

FROM ADAPTIVE LEARNING TO VIRTUAL TUTORS: RECENT ADVANCES IN AI FOR TEACHING AND LEARNING

Munmi Saikia¹, Derhasad Basumatary^{2*}

¹ Department of Mathematics, Patharkandi College, Patharkandi, Sribhumi-788724, Assam

^{2*} Department of Physics, Patharkandi College, Patharkandi, Sribhumi -788724, Assam,

*For correspondence. (derhasadbasmatury@gmail.com)

Abstract: Artificial Intelligence (AI) has changed education through the provision of personalization and adaptation through virtual tutors and adaptive learning systems. Prior research focused on the theories of benefits from using AI in education: better engagement of students and personalized feedback. However, there is little research on whether AI can be expanded and be more equitable in terms of access, opportunity, and more ethically sound. This review aims to explore these aspects by synthesizing qualitative insight and evidence of empirical observations to analyse the influence of AI on student outcomes and its implementation across different educational settings based on a systematic literature review on AI technologies in education, including AI-supported assessments, virtual tutors, and adaptive learning systems between 2014 and 2024. The findings highlight that AI tools significantly improve student performance and engagement by leveraging real-time data analytics and personalized feedback. However, challenges such as computational resource demands, algorithmic biases, data privacy concerns, and the digital divide in under resourced settings limit broader adoption. Ethical issues, including the potential for AI to reinforce educational disparities and reduce human interaction, were also explored. The review underscores the importance of balancing AI integration with the irreplaceable human elements of teaching, such as fostering creativity, emotional intelligence, and critical thinking. This comprehensive analysis offers actionable insights for policymakers, educators, and developers to promote sustainable, equitable, and ethical AI integration in education, ultimately enhancing both teaching practices and student learning outcomes.

Keywords: Artificial Intelligence in Education; Adaptive Learning Systems; Virtual Tutors; Personalized Learning; Student Engagement; Academic Outcomes.

1. Introduction:

AI revolutionizes education through an AI engine offering individualized, adaptable learning tailored to each student's needs, leveraging virtual instructors and adaptive learning software. Previous evaluations focused heavily on the theories of how AI could be beneficial but ignored what works and whether it is replicable. Many articles point to student engagement [1] and personalized feedback [2], yet these types of research lack information on whether the technology can be scaled up or not and if it can be applied in various educational contexts. Furthermore, prior reviews tend to overlook key equity issues, such as how AI systems perform in under-resourced settings or the ways they might exacerbate existing educational disparities [3]. It's also common to overlook ethical issues like algorithmic bias and data privacy [4]. This review aims to help bridge these gaps. We seek to integrate qualitative analysis from previous research into the quantitative data available to explain how AI can be used in the broader education realm, how scalable AI tools are in practicality, how student outcomes will likely be influenced, and finally how to ensure fair and equitable use of AI tools in diverse learning environments. Based on the earlier research combining theories and empirical results, we also offer specific strategies and recommendations to solve the problems relating to scaling up, equity, and ethical AI application in education.

2. Methodology:

To thoroughly explore recent advancements in AI technologies used in teaching and learning, a systematic literature review was carried out. Major academic databases such as Web of Science, Google Scholar were searched using key words: Artificial Intelligence in Education, Adaptive Learning Systems, Virtual Tutors, Personalized Learning, Student Engagement, and Academic Outcomes. The review focused on scholarly publications between 2014 and 2024 where the period is viewed as a crucial time for the growth in application of AI in education.

The search process began with the screening of titles and abstracts. Eligible articles were then subjected to full text reviews, during which key information was extracted for further analysis. Both thematic and comparative analyses were employed to synthesize findings, and a critical evaluation of the methodological rigor of each study was conducted.

To help with the review, five research questions were developed based on the increasing number of existing articles that talk about the role of AI in an educational setting.

RQ1: In this day of age, what contributions do online teachers and personalized learning technology have on learners' individualization?

RQ2: What are the statistical results of such applications in student achievement and motivation, and how does it compare with traditional approaches such as textbook learning?

RQ3: What challenges do educational institutions face when scaling AI technologies, and how can these barriers be addressed to ensure equitable access?

RQ4: How does adopting AI education software affect the ethical issue such as privacy, fairness, and algorithm bias?

RQ5: What are the long-term effects of AI tools on the role of human instructors, and how can AI complement rather than replace traditional teaching methods?

Studies were included based on the following criteria: they must focus on AI technologies within education, regardless of the specific domain, and could encompass adaptive learning systems, virtual tutors, AI-supported assessments, or any other AI-based educational technology. Both empirical research, which reports quantitative or qualitative data, and conceptual frameworks discussing AI's role in education were considered. Publications were drawn from peer-reviewed journals, conference proceedings, book chapters, and reports, to ensure a comprehensive overview of the research landscape. Only studies published in English, with full-text availability, were included to maintain consistency and thoroughness in the analysis. Additionally, a key inclusion criterion was that the study must explore AI's role in complementing or impacting traditional teaching methods, particularly in relation to human instructors, as this aligns with the overarching research focus on AI's long-term effects on teaching practices.

For the article review process, exclusion criteria must be set to determine the relevant and quality articles for the research study. Research articles in non-educational fields such as AI for businesses or medical care were not included, as well as studies that were not considering utilizing AI for the purpose of teaching, learning, or managing the educational system. Furthermore, all non-peer reviewed works such as news articles, blogs, editorial notes and non-peer reviewed sources were also excluded to guarantee the authority of the literature included. Finally, every source that does not consider studying and examining the relationship between AI and human

instructors was left out from the research, as it will be focused on this area for comprehending AI tools in relation to teaching processes.

The results of all studies reviewed were combined and evaluated with regard to the five questions proposed, giving an overview of AI impact on educational practices, key difficulties, the ethical issues associated with the use of AI in education, as well as the impact of AI on future roles of human instructors. It introduces some critical issues related to practical issues in adopting AI into classroom instruction, so as to better utilize it in teaching activities.

3. Overview:

3.1. Improving Personalized Education with Virtual Tutors and Adaptive Learning Systems:

Adaptive learning systems give out more satisfactory and practical learning experiences than the traditional, one-size-fits-all ways through real-time analytics and machine-learning algorithms which can change the contents for students based on their own needs [5]. What makes this kind of system an important innovation is its ability to track ongoing student interaction, such as how long it took a certain user to complete a particular task, the way a user responds, or where they have gaps in their knowledge, all of which can feed directly into the algorithms which will then predict the most optimal level of complexity or what type of content should be served [1]. The clear and profound technical progress has been made, one obvious example of these advances, especially in the STEM field, is aligned very closely with cognitive load theory, where students get just the right amount of instruction for their level and do not become frustrated trying to tackle too much too quickly [6]. This courseware enables virtual tutors to provide personalized feedback using AI technologies like Natural Language Processing (NLP) and reinforcement learning to simulate human interactions to offer students one-on-one tutoring experiences at scale [2].

Even with these merits, significant obstacles prevent larger use, distribution, and administration of such systems. One problem has to do with processing real-time data; adaptive systems require tremendous computational power in order to process a large amount of data about students, and to serve personalized content simultaneously. As such, it is challenging for under-resourced environments that have limited computational power or internet infrastructure [3]. Moreover, there are also worries of data privacy, bias in AI-driven systems. Personalized learning algorithms need large amount of data which involves ethical concerns about data protection especially systems deployed over different socioeconomic backgrounds [7], thus bias in the training dataset can result in unfairly benefitting certain demographics, especially over-representing privileged groups given that data driven AI models often reflect any existing disparity in the respective datasets [6].

Another key technical bottleneck for virtual tutors is their heavy reliance on AI without enough human intervention. Virtual tutors are very efficient at catching students' attention, but they can fail to address some aspects of a child's intellectual or emotional growth, especially when children learn difficult material or need to think deeply and creatively [4]. AI cannot always match human instructors on the emotional and cognitive realms; therefore, AI is also unsuitable as a helpful tool for students experiencing issues involving emotions or motivations.

3.2. Quantifiable Impact of AI Tools on Student Performance and Engagement:

AI tool-based adaptive learning system and machine learning model both have strong technical advantages in forecasting and improving student performance and engagement. These systems customize learning experiences by analysing large datasets in real-time and adapting information to each student's skills and learning preferences [8]. And, the latter can predict students' academic outcomes with great accuracy – up to 99.4%, by integrating machine learning algorithms such as multivariable linear regression models [9]. Furthermore, the models predict

student performance and provide the necessary timely feedback to facilitate educators' timely intervention in putting down effective personalized interventions for the at-risk students. In contrast, AI driven virtual labs and intelligent tutoring systems boost student engagement through simulation and emulation of interactive environment in real time [10]. Virtual labs also provide adaptive feedback based on student input, which has proven to significantly improve engagement and retention in hybrid learning settings.

However, AI systems still have some technical problems to be solved. The precision and effectivity of predictive models rely greatly on the high-quality and sufficient quantity of the training data sets so that the application of AI system is hard to be generalized across different students populations, more importantly, especially for those students coming from the under-resourced institutes [11]. There exists huge difficulty in scaling up due to the managing of big datasets and constantly updating of machine learning models for reflecting students' behaviour changes [12]. Besides, there also exist algorithmic biases in AI tools because they are prone to taking trained sample databases without representing the diversity from background. Such algorithmic biases might lead to unfair outcomes toward the marginalized students' groups [8]. However, on the bright side, though AI tools can help achieve personalized learning on an industrial scale, it is not good enough in providing a human aspect such as students' emotional or motivational needs [11].

One more technical challenge lies in the incorporation of these AI systems into pre-existing educational facilities and infrastructures. Many institutions do not have the requisite hardware, software, or enough capable people, and thus, limited funds from under-resourced schools hinder their application for their appropriate use [13]. In addition, the need for real-time data processing requires massive computing resources, which worsens the divide between wealthy and poor institutions [10]. As a result, although AI tools can improve students' achievement and motivation via adaptation and prediction via several learning and data analysis methods, these can only be used with barriers at an institutional scale because of algorithmic prejudice.

3.3. Addressing Scalability and Equity Challenges in AI Integration:

Incorporating AI into the school system reaps great benefits as far as technical potential is concerned, especially regarding increasing scale and scope for equitable access. AI-powered systems allow large populations of students to be supported through provision of tailored learning, a feat no single human instructor could accomplish on their own [14]. One technical strength of AI systems is their capacity to automate personalized feedback and assessments so that teachers are able to teach much larger classrooms, without compromising quality, thus freeing up more time for teacher input. Additionally, machine learning models can simultaneously process large data sets and provide real-time adaptation to suit individual student learning paths across many different contexts, thereby increasing both student engagement and retention rate of acquired knowledge [13]. Through utilising AI, institutions can adopt techniques such as smart tutor systems or adaptive learning platforms to reduce the ratio of students to teachers significantly, as well as offering tailor-made educational resources for every individual student to cater for different personal requirements [12].

However, there are many difficulties associated with expanding AI programs to resource-poor educational institutions: one of the biggest technical barriers is requiring high-powered computing infrastructure to cope with the real-time data processing which is required by an AI system; this might prove challenging in low-income schools without access to high-speed internet, cutting-edge hardware, or IT staff to support such technology [13]. In addition, for many AI-driven systems to work well, they require sizable quantities of high-quality data. If student information and data from limited digital platforms create heterogeneity across educational populations and setting them apart, the effects of using an AI-driven system could worsen these divides and make it harder to use personalized AI to augment learning [14].

Due to imbalance in how AI technologies are being distributed, equity problems happen, where the well-funded institutions enjoy the infrastructure and technical supports to implement such facilities, meanwhile, underfunded schools may stay far behind the furthest gap to widen the digital divide [8]. Furthermore, AI algorithms themselves may introduce biases if they are trained on datasets that lack diversity, leading to unfair learning outcomes for marginalized students [11]. Besides, the algorithmic transparency is also a problematic issue which students from the less fortunate backgrounds may fall prey to, because most of them know nothing about the implicit bias [12].

To address these challenges in terms of both equity and scalability, multiple means will have to be implemented so as to develop more user friendly and low resource dependent AI models, which can be employed without causing tremendous spending over IT; furthermore, public private partnership can be used to integrate resources and push the modern digital equipment into schools, as well as offering equal opportunities for access to AI powered educational tools [14]. In addition, constant monitoring on how the AI programs work would also guarantee that the AI would not be responsible for making discriminatory contributions toward exacerbating inequality instead of overcoming it.

3.4. Ethical Aspects of AI Education: Algorithmic Bias and Data Privacy:

AI can bring a number of technical advantages into education, including data processing and decision making. However, there is a risk from ethical concerns, mainly concerning algorithm bias and data privacy issues. AI systems have an advantage over other technology due to their ability to analyse huge amounts of data about students in real time, specifically using large data sets for things like adaptive learning and performance prediction. As such, they can provide highly targeted learning experiences to each student [15]. However, these benefits come with considerable privacy risks. Many AI tools collect sensitive student data, including behavioural patterns and academic history, which if not securely managed, can lead to unauthorized access or misuse [16]. The technical complexity of these systems makes it difficult to ensure that all privacy safeguards, such as data encryption and secure storage, are consistently applied.

One of the significant hurdles in securing data privacy is the opacity of AI programs. Students and teachers are usually not clear on how their personal information or educational data was processed, or what algorithms have led to decisions made by AI, which creates an issue called "black box" problem. As there is no visibility into the functionality of such black box programs, it poses difficulty in putting in place solutions that aim to safeguard data privacy, given that relevant procedures like GDPR are tough to follow without visibility [17]. Besides, there is a higher possibility that there will be security issues as most Big data applications rely heavily on cloud-based infrastructures to perform operations on big datasets, and an attack at a point of the system will likely result in all large volumes of private information being leaked. The larger and more widespread the deployment of AI systems, the bigger such risks become.

Another critical ethical dilemma is algorithmic bias. These systems that run on imbalanced or incomplete data sets end up perpetuating pre-existing inequalities in educational results, such that algorithms might favour students from particular economic statuses, extending inequality in education that is contained within data, such as through the disproportionate representation of students with certain economic statuses [15]. Algorithmic bias could arise from technical factors such as the choice of training data, and the structure of AI models. Examples include having biased algorithms generate unfair grading systems, admissions criteria, or the way that resources get allocated, all of which work to disadvantage marginalized student groups [18]. Also, given how complex AI systems are, deterring or curing their effects can be tough to do without major technical expertise. There are current approaches such as fairness aware algorithms and model audits proposed to alleviate bias present, but these aren't widely applied, because of poor or non-existent regulation for these tactics and it is quite challenging to have an encompassing approach that works across multiple pedagogical models and frameworks [19].

To address these challenges, the development of transparent AI systems that allow regular auditing and enforce data protection protocols is essential. Proactive interventions, such as bias detection mechanisms and the use of fairness algorithms, are critical to ensuring that AI technologies promote educational equity rather than exacerbate existing disparities [20]. Additionally, frameworks like Fairness in AI in Education (FairAIED) offer promising solutions by integrating ethical considerations into AI design, but achieving a balance between fairness and efficiency remains a significant technical challenge.

3.5. AI's long-term effects on human teachers and how it might enhance conventional instruction:

For a long time, the application of AI in the educational sector has technical advantages that can significantly improve the effectiveness of learning and assist human teachers. Automating tedious tasks such as grading and performance and content analysis helps teachers direct their energies toward creating innovative, captivating ways of teaching [21]. Adaptive learning systems powered by AI can provide customized, scaled up individualized assistance based on data and information collected from each student's activities, allowing teachers to do more customized teaching in the classroom [22]. Moreover, AI-powered tools, like virtual tutors, are capable of providing instant, personalized feedback in large enrolment courses, which is generally beyond the means of a regular teacher, no matter how well-versed they are in classroom instruction.[23].

Despite these benefits, dependency on AI remains suboptimal because of obvious disadvantages, constraints, as well as the extreme dehumanization and automation of certain aspects of the job. As much as AI can work efficiently on repetitive tasks, it still falls short in fulfilling the emotional intelligence and critical nuance necessary to address complicated issues of students' emotions, society, and motivation [24]. Due to a dearth of this inherent characteristic of human beings that is invaluable in building profound student-teacher relations, relying completely on AI results in placing our school education in a dire position of depending exclusively on transactional and data-driven interactions. Likewise, overstressed reliance on AI might lead to lesser importance placed on stimulating creativity, encouraging critical thinking or promoting collaborative learning aspects that often mark much greater success of instructors than automated modules.

Yet another technical bottleneck is creating problems for integrating AI systems with traditional teaching methods. Although AI systems can strengthen instructors by facilitating content presentation, many educational institutions have yet to implement such technology solutions because of restricted conditions on their equipment resources and insufficient training on teachers' professional knowledge about how to effectively utilize such technology [25]. Additionally, since most teachers lack sufficient technical skills to work with AI tools, improper usage of AI will become likely. More concerning is that when AI is scalable, under-resourced schools may lack access to AI enabled teaching tools the same way that schools with more resources have benefited from them [26].

For AI to play a positive part in future traditional instruction's development, an ethical and responsible application of AI to assist in classroom and online learning is required. AI should complement human instructors rather than replacing them and provide instructors with student specific information they can use to adjust instruction. AI literacy among educators is essential for ensuring that AI tools are used responsibly and effectively [23]. In the best-case scenario, where effective regulations are put into place, AI will improve students' learning experience without interfering with or underlining the core of human teachers and learners' main tasks.

4. Recommendations:

Root Cause Analysis of AI Scalability Issues

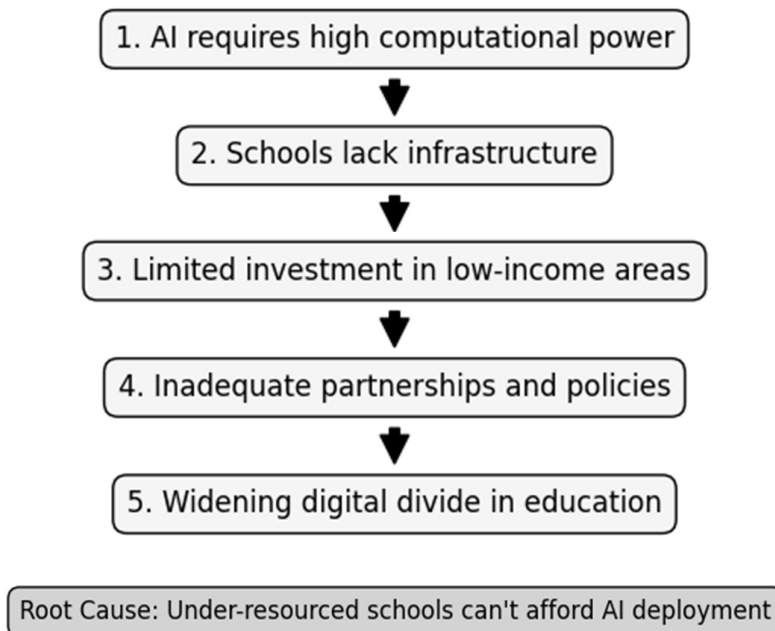


Figure 1: Root cause analysis of AI Scalability issues

Based on the root cause analysis in Figure 1, lack of proper infrastructure is acknowledged as one of the critical issues, therefore, public-private partnership approach has been advocated.

Expansion of access to adaptive learning systems in resource-deprived environments:

Adaptive learning systems and virtual tutors should also be widely available to all students, particularly those in low-resourced environments, so more institutions need to build AI solutions that do not depend on tremendous computational resources, and governments and schools may cooperate with each other and the private sector to reduce implementation costs for AI. Besides, as a developer, we should pay more attention to building resource constrained AI models that can still work well under low-end technical environment and poor Internet conditions.[3][6].

Improve the way quantitative data of the effects of AI is gathered:

While current studies have pointed to improved results and increased engagement of students, more longitudinal studies will provide hard long-term data on how AI is affecting education, so educators, institutions, and AI developers should work together to continuously monitor student outcomes, such as test scores, retention rates, and engagement metrics, across time. This type of systematic approach can result in higher quality evaluations on the lasting effects that AI, such as adaptive learning platforms, can make on student success.[25][1].

Take a firm hold of ethical AI development and usage:

AI developers and educators need to address issues of student privacy as well as algorithmic bias. Constant checks on algorithmic processes should be made to assure that machines don't give certain students an advantage. Additional measures such as adding more transparency in the AI processes to allow educators to perform oversight

of moral actions. Additionally, algorithms should be improved and worked on to make them fair to everyone [19][7].

Balance AI and Human Instruction:

AI can automate menial instruction tasks and give real-time personalized feedback; nevertheless, the human element must still be present for teaching. Teachers need to use their ability to inspire creativity, emotional intelligence and deep-critical-thinking skills. Also, teacher training programmes can be established which enable teachers to instruct their pupils on how to implement AI into their classroom use so they are additive to, not subtractive of, human teaching [23][25].

Promote Equity in AI-Enhanced Education:

For AI to be used in education more widely, equality issues must be resolved. The creation of AI systems that meet a range of learning requirements and are available to all students, irrespective of their socioeconomic status, must be a top priority for policymakers and leaders in education. Making sure AI tools are used in a way that doesn't exacerbate the digital divide is part of this. To assist schools in low-income regions, embrace AI technology fairly, institutions should give them extra resources, including grants or subsidies [7][3].

5. Discussions:

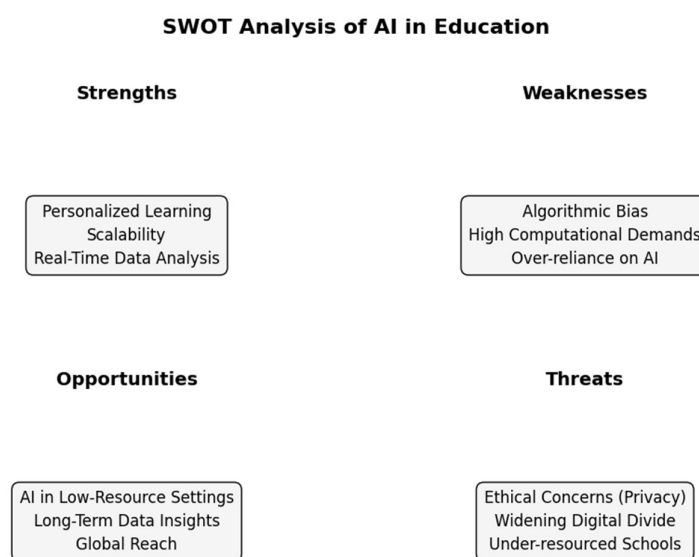


Figure 2: A paradigm for interpreting AI-powered learning materials under the scope of Strengths, Weaknesses, Opportunities, and Threats (SWOT).

The SWOT analysis framework may be used to methodically assess the substantial potential and difficulties that come with integrating AI into education. These factors may be successfully incorporated into the strengths, shortcomings, opportunities, and dangers of AI-driven educational technologies in order to properly address Research Question 5, which focuses on the long-term implications of AI on human instructors and how AI complements conventional teaching.

Strengths:

One of AI's greatest advantages in the field of education is that it can enhance teachers by automating mundane processes such as marking homework, presenting the lessons and monitoring performance, giving them greater opportunity to spend time on creative, engaging, and student-focused instruction. In addition, AI systems, such as adaptive learning platforms, can produce instant personalized feedback, thereby allowing instructors to run bigger classes at high quality with minimum additional input of effort and materials, while simultaneously reducing repetitive administrative load. Automating routine tasks and enabling routine tasks to be performed with lower margins of errors increases operational efficiencies while preserving personalised attention to learners afforded to them by their instructors.

Weaknesses:

However, overusing AI tends to create barriers rather than bridge them, especially when used as the only mode of education and leads to dehumanization of the teaching environment. It cannot replace the emotional connection and empathy provided by humans since students require emotional support from teachers and activities stimulate cognitive, creative, and diverse potential that is beyond what machines can present. In addition, due to high economic costs and lack of sufficient equipment and technologies, AI systems have difficulty scaling up. Under-equipped schools that lack sufficient equipment and technological support are unable to fully embrace AI-based education. If this remains unattentively neglected, the segregation of socioeconomic status would be exacerbated, leading to an increase in inequality.

Opportunities:

AI uses its data-driven insights to have an enormous impact on human teaching. Teachers can tweak their ways to teach based on such data through the means of AI. AI has a better reach as teachers monitor big classes which do not affect the quality of education with the help of advanced technological tools. AI can discover learning deficiencies, provide specific directions, and create a more adjustable and responsive setting via optimal analysis of students' information.

Threats:

However, given AI may be wrongly perceived as an educational substitute for teachers, serious risk arises where educators will fear for their jobs. Further, students are bound to suffer from the decline in human interaction that is so vital for enhancing creativity, critical thinking and emotional intelligence. If this happens, one can be confident that teacher-centred AI will end up being used not to complement but rather replace teachers. This is unacceptable.

To guarantee that AI is utilized as a tool to enhance instead of detract from the quality of traditional education, it is imperative to adopt an integrated approach. Educators should receive training on how to implement AI to enhance teaching so that they are aware of those aspects that cannot or should not be automated in class lessons. Likewise, ongoing auditing and frequent adjustments of bias need to be performed along with implementing fairness-aware AI to avoid unfair results from AI. Scarcity of resources might be addressed through making use of low-resource models or collaborative efforts between the public and private sectors. The education sector needs to utilize the benefits of AI and reduce the negative risks by having an inclusive environment through implementing appropriate algorithms.

6. Conclusion, limitation, and future direction:

With an emphasis on how AI technologies enhance conventional teaching methods and their long-term effects on human teachers, this review article explored the role of AI in education. The evaluation covered a range of educational scenarios and emphasized how AI may improve student engagement, automate repetitive work, and enable individualized learning. AI tools that can enhance teaching methods and learning results include data driven analytics, intelligent tutoring systems, and adaptive learning systems. But the assessment also pointed several drawbacks, including the danger of relying too much on AI, possible decreases in human contact, and moral questions about prejudice and equality. The results highlight the necessity of a well-balanced AI integration that maintains the indispensable role of human educators in promoting creativity, emotional intelligence, and critical thinking.

There are many restrictions on this review. First, although it sought to give a thorough picture of AI's effects on education, only English-language research were included, thereby leaving out important information from publications written in other languages. Second, the review covered a wide range of publishing formats, such as book chapters, conference proceedings, and peer-reviewed journal articles, which might have affected the methodological rigor of the research that were taken into consideration. Third, the review relied on qualitative research rather than a meta-analysis to statistically synthesize the effects of AI technology, which may have limited the findings' generalizability across various educational contexts.

To understand whether these technologies can bring about sustainability in education, we need studies that follow changes of teachers' roles over time, allowing us to see how they use both human and AI instructors in their classes. In addition, it will be necessary to know more about what the ethical implications are of including AI in schools as well, ensuring that everyone has equal access to educational benefits of AI and that biases are decreased in AI technology. Finally, our teacher training programs should be integrated with AI to ensure that educators are ready for the future and able to interweave various forms of teaching and learning alongside these new technologies.

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