, communication, and multilingual learning. Speech recognition systems can transcribe spoken language, assess pronunciation, provide captions, and support language learning activities. These technologies are particularly beneficial for students with hearing impairments,

language barriers, or reading difficulties because they create more inclusive learning environments. Natural language technologies can also analyze classroom discussions, identify emotional tone, and support real-time translation in multilingual classrooms. Teachers increasingly use speech recognition tools to evaluate oral presentations, provide pronunciation feedback, and support conversational language practice. Emerging technologies are becoming more capable of understanding accents, dialects, and emotional cues, thereby improving their usefulness in diverse educational contexts. Nevertheless, concerns remain regarding linguistic bias and the ability of speech technologies to accurately recognize non-standard speech patterns. Teacher preparedness is therefore critical because educators must understand both the advantages and limitations of speech recognition systems before integrating them into classroom practice.

Recommendation Systems and Personalized Learning Technologies

Recommendation systems are increasingly important educational technologies because they help students navigate large volumes of digital content by suggesting relevant resources, assignments, videos, and activities. These systems use collaborative filtering, content-based filtering, and predictive analytics to match students with learning materials that align with their interests, abilities, and progress levels [53,54]. Recommendation systems are particularly valuable in online and blended learning environments where students may need guidance in selecting appropriate content. Generative artificial intelligence further enhances these technologies by allowing recommendation systems to create personalized study plans, adaptive exercises, and individualized explanations. Teachers can also use recommendation systems to identify which resources are most effective for specific groups of students. However, recommendation systems raise concerns regarding filter bubbles, bias, and student autonomy because students may repeatedly receive similar content rather than being exposed to diverse perspectives and learning experiences. Future educational recommendation technologies are likely to become more transparent and teacher-controlled in order to support fairness and critical thinking.

Immersive Learning Technologies: Virtual Reality and Augmented Reality

Virtual reality and augmented reality are becoming increasingly integrated with generative artificial intelligence to create immersive learning technologies in K-12 education. These technologies allow students to explore virtual laboratories, historical environments, scientific simulations, and interactive learning spaces that would otherwise be difficult or impossible to access. Augmented reality can overlay digital content onto physical classroom environments, while virtual reality can create fully immersive educational experiences. Generative artificial intelligence enhances these technologies by enabling dynamic content creation, adaptive simulations, and personalized virtual tutors. In STEM education, immersive learning technologies are particularly valuable because they help students visualize abstract concepts, practice procedures, and interact with complex systems. However, schools face significant implementation challenges related to infrastructure costs, hardware availability, teacher training, and equitable access. There are also concerns regarding screen time, student well-being, and the potential for immersive technologies to widen digital inequities between well-resourced and underserved schools.

Cloud-Based AI Systems and Educational Platforms

Cloud-based AI systems are becoming increasingly important because they allow schools to access advanced artificial intelligence technologies without requiring expensive local infrastructure. Cloud-based educational platforms can host large language models, analytics dashboards, intelligent tutoring systems, and content generation tools in centralized environments that are accessible from different devices and locations [55-57]. These technologies are especially valuable for schools that lack in-house technical expertise because they reduce maintenance costs and simplify updates. Cloud-based AI systems also support collaboration by allowing teachers, students, and administrators to share resources, monitor progress, and communicate across digital platforms. However, reliance on cloud-based systems introduces concerns regarding cybersecurity, vendor dependence, student privacy, and data sovereignty. Many schools remain uncertain about where student data is stored, how it is processed, and who has access to it. Public concerns regarding student data sharing continue to influence trust in educational AI technologies, making transparent governance and strong cybersecurity protections increasingly important.

Explainable AI, Responsible AI, and Governance Technologies

Explainable AI, responsible AI, and governance technologies are increasingly recognized as essential components of sustainable artificial intelligence adoption in K-12 education. Explainable AI technologies help teachers, students, and administrators understand how AI systems make decisions, generate recommendations, and produce outputs. These technologies may include visual dashboards, confidence scores, explanation interfaces, and audit trails that improve transparency and accountability. Responsible AI frameworks also include technologies for detecting algorithmic bias, monitoring fairness, protecting privacy, and ensuring compliance with ethical standards. Governance technologies are becoming particularly important as schools develop policies for AI use, teacher professional development, academic integrity, and digital citizenship. Recent evidence indicates that many schools still lack clear policies for student AI use and teacher training, creating uncertainty about acceptable practices and ethical boundaries. Future developments are likely to focus on building comprehensive governance ecosystems where explainable AI, transparency tools, and human oversight are integrated directly into educational technologies.

3.4 Artificial intelligence models

Foundation Models in K-12 Education

The use of foundation models has become the prevalent form of artificial intelligence model in K-12 education since it has provided the computational subsistence of a broad (various) educational uses, such as lesson planning, content generation, assessment plan, feedback, and classroom aid. Training foundation models on large data sets and fine of-tuning them to various educational tasks are possible, as well as, curriculum alignment [58,59]. The significance of these models is also likely due to the ability of different schools to apply the same system to the various classroom functions instead of having distinct technologies on every educational exercise. In education at the K-12 level, there is a growing use of foundation models to facilitate digital pedagogy, personalized learning, and human-AI collaboration. They are also flexible and can be used by schools that want scalable educational technology that can be used across grade levels and subject domains. Nevertheless, the proliferation of foundation models also introduces issues in regard to teacher readiness, explainable AI, and algorithmic bias, as well as ethical governance due to the fact that teachers are often not AI literate enough to comprehend the functioning of these systems entirely. According to the latest tendencies, the future foundation models will be more efficient, multimodal and tailorable, as that will ensure schools implement AI systems that will be more representative of local curricula, local cultures, and needs of students. The trend with the increasing role of the foundation model age is likely to continue in the future of educational technology and teacher professional development.

Large Language Models and Transformer-Based Models

The model of large language models can be considered the most popular artificial intelligence model used in K-12 education currently due to the support of conversational AI, auto-generation of content, virtual tutoring, and adaptive learning. These models are constructed on transformer based architectures that learn to interpret context and relationships among language inputs with attention mechanism. ChatGPT, GPT-4, Claude, Gemini, LLaMA, and Mistral are examples of large language models that promote the use of these models in classroom settings due to their ability to create lesson plans, quizzes, summaries, discussion prompts, and differentiated instructions. These models are frequently used by teachers to decrease the work of administration, facilitate multilingual teaching, and enhance student interaction. Nevertheless, other sources also show that big language models have a significant set of issues in terms of hallucination, misinformation, overconfidence, and transparency. It is often mentioned by teachers that students can be overconfident about AI generated responses and neglect to properly judge their precision. It was also found in research that the large language models are still unevenly distributed in schools as better-equipped schools have a higher chance of gaining access to high-quality AI tools and teacher education. Nevertheless, regardless of those issues, large language models are growing fast, and will likely be the focus of the future of K-12 education due to their capability to facilitate personalized learning as well as classroom flexibility..

Multimodal Large Language Models

Multimodal large language models are an especially important recent advancement in artificial intelligence since it is capable of processing and producing content in text, images, speech, video, and diagram. They are models that enhance the functions of the old large language models by incorporating computer vision and speech recognition as a single system [3,60-61]. Multimodal large language models are especially useful in K-12 education since there are numerous learning tasks that use textual and visual data. Students may have to combine visual and textual interpretation when science diagrams, historical maps, mathematical graphs, images of laboratories are involved. Multimodal large language models can also be used to make education more interactive and richer, such as assisting learners to interpret visual information, describe diagrams, and learn work with multimedia learning materials. According to the recent researches, educators are particularly attracted by multimodal models since they may facilitate the inclusive education process, multilingual learning process and differentiated instruction process. Simultaneously, multimodal models come with extra ethical issues since they demand more types of student data, such as images, speech, and behavioral data. The teachers have consistently given complaints that they are not confident on how these models process multimodal data and whether they can be relied upon in sensitive classroom settings. In K-12 environments, multimodal models are likely to gain importance in the future due to their close correspondence with the nature of classroom instruction as being diverse and interactive..

Proprietary AI Models in Education

Proprietary artificial intelligence models have gained traction in K-12 education, in part due to the large number of systems of this type that are run by private companies. GPT-4, Claude, and other enterprise systems like gemini are models that are frequently accessed via subscription-based educational systems with added capabilities, security, and classroom-specific solutions. Schools have found proprietary models to be appealing as they tend to achieve higher levels of performance, improved reliability and more refined interfaces than open source options. And lastly, these systems have higher chances of integrating automated assessment, curriculum alignment, teacher dashboards, and content moderation. Proprietary models have concerns however with cost, vendor dependence, data privacy and digital equity. Learning institutions with low resources might not be in the position to purchase high-end AI subscriptions, resulting in disparities in access to high-tech education. Moreover, school leaders and teachers usually lack the knowledge of the proprietary model training, student data storage and decision-making in the system. The concerns above render responsible AI governance and teacher preparedness particularly significant, since schools have to analyze the advantages and the disadvantages of turning to commercial AI vendors. New debates are placing more and more importance on the necessity to have transparent contracts, ethical protection and independent auditing of proprietary educational model.

Open-Source AI Models and Localized Systems

AI models that are open source are gaining wider relevance in the K-12 education field due to its ability to offer greater control, transparency, and flexibility to schools compared to proprietary models. Open-source models like LLaMa, Mistral, Falcon, and other large language models can be customized to specific educational tasks and further localized to educational curricular specifics [62-64]. Another area where open-source systems will be especially beneficial is in schools that wish to embed AI on-premises, safeguard the data of students and not rely on the services of their commercial partners in the long run. Multilingual education, culturally responsive instruction, and domain-specific content building models can also be adapted to these models. Localized open-source systems are also beginning to be considered as a solution to digital equity in K-12 education and the possibility that schools in various areas can have access to affordable AI systems. Nevertheless, open-source models are also not without technical skills, infrastructure, and support maintenance requirements, which can present a challenge to schools with low financial means. In many cases, teachers require further professional growth in order to learn more about the differences between open-source models and commercial tools as well as the way in which they can be responsibly used in the classroom. Trends indicate that there is a possibility of increased usage of hybrid ecosystems that combine proprietary and open-source

frameworks in the future due to the availability of a reasonably priced performance-affordability-local-control balance.

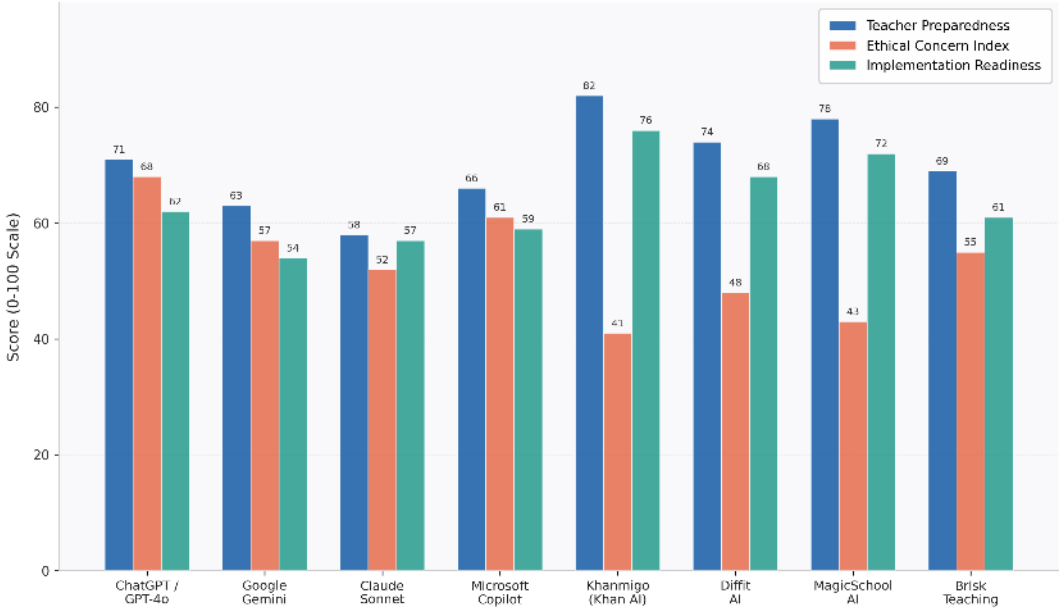

Fig. 4 Teacher Preparedness, Ethical Concern, and Implementation Readiness Across GenAI Platforms

Fig. 4 visualizes a grouped bar chart provides a comparative multidimensional assessment of eight generative AI platforms commonly encountered in K-12 settings, evaluated across three critical indices: teacher preparedness, ethical concern index, and implementation readiness. The platforms span both general-purpose large language models such as ChatGPT/GPT-4o, Google Gemini, Claude Sonnet, and Microsoft Copilot, as well as education-specific tools including Khanmigo, Diffit AI, MagicSchool AI, and Brisk Teaching. A consistent color scheme differentiates the three dimensions across grouped bars, with numerical labels atop each bar enhancing quantitative readability at a glance. Notably, education-native platforms such as Khanmigo and MagicSchool AI score substantially higher on teacher preparedness and implementation readiness, while exhibiting lower ethical concern indices, suggesting that purpose-built tools are designed with safeguards that general-purpose models may lack. In contrast, GPT-4o and Microsoft Copilot, despite strong capability profiles, carry higher ethical concern scores, reflecting ongoing debates around student data usage, content moderation, and age-appropriateness. This plot directly supports arguments for domain-specific AI tool development over generalist deployments in sensitive K-12 contexts.

Retrieval-Augmented Generation Models

The retrieval-augmented generation models have gained significant importance as they tackle one of the most prevalent shortcomings of large language models i.e. hallucination and factual inaccuracy. These models use generative AI with external retrieval systems, which require access to trusted knowledge sources prior to responding. Retrieval-augmented generation models are particularly applied to practical value in K-12 education, as they can be based on answers to textbooks, curriculum documents, digital collections and approved school-based materials. This enhances the precision of lesson plans, assessment questions and pedagogical chatbots and minimizes the possibility of misinformation. Generation that is augmented with retrieval is especially useful in science, history, and civics where precision of facts is paramount. Recent studies also indicate that retrieval-augmented generation models are coming out of their basic text retrieval framework and towards more complex structures that feature multimodal retrieval, hierarchical knowledge graphs and domain specific database. Such models are becoming a viable solution to responsible AI due to the high levels of explainability, trust and transparency they offer. When teachers understand that the responses are based on authorized educational resources and are not produced exclusively on the basis of parametric knowledge, the probability of the adoption of AI systems increases.

Multimodal Retrieval-Augmented Generation Models

Multimodal retrieval-enhanced models Multimodal retrieval- augmented generation models are a growing type of artificial intelligence model that integrates multimodal large language models with retrieval models that are able to access both text, images, video and audio content. Such models are especially applicable to K-12 education due to the number of tasks in the classroom, when students have to deal with several types of information at the same time [19,65-67]. As an example, in most cases the teaching of science would ask students to read diagrams and written explanations at the same time, and language learning to use images, speech and text. Multimedia retrieval-enhanced production models give access to pertinent education content in alternative media and apply the information to generate more appropriate and contextual answers. It is particularly useful in personalized learning, multimodal learning analytics and chatbots in education. Recent surveys indicate that multimodal retrieval-enhanced models [understood as generation models] demonstrate a higher level of performance compared to standard text-only generation systems when it comes to having to comprehend both visual and textual information. Such models will most probably gain greater importance in classes of future since they present a more integrated format of retrieving knowledge and creating content. Yet, they need more powerful computer resources, more advanced systems of governance, and higher teacher AI literacy due to the complexity of multimodal data processing.

Fine-Tuned and Domain-Specific Models

K-12 education is also finding more applications with fine-tuned and domain-specific models rather than general large-scale models since they do not necessarily match classroom requirements. Fine-tuning is a step of adjusting a model by applying certain educational data, curriculum requirements, or subject context to ensure the model gives more pertinent and correct results. In mathematics, science, language learning, and special education general Domain-specific models are especially explicit as they can be optimized to the vocabulary, reasoning patterns, and teaching needs of a given domain. To illustrate, a more refined model of science can produce more precise solutions regarding laboratory ideas, whereas a mathematics model can produce stepwise solutions that correspond to the grade-level standards. Recent trends indicate that the content that has been created by teachers and the school-specific materials are growingly coupled with fine-tuned models to enhance the relevance to context. General-purpose AI systems have certain drawbacks to most teachers: they tend to favor models within a domain that yield predictable and curriculum-aligned results. Nevertheless, there are also such issues with fine-tuning as data quality, bias, scalability, and maintenance since educational data are not always vast and evenly distributed across geographic areas and subjects.

Conversational AI Models and Virtual Teaching Assistants

K-12 education is often defined as a common area of the use of conversational AI models as it offers both students and teachers real-time assistance in the form of chatbots, virtual assistants, or even tutoring services. These are models that are meant to mimic human discourse and are now able to even give contextual explanations, answer queries, and take students through learning processes [68-70]. Conversationally-based virtual teaching assistants can be applicable particularly in blended learning and distance education as it provides assistance during the off-hours, and it could decrease the teacher workload. These models are used by students to do their homework, practice languages and to explain any difficult concepts. Another way of teachers using conversational AI is the automation of communication, reminders, and classroom management. Nonetheless, conversational AI can cause dangers in the field of overdependence, misinformation and less interaction with peers or classmates when their use is abused. Recent evidence indicates that learners can be too easily persuaded to adhere to AI provided responses in the absence of questioning their quality. Subsequently, increased involvements of explainability features, teacher monitoring applications, and anti-inappropriate/biasing content safeguards are expected of future conversational AI models.

Knowledge Tracing and Predictive Models

Knowledge tracing and predictive models have gained relevance in the K-12 education as they assist the teachers in learning how student knowledge changes with time. They are machine learning, deep

learning, and learning analytics models that forecast the concepts that are learnt by students and the areas where they need more assistance. Adaptive learning platforms typically rely on knowledge tracing models due to the ability of the system to tailor instruction based on individual learning histories. At-risk students can also be identified with the help of predictive models, academic performance is forecasted, and specific interventions could be suggested. Transformer-based knowledge tracing models and multimodal predictive systems are increasingly popular in recent years due to their ability to take into account the quiz, assignments, classroom dynamics, and online learning behavior data. These models are particularly useful in mathematics, science, and language learning due to the fact that teachers can determine the learning gaps which may be corrected even before they will be serious. Nevertheless, the use of predictive models raises ethical issues as they could end up supporting stereotypes, diminishing the confidence of the students, and the growth potential of students. The issue is that the teachers should be AI literate enough to assess the predictive outputs critically and make the decisions as unbiased and situation-sensitive as possible.

Explainable AI Models

Explainable AI models are gaining more significance in K-12 education since teachers, students, and school leaders need to know how artificial intelligence systems reach their conclusions. Conventional deep learning and transformer systems can be viewed as black boxes, so it is hard to establish the reasoning behind why a model generated a given answer [71-73]. Explainable AI models attempt to resolve this dilemma by offering comprehensible descriptions, confidence ratings, ranking of importance of features, and clear lines of logic. Applications of explainable AI in the educational sector include adaptive learning, predictive analytics, automated assessment and recommendation systems, since any of these tasks immediately affect the student performance and teacher judgment. By being able to observe the reasoning behind a student being flagged as at risk or why a particular learning resource was suggested, teachers will have more reason to trust the AI system in its opinions. The notion that explainable AI represents not only a technical but also an ethical imperative deserves growing attention in recent debates due to the mandatory climate of accountability, fairness, and transparency of responsible AI governance. The future explainable models will be more interactive and personalized and will give teachers the opportunity to check decisions in a manner that is compatible with classroom requirements and student backgrounds.

Human-in-the-Loop Models and Teacher-Centered AI

The human-in-the-loop models are considered to be the most suitable modality of applying artificial intelligence in the K-12 education due to their ability to maintain the control of the teacher and to keep the AI systems focused on the purpose of pedagogies. These paradigms presuppose a situation in which teachers actively screen, revise, and authenticate outputs of AI-programs instead of letting systems run on their own. The use of human-in-the-loop models has been of particular concern to automated assessment systems, lesson planning systems, recommendation systems and predictive analytics due to the fact that teacher control can help minimize errors, bias, and unsuitable content. The teacher-centered AI paradigms stress a partnership between machines and humans, not a substitution, which is a move in the right direction given the increasing understanding that generative artificial intelligence must be used to supplement, and not to replace, teacher experience. It has also been postulated based on recent studies that AI is more likely to be adopted by teachers who maintain the final decision and can modify the results to the classroom reality. Responsible AI governance can be supported by this model as well as it strengthens accountability, transparency and ethical decision-making. It can be assumed that further processes will be directed at hybridization, where educators and AI models co-operate interactively, generating the effectiveness of speed and the level of context and emotionalism of human educators..

3.5 Artificial intelligence applications

Personalized Learning and Adaptive Learning Applications

One of the most commonly discussed forms of generative artificial intelligence use in K-12 education is the concept of personalized learning since it allows adjusting instructional material, tasks, and exams

to the unique student requirements. Generative artificial intelligence systems have the ability to assess the performance, learning styles, level of engagement and other learning data on the students to design tailor-made learning paths that facilitate adaptive learning [50,74-76]. They come in handy especially in mathematics, science, and language learning as the students are able to move at their own pace getting a personalized feedback and targeted intervention. Individualized instructional applications also assist the educators in the differentiation of instruction to the students of different abilities and thus enhancing student interaction and probability of students not experiencing a gap in learning. The latest trends in the area indicate that schools are turning to AI-based adaptive platforms to suggest content, track progress and create personalized practice resources to students in increasing numbers. The possibility of assisting neurodivergent learners, students that are multilingual, and students with disabilities in this manner, delivering the content in terms more accessible and flexible, is growing in interest as well. Nevertheless, inequity in infrastructure, teacher readiness and access to devices still restrict the fair use of personalized learning technologies in schools.

Lesson Planning and Instructional Content Generation

Generation of content and lesson planning has emerged as a significant area of use of generative artificial intelligence as teachers are now embracing the use of AI tools to save time, lighten the administrative load and to improve on the instructional design. The large language machines like ChatGPT are traditionally employed to produce lesson plans, quizzes, rubrics, work paper, discussion questions, the classroom activities, and differentiated lesson instructional resources. One of the most valuable aspects the teacher can ask AI systems to develop content based upon particular grade levels, curriculum requirements, and learning goals, which makes these tools highly useful in classrooms. Depending on the latest evidence, numerous educators utilize AI-generated materials to maintain productivity and minimize time spent on tedious planning processes so that they could allocate more time to interact with students and provide them with direct support. Simultaneously, it is feared that excessive dependence on AI-generated content would undermine teacher creativity, professional judgment, and curriculum expertise because the teacher may not properly consider outputs. Due to this, the focus of teacher professional development has been oriented more towards prompt engineering, content validation and critical review of AI generated resources to ascertain that lesson planning is pedagogically sound, ethically responsible.

Intelligent Tutoring Systems and Virtual Teaching Assistants

A Virtual teaching assistant and intelligent tutoring system are gaining popularity among K-12 education systems owing to the fact that students are given support throughout the day and outside the classroom setting. Conversational AI, large language models, and adaptive learning technologies are applied in these applications to answer questions, explain concepts, give hints, and walk students through assignments [77-79]. The intelligent tutoring systems are particularly effective in the areas like mathematics, science, and learning a language since repetitious explanation and instant feedback are demanded among students. Virtual teaching assistants also assist teachers in automating some of their normal processes through answering more common questions, providing reminders, and arranging learning materials. The current trends are that schools are starting to employ the use of AI systems where the reasons of the students are challenged and the answers are not given immediately thus encouraging them to think more deeply and critically. Such systems are now more often programmed to become learning companions that support discussion, reflecting on what has been learned and problem solving. Nevertheless, it is still feared that the students will be displaced to be too reliant on AI tutors and miss out on peer learning and teacher engagement. Proper implementation is hence sacrificed with the reality that there must be a balance between automated assistance and human one.

Automated Assessment and Formative Assessment Applications

One of the most commonly-used generative artificial intelligence applications is automated evaluation since assessing student work more quickly and efficiently is now possible, and feedback can be provided promptly. Artificial intelligence-based systems are able to evaluate essays, short-answer questions, quizzes, coding work, and verbal answers and issue personalized feedback as a result of the assessment. Formative assessment application is more essential in K-12 education since the teacher can recognize

the misconception, track progress, and modify teaching in response to the needs of learners. Generative AIs have the potential to generate practice questions, model responses, feedback messages, and performance feedback to facilitate more responsive and data-oriented teaching. Recent studies emphasize that AI-enhanced formative assessment can enhance efforts at the student level, such as feedback that is more timely and needs to be more personalized. But educators are still worried about the idea of fairness, reliability, and validity since automated systems might not be able to consider creativity, cultural background, and subtle reasoning. Another consequence of AI being used more extensively in assessment has been an increase in the debate over plagiarism, cheating and academic integrity, as more and more schools are increasingly redesigning their assessments in a manner that allows students to engage in critical thinking, oral discussion, and project-based learning.

Learning Analytics and Predictive Analytics Applications

Learning analytics and predictive analytics are also becoming critical uses of artificial intelligence since they can assist schools in identifying at risk students, tracking progress in school, and offering individualized interventions. These systems process the attendance, grades, participation, assignment completion and the online learning behaviors and come up with an insight about the performance of the students [80-82]. The AI-driven dashboards may assist the teachers in determining who is struggling, what should be given more focus, and what teaching and learning methods are most beneficial. Applications of predictive analytics are particularly useful since they allow prompt actions to be taken before the learning problems become severe. Generative AI is also being adopted to generate reports, progress summaries, and individually tailored recommendations in schools automatically based on predictive data. Nevertheless, concerns have been raised that predictive systems can harm suffering disparities in case they are prepared on unfair or be complete information. The students in deprived communities might be unfairly termed as being at risk and the teachers might not have complete exposure on how the predictive decisions are arrived at. Consequently, explainable AI, teacher control, and responsible AI regulation are progressively considered as the requirements to the application of learning analytics in K-12 education.

Conversational AI and Educational Chatbot Applications

Chatbots in conversational AI and learning chatbots are fast gaining presence in the K-12 sector as it offers students immediate access to information dissemination, advice and other learning opportunities. The applications may provide answers, demonstrate ideas, summarize texts, translate languages, and provide directions to the assignments. Chat bots are also applicable to educational settings especially in remote and blended learning settings where 24-hour support is required after classrooms. Conversational AI is also employed by teachers to make communication with students and parents automatic and control classroom announcements and deadlines or assignment prompts. The last few years reveal a tendency towards the fact that educational chatbots are gaining emotional sensitivity, becoming more contextually sensitive, and able to maintain longer dialogues, which would facilitate more profound learning. Nevertheless, learners might blindly accept the results of AI-based answers without disputing them, which puts them at a higher risk of being misinformed and getting a superficial knowledge. It is also feared that the overuse of conversational AI will decrease socialization, teamwork, and cognitive abilities. Educational establishments are thus starting to be urged to educate learners on how to challenge, prove, and approach AI-created reactions in a critical and objective manner.

Applications in STEM Education

Generative artificial intelligence has had a specific impact on STEM education as it helps with problem solving, simulations, adaptive practice, and real time feedback, especially in mathematics, science, engineering, and technology courses. Examples of AI in STEM education are intelligent tutoring system, virtual laboratories, automated code helpers, mathematical explanation systems and simulation based learning environments [20,83-86]. Generative AI has been widely adopted by teachers to develop science experiments, laboratory activities, coding tasks, and math problems of different levels of ability the student currently possesses. It is also possible to define abstract ideas using diagrams, animations, and interactive models, which are facilitated by AI to make the STEM material more approachable and more interesting. There is recent indicative evidence that mathematics and science educators are some

of the most enthusiastic users of generative AI since the two subjects are highly sensitive to adaptive learning and real-time feedback processes. Simultaneously, it is feared that students can avoid problem-solving activities and instead acquire a conceptual knowledge by using AI. Due to this, more and more teachers start to underline the significance of the combination of AI tools with inquiry-based learning, practical activities, and critical thinking.

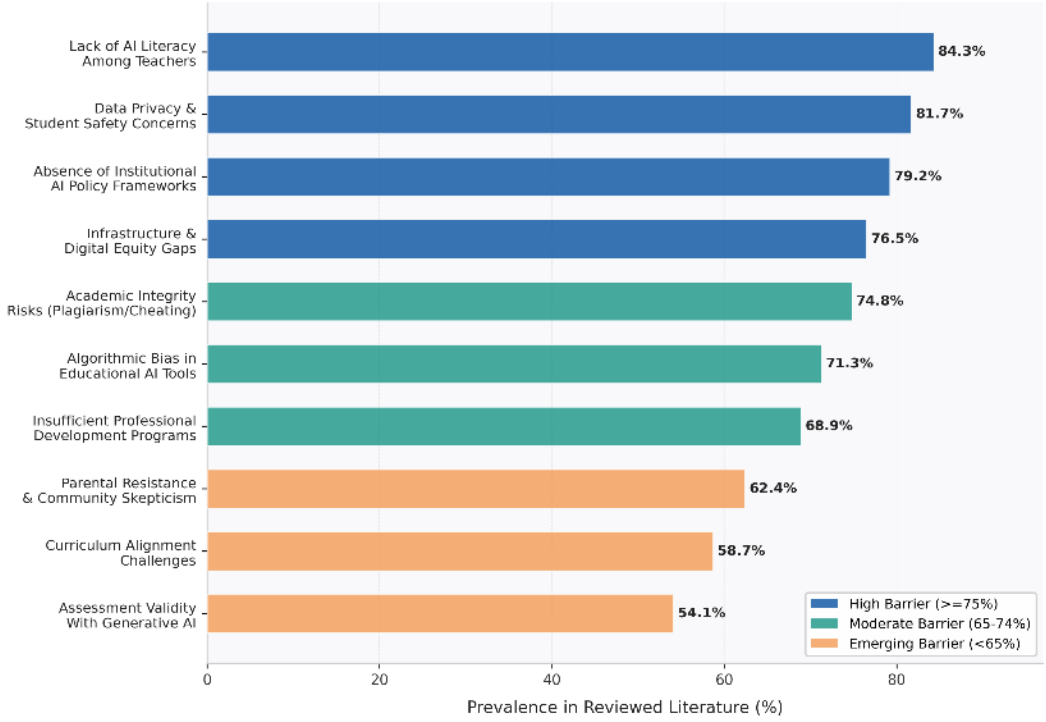

Fig. 5 Prevalence of Implementation Barriers to Generative AI in K-12 Education

Fig. 5 represents a horizontal bar chart presents ten systematically identified barriers to the adoption of generative AI in K-12 education, ranked by their prevalence across the reviewed literature. The barriers span technical, pedagogical, ethical, and societal dimensions, covering issues such as lack of AI literacy among teachers, data privacy and student safety concerns, absence of institutional AI policy frameworks, infrastructure and digital equity gaps, and academic integrity risks including plagiarism and AI-assisted cheating. Color coding distinguishes high-severity barriers (blue, above 75%), moderate barriers (teal, 65-74%), and emerging barriers (orange, below 65%), enabling rapid interpretive triage of intervention priorities. Lack of AI literacy among teachers ranks highest at 84.3%, closely followed by data privacy concerns at 81.7% and missing institutional policy frameworks at 79.2%, collectively underscoring that structural and human-capacity barriers dominate over purely technical obstacles. This chart's descending layout intuitively communicates relative urgency, making it particularly valuable for policymakers, curriculum designers, and educational technology researchers seeking to prioritize remediation efforts. The visualization aligns with emerging calls in the literature for comprehensive AI readiness frameworks that address teacher preparation and governance in tandem.

Multilingual Learning and Inclusive Education Applications

Generative artificial intelligence has a big opportunity of enhancing multilingual learning and inclusion education since it can be used to translate it, simplify language, create captions, and communicate per various linguistic and cognitive requirements. The AI-based translation systems can assist learners, who use multiple languages, in obtaining classroom materials better, and the speech recognition and text-to-speech systems can make it easier to include students with disabilities. These applications are particularly useful in K-12 environments, among students with hearing disabilities, reading problems, disabled under the autism spectrum, and having a language barrier. Generative AI may also follow the levels of readings, generate personalised explanation, and produce other forms of instructional material. The recent debates point more and more at the importance of AI in assisting equitable access to

education, as it allows differentiated and more inclusive learning experiences. Nevertheless, the fact that not all people have access to technology, the lack of teachers training, and poor infrastructure are also major obstacles in the adoption of inclusive AI applications. Less well-staffed schools might be unable to install superior accessibility packages, enhancing the digital divide between ravished and underserved groups.

Creativity Support and Project-Based Learning Applications

Another application of generative artificial intelligence that is gaining significance due to students and teachers using AI tools to create stories, images, music, videos, and creative projects is creativity support. Applications can be effectively used in arts education, language learning and project-based learning since they are a good support to experiment, imagination and collaborative problem solving [87-89]. AI can be used by students to brainstorm, generate visual designs, come up with narratives, and found multimedia presentations. AI-generated content can also help teachers to develop interesting classroom activities and interdisciplinary projects. Nevertheless, the application of AI to creative topics is very debatable since a lot of educators are concerned that the use of AI to produce creative content will lead to decreased originality, personal artistic value, and genuine skill acquisition. One of the most controversial AI adoption fields is the sphere of art education since educators and learners disagree on whether or not the emergence of generative tools should be regarded as a supportive or a creatively-threatening technology. These issues notwithstanding, it is increasingly being acknowledged that students should receive the opportunity to critically interact with AI as part of creative programs since this category of tools is likely to be even more widespread in the work setting and industry in future.

Administrative Automation and Classroom Management Applications

One of the most viable applications of generative artificial intelligence is administrative automation given that it aids educators and school heads in saving time on tasks that are repetitive. AI can be used to track attendance, generate reports, schedule, write emails, communicate with parents, and remind classroom managers. Educators rely on AI applications more and more to manage teaching materials, create rubrics and summarize the performance of students, and create meeting notes. It is also possible to use classroom management applications to recap the tendencies of studying behavior, track the interaction, and advise students who might need to be given extra attention. Widening evidence indicates that educators frequently perceive the most benefit of the AI in the area of administrative efficiency since it enables time to be free, one-on-one work with students and structuring relations. Some worry however that it may imply over dependence on automated systems hence fewer chances of human judgment and interpersonal communication in schools. The teachers should also be well trained so that automated tools can be used in the right manner and that intelligence of students is not misused either.

AI Applications for Teacher Professional Development

The professional development of teachers has become a highly significant field of application of generative artificial intelligence since teachers widely need a helping hand in discovering to use AI in order to act reasonably and efficiently. Professional development systems based on AI can offer customized training modules, give suggestions on instructional plans, generate examples in a classroom, and simulate teaching contexts [3,90-92]. The use of AI by the teachers will enable them to rehearse prompt engineering, test ethical issues and acquire AI literacy skills, which can be applied in the classroom integration. Recent studies have indicated that there is a large number of educators who are keen on generative AI yet do not feel ready to make full use of it due to the lack of training opportunities and knowledge about school policies. The use of professional development is thus growing in terms of assisting teachers in learning about the governance of AI, data privacy, academic integrity, and ethical decision-making. Schools are starting to implement AI solutions to bridge the competency gap of teachers and suggest specific professional learning services as well. The adoption of AI will likely lead teacher professional development to become one of the highest-ranking variables in deciding whether a successful and sustainable implementation of the generative artificial intelligence takes place and succeeds in K-12 education.

Applications for Ethical AI, Digital Citizenship, and Misinformation Literacy

Each time, more and more, generative artificial intelligence is applied to teach ethical AI, digital citizenship, and misinformation literacy in K-12 education since students should grasp both the opportunities and risks of AI technologies. Starting to be introduced into the school curriculum at various grade levels, AI ethics, responsible usage, algorithmic bias, data privacy, and detection of misinformation have become the subjects of schools. The students learn to spot the false information generated by AI, doubt the sources, and ponder about the ethical aspect of the use of generative tools. Recent trends demonstrate the increased awareness that misinformation literacy will be considered an essential skill since pieces of text, pictures, and videos generated by artificial intelligence easily disseminate fake or misleading information. It is also important to mentioned that there is growing interest in assisting students to realize the social implications of algorithmic bias, surveillance, and unequal technology accessibility. Also, schools making use of ethical AI education have a higher likelihood of equipping students to be responsible players in an ever more digital society. Nevertheless, this is a significant field of development because many schools do not have definite policies and prepared curriculums on teaching AI ethics.

4. Discussion

In the discussion, it has been established that generative artificial intelligence has developed swiftly as an experimental educational technology to a common part of K-12 education, fundamentally changing the way teaching, learning, and school administration are conducted. Large language models, chatbots, educational chatbots, automated grading systems, intelligent tutoring systems and multimodal learning environments are becoming more and more common in the classroom to assist in personalized learning, adaptive learning and curricular integration [8,12,93-95]. Nevertheless, the results are always consistent that the preparedness of teachers is not even and is usually trafficed in technological advancement. The generative artificial intelligence is associated with enthusiasm by many teachers due to the potential to decrease workload, carry out the lesson planning, achieve the classroom integration, and deliver the more differentiated instruction. Concurrently, teachers often announce a lack of self-confidence in timely engineering, AI literacy, explainable AI and ethical decision. The emerging data indicates that the perceived and actual AI competency gap is a significant issue with some teachers overestimating their preparedness on the one hand and other ones underestimating their capability to responsibly apply AI in teaching on the other. Teacher preparedness will continue to be one of the most powerful factors in the future adoption of generative artificial intelligence in schools as the growing focus on teacher professional development, AI readiness, and digital pedagogy has shown.

The review also reveals that ethical issues are the focus of the debate on generative artificial intelligence in the K-12 education. The issues which have been most commonly reported are: algorithmic bias, data privacy, academic integrity, misinformation, surveillance, intellectual property, digital equity, and student well-being. One reason teachers have become worried is that generative artificial intelligence will undermine critical thinking, decrease creativity, and encourage more overreliance on automated systems by students. According to recent polls, a number of teachers think that students already are losing writing proficiency, communication expertise, and problem-solving self-dependence due to excessive dependence on generative AI tools. Even issues of academic integrity have been aggravated as students are more taking recourse to large language models in performing assigned tasks, essays, and examinations without actually engaging in the process. Simultaneously, more and more people are becoming aware that the idea of generative artificial intelligence prohibition is impractical and ineffective. In its place, schools are becoming more oriented to responsible AI practices that pay more attention to ethical AI, human-AI interaction, transparency, and digital citizenship. It is a change that indicates that in the future the educational policy will probably concentrate less on technology limitations, and engage the students on how to act responsibly, critically and ethically when using AI.

Table 1. Artificial Intelligence Applications, Techniques, Methods, Technologies, and Models in K-12 Education

Sr. No.	Application	Techniques/Methods	Technologies/Models
1	Personalized learning	Adaptive learning, predictive analytics	Large language models, recommendation systems
2	Lesson planning	Prompt engineering, content generation	ChatGPT, GPT-4, Claude
3	Classroom management	Learning analytics, automation	AI dashboards, virtual assistants
4	Automated assessment	Natural language processing, rubric generation	Generative feedback systems
5	Intelligent tutoring	Reinforcement learning, adaptive instruction	Intelligent tutoring systems
6	Homework support	Conversational AI	Educational chatbots
7	STEM education	Simulation, problem-solving support	Multimodal AI, computer vision
8	Language learning	Speech recognition, translation	Conversational AI, multilingual models
9	Inclusive education	Accessibility tools, multimodal learning	Text-to-speech, speech recognition
10	Teacher professional development	AI literacy, scenario-based learning	AI coaching platforms
11	Curriculum integration	Domain-specific fine-tuning	Retrieval-augmented generation
12	Student engagement	Gamification, conversational AI	Virtual teaching assistants
13	Academic performance monitoring	Predictive analytics, knowledge tracing	Learning analytics dashboards
14	Creativity support	Generative design, multimodal creation	Image generators, music generators
15	Parent communication	Automated communication	Chatbots, email generation systems
16	Attendance monitoring	Predictive analytics	AI dashboards
17	Emotional support	Sentiment analysis	Conversational AI
18	Science learning	Visual analysis, simulations	Multimodal large language models
19	Mathematics support	Step-by-step reasoning	Transformer models
20	Policy compliance	Explainable AI, governance	Audit systems, monitoring tools
21	Student risk detection	Predictive modeling	Early warning systems
22	Teacher workload reduction	Automation, summarization	Generative AI assistants
23	Project-based learning	Content creation, brainstorming	Multimodal AI systems
24	Multilingual support	Translation, speech processing	Natural language processing
25	Ethical AI instruction	Bias detection, digital citizenship	Explainable AI systems

The other significant outcome is that the implementation problems are very unequal at the school, region, and socioeconomic levels. With sufficient funds, schools tend to access superior educational technology, educator training, cloud-based AI applications, and school administrative frameworks, which facilitate the integration in the classroom [96,97]. Conversely, the barriers to implementation, particularly infrastructure, digital equity, support to use technology, and teacher training, in rural schools, low-income districts, and underserved communities are more evident. The literature continues to highlight several times that generative artificial intelligence has the power to increase existing educational inequalities to the extent that schools fail to embrace an inclusive and equitable approach towards implementation. Digital transformation thus should mean not only the introduction of AI tools to classrooms, but also investment into broadband access, device access, cybersecurity, multilingual resources, and culturally responsive instructional design. The contemporary policy debates are placing more emphasis on the value of school leadership, AI governance, and national competency frameworks in order to eliminate the role of artificial intelligence in generating additional value to all the teachers as well as students instead of those who are in advantaged educational establishments.

The results also indicate that the further development of the application of generative artificial intelligence in K-12 education requires the preference to transition beyond the simplistic promotion of prompt engineering and technical training to a set of more comprehensive models of AI literacy. The schools are starting to discover the importance of students and teachers being aware not only of how to apply AI tools but also of how these systems operate, what constraints they also have, and what ethical impacts they generate. Recent debates are drawn more and more to the distinction between AI literacy, AI proficiency, and AI fluency, with more in-depth understanding of algorithms, data, machine learning, human-AI interaction and responsible AI governance. The significance of this broad instead of a narrow focus is in the fact that prompt engineering might promote shallow interaction with AI and overlook critical thinking, digital citizenship, and teacher agency. The literature also promotes the synergistic

teacher-AI interactions in which the role of teachers as active-decision makers working in consultation with AI systems is embraced as opposed to displacing AI systems. The new paradigm makes generative artificial intelligence an assistant in education and not a teachers instructional agency.

Table 2. Challenges, Opportunities, and Future Directions of Generative Artificial Intelligence in K-12 Education

Sr. No.	Challenge	Opportunity	Future Direction
1	Low teacher preparedness	Professional development	AI literacy frameworks
2	Limited AI competency	Continuous teacher training	Competency-based certification
3	Algorithmic bias	Fairness auditing	Bias detection systems
4	Data privacy risks	Responsible AI governance	Privacy-preserving AI
5	Academic dishonesty	Assessment redesign	Authentic assessment models
6	Student overreliance on AI	Human-AI collaboration	Balanced classroom integration
7	Weak policy frameworks	Institutional AI governance	National AI standards
8	Unequal access to AI	Digital equity initiatives	Infrastructure investment
9	Lack of transparency	Explainable AI	Interpretable educational models
10	Teacher resistance	School leadership support	Change management strategies
11	Misinformation risks	Retrieval-augmented generation	Verified content systems
12	Poor infrastructure	Cloud-based educational systems	Scalable AI platforms
13	Inadequate curriculum integration	Curriculum redesign	AI-infused learning standards
14	Limited multilingual support	Inclusive education tools	Multilingual AI models
15	Teacher workload	Automation of routine tasks	AI-supported administration
16	Weak student critical thinking	AI-supported inquiry learning	Critical AI literacy education
17	Concerns about creativity loss	Creative collaboration with AI	Human-centered design
18	Student surveillance concerns	Ethical monitoring systems	Privacy-first analytics
19	Lack of trust in AI systems	Explainable recommendations	Transparent AI governance
20	Technical maintenance barriers	Open-source AI ecosystems	Localized school AI systems
21	Limited support in rural schools	AI coordination hubs	Regional support centers
22	Difficulty measuring impact	Learning outcome evaluation	Longitudinal AI studies
23	Inconsistent school policies	Shared governance models	Cross-sector partnerships
24	Teacher identity concerns	Teacher-centered AI	Synergistic teacher-AI teaming
25	Unclear legal responsibilities	Regulatory frameworks	AI compliance guidelines

On the whole, the literature suggests that generative artificial intelligence will become an effective and crucial part of school education, and its place there will remain stable and possibly even grow. The success of the classroom integration in the long-term, will however, require how schools are able to respond to the matters of teacher preparation, ethical issues and barriers of implementation in a balanced and sustainable manner. Further studies should then be completed on the topic of longitudinal research on teacher identity of professionals, student achievement, AI literacy acquisition, and fair access to it in various learning institutions. An increasing number of studies on comparative international research, investigating the role of various policy systems, systems of governance, and model teacher training in the uptake of generative artificial intelligence in schools are also needed. The solution to K-12 education in the future will not hinge on technological innovativeness only but on the quality of educators, school leaders, policymakers, and communities to develop responsible, transparent, and human-centered solutions to the adoption of artificial intelligence.

5. Conclusions

Implementation of generative artificial intelligence in K-12 education has been one of the most radical changes to the field of modern educational technology with notable consequences to the preparation of teachers, practice in classrooms, and organization on institutions. This review shows that generative AI applications, including large language models, intelligent tutoring platforms, multimodal content creators, and adaptive learning platforms, are becoming more and more influential on the instructional design, assessment, lesson planning, and engagement of students. Educators are starting to realize the importance of such technologies as a means of decreasing administrative effort, differentiated instruction, personalized learning, and digital pedagogy. Nevertheless, there is a consistent literature indicating that teacher preparedness is still inequitable, as a high number of teachers have inadequate AI literacy, technological confidence, as well as pedagogical knowledge to implement generative AI successfully in the K-12 classroom.

The review also indicates that the issue of ethical concerns continues to be one of the primary subjects of responsible AI adoption in schools. Among the major concerns that have been raised is the existence of algorithmic bias, student data privacy, academic integrity, misinformation, concerns about intellectual property, the risk of surveillance, and the increase in digital inequity between schools with varying technological infrastructure. These issues are the most significant in K-12 environments since younger learners are more prone to biased output, untrue information, and reliance on automated systems. Another idea promoted in the literature is that unlimited use of generative AI can diminish teacher agency, disempower human communication, and present doubts over the role of the professional in more AI-enhanced classrooms. Thus, education in the future should focus on the responsible AI governance, open-minded decision-making, explainable artificial intelligence models, and instructions on ethical principles that will protect the rights of students and promote innovation.

The other key finding is that the key success factors in implementing it revolve around teacher professional development, school leadership, institutional readiness and policy alignment. Existing literature indicates that the majority of professional learning programs should go beyond technical training programs and encompass AI ethics, curriculum integration, classroom management, redesigning assessment and critically analyzing AI-generated content. Teachers require long-term chances to foster confidence, make classroom implementation, learn the skills of human-AI collaboration that does not usurp but enhances the expertise of the teachers. The digital infrastructure, equitable access, cybersecurity protections, and support systems were also essential investments towards minimizing disparities in rural, urban, and underserved educational environments necessitate its investment by schools and policy-makers. New frames are pushing towards the notion of a synergistic teacher-AI engagement, where generative AI is meant to augment teacher judgment and creativity, and professional judgment and expertise, instead of being an autonomous substitute.

The further investigation of generative AI effects on teacher identity, student learning outcomes, classroom equity, and school culture should go on in the future. An increasing necessity of cross-national research, discipline-based research, and evidence-based models that could assess the effectiveness of AI-driven instruction in a variety of K-12 environments is also becoming a need. The new challenges in multimodal learning environment, explainable AI, inclusive education, culturally responsive AI systems, and the developing dynamic relationship between teachers and intelligent technologies should get further attention as well. The future of K-12 education will not simply rest on the effectiveness of technological innovation as generative artificial intelligence keeps improving but also the capacity of the educator, institutions and policymakers to introduce such systems in an ethical, equitable and sustainable manner.

Conflict of interest

The authors declare no conflicts of interest.

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