AI-Supported Science Pedagogy: Emerging Trends, Educational Implications And Future Directions

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Abstract:

Artificial Intelligence (AI) in education is obviously an emerging strategy. In science education, its place is justified like other disciplines. It influences the classroom interaction, although it has certain negative effects. There is nothing which has only a positive effect on society as a whole. Nevertheless, AI and science have a future-oriented combination like simulations, virtual labs and adaptive learning platforms. A new opportunity is visible ahead when we consider AI tools and learner-centred science pedagogy. Thus, the learning experiences seem highlighted with better conceptual understanding. This conceptual research-oriented paper is based on a thematic review of contemporary literature related to Artificial Intelligence in education and science teaching-learning processes,also critically examines the major challenges in relation to AI integration in science education, including certain policy-related concerns like digital divide, data privacy, bias in algorithms, and overdependence on technology and compromising with self-integrity (Sharma & Mishra, 2023). A balance is made in this paper for pedagogical effectiveness. AI-supported pedagogy seems to transform future science education by improving certain contemporary classroom challenges, like engaging students by making the classroom more enjoyable, more interactive, inclusive, and adaptive. This would be successful if and only if teachers are prepared at the same time as per expectations. The prepared teachers are expected to be digitally competent and ethically aware in AI-integrated classrooms.

An attempt is made to explore emerging trends in AI-supported science pedagogy and the educational implications for curriculum, pre-service and in-service teachers, and learners in improving classroom practices. A technology-enriched learning environment, looking forward to better science conceptual understanding, problem-solving skills in science, inquiry, experimentation and becoming creative and learning with collaboration in science projects using AI to address the demands of 21st-century learning environments.

Keywords: Artificial Intelligence, Science Pedagogy, Personalised Learning, Educational Technology

1.0 Introduction:

AI is not going to replace human teachers (Timms, 2016). However, as a science teacher, a teacher must continuously adapt and evolve to take advantage of AI; otherwise takes lots of time in teaching preparation.These can include checking scientific facts like data related to climate change, deforestation,waste management,etc. (Barbhuiya, 2023). Intelligent Tutoring System (ITS), is a computer- based education platform that is designed to provide personalised and effective instruction (Akyuz, 2020), guidance, and feedback to students. Initially, theywerecomputer programmes, and they use artificial intelligence techniques to enhance and personalise automation both in teachingand learning in schools(Alkhatlan& Kalita, 2019). It offers personalised, adaptive learning experiences through digital platforms, contrasting with traditional methods. The integration of AI enhances ITS capabilities, providing dynamic adaptation, real- time feedback, and optimised outcomes (Gomes,2024). Traditional teaching methods involve a single tutor to carry on teaching a varied number of students with specific needs. The teaching materials used in most cases are the same and are used repetitively. This is a difficult situation for students with special needs or students requiring special attention. Here comes the main concern in developing an unbiased, personalised, and effective tutor for each student. Here, it gives the feel of an individual teacher for every single learner. For an effective intelligent tutoring system, some aspects of the tutoring environment should be considered. The system must be interactive and easy to use, making it clear and easy to use. The system should be tailored to meet the requirements of a specific topic for all concerned levels of learners.In AI technologies, we include robotics, chatbots, machine learning, and automated scoring and feedback, which have enhanced the learning outcomes of the students. Students' engagement in the classroom has been reported and facilitated personalised education in science classrooms. Further, it

identifies diverse methodological approaches and pedagogical strategies, including hands-on learning, blended learning models, inquiry-based methods, and feedback-based learning, as practical means of incorporating AI within science classrooms. Findings say that the importance of professional development, infrastructure investment, and ethical guidelines is so high that they support equitable implementation of AI in science education. (Kavitha & Joshith, 2024).

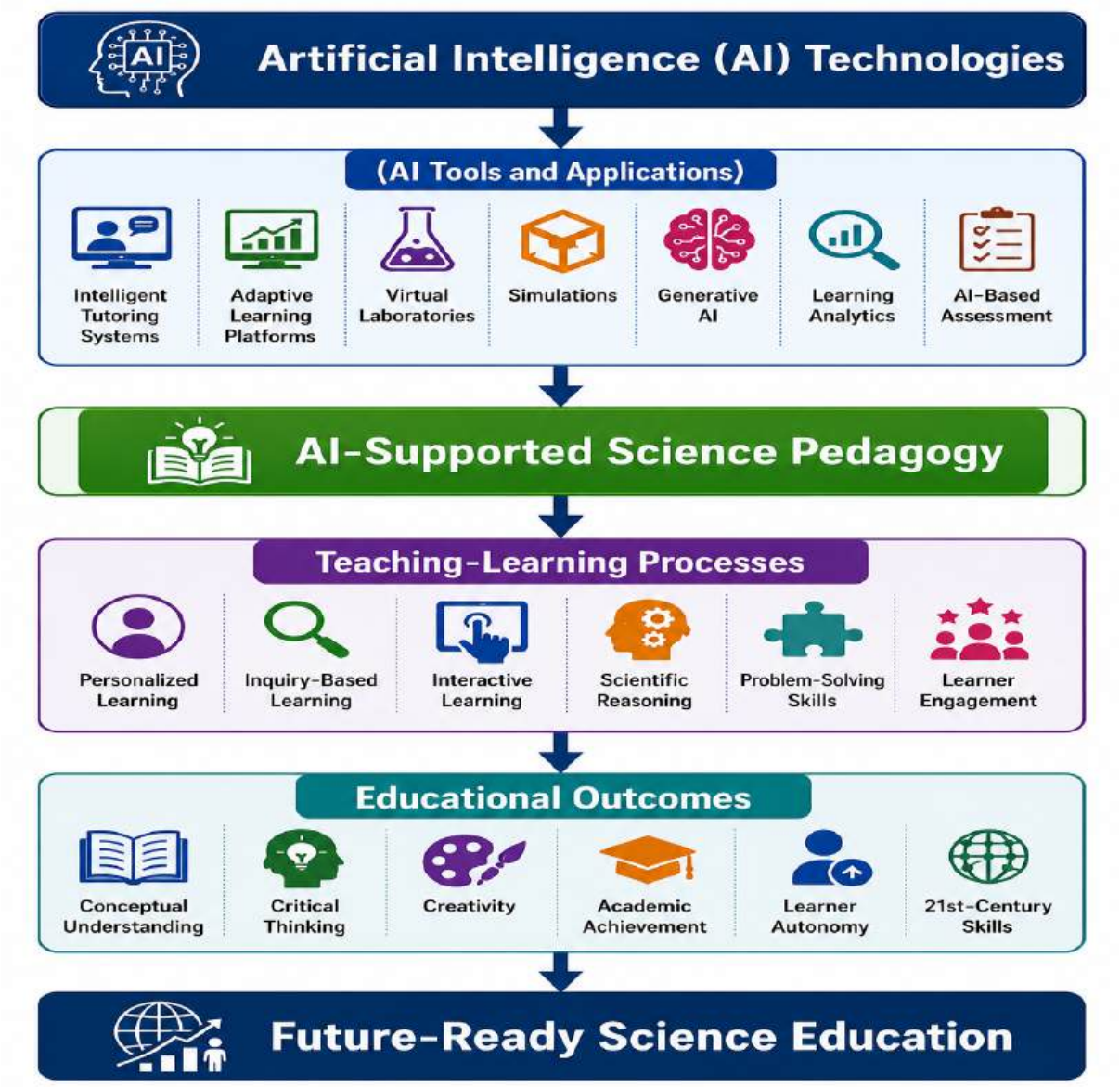
Artificial neural networks work by mimicking our best model for how the human brain functions (Mattalo, 2024).New possibilities are opened to integrate AI into education for personalised learning, intelligent tutoring, adaptive assessment, automated feedback, and data-driven instructional practices.Science education, in particular, requires innovative pedagogical practices that can promote conceptual understanding, inquiry-based learning, scientific reasoning, experimentation, and problem-solving abilities among learners. Traditional methods of science teaching often face challenges in addressing individual learning differences, sustaining learner engagement, visualising abstract scientific concepts, and facilitating interactive learning experiences. In this context, AI-supported science pedagogy offers significant opportunities to transform conventional instructional practices into more learner-centred, interactive, and technologically enriched learning environments.

AI-supported science pedagogy incorporates various digital tools and intelligent systems, such as virtual laboratories, simulations, intelligent tutoring systems, chatbots, adaptive learning platforms, predictive analytics, and generative AI applications, to enhance teaching and learning effectiveness. These technologies can support personalised instruction, provide immediate feedback, facilitate collaborative learning, and improve students' engagement with scientific concepts. Furthermore, AI-based educational tools have the potential to foster higher-order thinking skills, creativity, critical analysis, and self-directed learning among students. Generative AI technologies have further accelerated discussions regarding the future of science education. AI-powered systems are increasingly being utilised for content generation, lesson planning, automated evaluation, academic assistance, and student support services. Consequently, educators, researchers, and policymakers are examining the educational implications, ethical concerns, opportunities, and challenges associated with AI integration in classroom practices. Issues related to digital equity, teacher preparedness, data privacy, algorithmic bias, and academic integrity have become important considerations in AI-supported educational environments.

Various approaches have been highlighted for AI integration in science classes that teachers are employing in order to increase learning experiences and comprehension of scientific concepts (Almasri, 2024; Demir &Güraksın, 2022; Mnguni et al.,2024). There should be readiness and willingness for science teachers to utilise the available advancements forthe successful implementation of AI tools, as their attitudes can significantly influence both educational practices and student engagement levels. (Efe & Efe, 2025)

2.0 Conceptual framework:

The conceptual framework of the study is based on the integration of Artificial Intelligence technologies with science pedagogy to enhance personalised learning, learner engagement, conceptual understanding, and scientific inquiry. The framework assumes that AI-supported instructional tools positively influence teaching-learning processes and contribute to the development of higher-order thinking skills and future-ready competencies. The framework also recognises the importance of teacher competency, ethical considerations, technological infrastructure, and institutional readiness for effective implementation of AI-supported science education.



3.0 Review of Related Literature:

1. UNESCO (2021) recognised AI as an important tool for promoting inclusive and quality education.
2. UNESCO (2023) emphasised that Generative AI should be integrated into education through a human-centred framework that promotes ethical, equitable, and pedagogically meaningful learning experiences.
3. UNESCO highlighted that Artificial Intelligence can transform teaching and learning practices while simultaneously requiring safeguards to ensure inclusion, equity, and responsible implementation.
4. UNESCO has emerged as one of the leading international organisations advocating the responsible integration of Artificial Intelligence in education. According to UNESCO, AI possesses significant potential to transform the teaching-learning process through personalised instruction and adaptive learning systems. However, UNESCO also emphasises that principles of inclusion, equity, human agency, and ethical responsibility must guide the implementation of AI. In its recent guidance on Generative AI in education and research, UNESCO highlighted concerns regarding data privacy, algorithmic bias, academic integrity, and the preparedness of educational institutions to regulate emerging AI technologies effectively. The organisation advocates a human-centred approach

that ensures AI functions as a supportive educational tool rather than a replacement for human interaction and pedagogical decision-making. These perspectives provide an important foundation for understanding the opportunities and challenges associated with AI-supported science pedagogy in contemporary educational contexts.

5. AI can support competency-based education and facilitate the development of 21st-century skills. AI in augmenting instructional effectiveness and learner support (Rose Luckin).

6. Efe & Efe (2025) worked on teachers' perceptions of AI and morally responsible integration of AI in science learning environments. Here, it focuses on science teachers' perceptions of AI in science classes. The challenges, preparedness, advantages, and its effect on student learning were considered. 383 science teachers were participated in the study. It was disclosed that the participants viewed lack of adequate training and data privacy concerns as the most prominent barriers for integrating AI in science classes. Familiarity significantly affects AI Readiness and AI-Supported Assessment & Feedback, while Teaching experience has a significant effect on Barriers to AI Adoption, emphasising the significance of familiarity with AI and teaching experience on these outcomes.

7. Webb &Galamba (2026)studied on Transforming Pedagogy with GenAI-Supported Formative Assessment: Challenges for Teacher Education, by asking question like, "How can GenAI be integrated into formative assessment practices to increase students' learning by supporting teacher agency and professional judgement" and argued that GenAI, when critically and thoughtfully deployed, can create new opportunities for personalised feedback, dynamic learning pathways and the co-construction of knowledge between teachers and students. It further suggested that teacher quality in this evolving pedagogical landscape should be understood as adaptive, multifaceted and grounded in both technological fluency and sound formative assessment principles, moving beyond the narrow and prescriptive definitions.

8. Karampelas (2026) worked on Artificial intelligence in inquiry-based science teaching: A bibliometric study. A Scopus query retrieved 26,283 documents, which were analysed through descriptive statistics and science mapping. Findings reveal a sharp rise in publications since 2017, with notable peaks in 2024 and 2025, reflecting the rapid mainstreaming of AI in science education. By providing a large-scale bibliometric analysis of research at the intersection of AI and inquiry-based science education, this study establishes a foundation for future scholarship while underscoring unresolved challenges surrounding equity, ethics and collaboration. The findings also provide evidence to inform policy initiatives, teacher training programs and equitable investment in AI-enhanced science education.

9. Kesgin (2025) worked on Bibliometric Analysis and Predictive Modelling Map the Role of Artificial Intelligence in Science Education from Research Trends to Classroom Integration, and the meta-analysis of 39 empirical studies revealed a significant overall positive effect of AI on science learning outcomes. The findings extend constructivist, sociocultural, and Bloom's frameworks by showing how AI fosters individualised inquiry, collaborative learning, and higher-order cognitive tasks. Practically, they highlight the need for teacher training frameworks such as Technological Pedagogical Content Knowledge (TPACK) and the 5E model to ensure meaningful integration of AI tools. This study offered predictive informationtoeducators, and other stakeholders like policymakers, and researchers about both current trends and future trajectories of AI in science education.

10. Mattalo (2024) studied Artificial Intelligence: The Future of Pedagogy and suggested that academics should research the use of generative AI to improve teaching effectiveness and efficiency. Suggestions were offered on how these tools can be used to advance pedagogical practices.

However, existing literature also identifies important concerns related to ethical issues, teacher preparedness, digital inequality, algorithmic bias, and academic integrity. Therefore, balanced and pedagogically sound integration of AI remains essential for sustainable educational transformation.

4.0 Objectives of the study

1. To examine the emerging trends in AI-supported science pedagogy.

2. To analyse the pedagogical implications of Artificial Intelligence in science education.
3. To explore the role of AI in promoting personalised and learner-centred science learning.
4. To identify the opportunities and challenges associated with AI integration in science classrooms.
5. To discuss ethical concerns and future directions of AI-supported science education.

5.0 Emerging Trends in AI-Supported Science Pedagogy:

5.1 Generative AI in Education-

The lesson planning, content generation, science-concept explanation, and AI-powered conversational systems provide learners with immediate responses and personalised learning guidance, and students learn at their own pace.

5.2 Personalised and Adaptive Learning-

Here, it analyses learner behaviour and performance to provide individualised instructional experiences. Personalised learning environments help students learn scientific concepts according to their learning pace and needs

5.3 Intelligent Tutoring Systems-

With the help of AI, the intelligent tutoring systems simulate one-to-one instructional support through both automated feedback and guided learning experiences.Surprisingly, in these systems,conceptual clarity is individually cleared, learners' engagementimproves, and problem-solving skillsare enhanced.

5.4 Virtual Laboratories and Simulations-

AI-assisted virtual laboratories and simulations help learners to visualisecomplex scientific phenomena and conduct experiments in safe and interactive environments. Such technologies are especially useful where physical laboratory access and facilitiesare limited.Subjects like science and the real experiments in real laboratories are not possible due to financial and infrastructural constraints. The virtual labs and simulations are helpful in these situations (Agarwal & Arya, 2016)

5.5 AI-Based Assessment and Learning Analytics-

AI-supported assessment systems facilitate automated evaluation of the students, automatic diagnostic feedback, and learners' monitoring, etc. Learning analytics help educators identify learning gaps and provide timely intervention to improve learning.

5.6 Immersive Technologies-

The integration of AI with Augmented Reality (AR) and Virtual Reality (VR) is creating immersive science learning experiences that enhance learner engagement and experiential learning.

5.7 Educational Implications of AI-Supported Science Pedagogy-

The integration of AI into science education has significant implications for teachers, learners,and educational institutions. AI-supported pedagogy promotes learner-centred instruction, personalized learning, collaborative learning, and development of higher-order thinking skills.Teachers are increasingly expected to function as both facilitators and co-learners, mentors, and designers of meaningful learning experiences rather than mere transmitters of information and transmitters of knowledge. Therefore, teacher educators' and pre-service teachers' competency, their digital literacy, and professional preparedness have become essential for effective AI integration.AI-supported science learning environments also encourage self-directed learning, creativity, scientific inquiry, and critical thinking. Educational curricula may require restructuring to incorporate digital literacy, ethical awareness, computational thinking, and AI-related competencies.At the institutional level, implementation of AI-supported pedagogy demands adequate technological infrastructure, policy support, and teacher training,

5.8 Benefits of AI in Science Classes-

Different advantages of AI in science classes are reported in the literature review. AI contributes to science teaching by improving classroom engagementthrough improved interactive classroom discussion, simplifying complex scientific concepts for students (Almasri, 2024; &Azari et al., 2024). Similarly, AI can customise educational experiences to suit each student's unique requirements, helping to address diverse learning styles and abilities (Ali & Okon, 2024; Seo et al., 2024). It has the potential to help nurture skills including critical thinking, creativity, and problem-solving (Ayanwale et al., 2024; Luckin, 2018; Wu et al., 2024). These benefits are more evident in scientific writings, where AI can provide scaffolding for students and help them develop critical thinking skills (Kim & Kim, 2022). Challenges in AI Integration Despite the benefits of AI in science teaching, some potential challenges are also reported in the related literature. Limited access to AI tools and resources, particularly in underserved regions, is one of the important challenges (Arvin et al., 2023; Azari et al., 2024). Similarly, studies revealed that teachers often feel unprepared to use AI effectively due to insufficient training and support (Morze et al., 2024). Data security, the potential for excessive dependence on technology (Ali & Okon, 2024), and the difficulties of integration of AI into existing science teaching, as it requires careful alignment with educational goals (Park et al., 2023; Williams et al., 2021), are other major challenges of AI in science classes.

5.9 Ethical Concerns around the Progress of AI-

Despite its educational potential, AI integration in science pedagogy faces several challenges. One major concern is the digital divide, particularly in developing regions where technological infrastructure and internet accessibility remain limited.Ethical concerns related to data privacy, surveillance, algorithmic bias, and misuse of learner information are increasingly significant. Overdependence on AI technologies may also reduce human interaction and critical engagement in educational settings.Academic integrity issues, including plagiarism and unethical use of generative AI tools, have emerged as important concerns in modern education. Additionally, many teachers lack adequate professional training and technological competence for effective AI integration.

Therefore, responsible implementation of AI-supported pedagogy requires ethical awareness, balanced technological use, teacher preparedness, and equitable educational access. We see an unprecedented level of automation in various areas, even in science. It is becoming difficult to predict the impact of AI inthenear future in the areas of science(&its pedagogy), healthcare, digitalsurveillance, cyber warfare, etc.Educators struggle to determine the essential future skills that today's school-going learners should be equipped with.However, there are concerns about the implications of unregulated research and innovation in AI.Any AI model is data-hungry. There is a tremendousinterest in collecting data, includingthe datafor writing a research paper.Consider big technology corporations collecting data about our personal and social life, including what we write that goes viral,and whatwe talk about, a concept in science or any other discipline.Such personal data can beexploited andmisused if they are misused. In the context of education,constantmonitoringof student behaviours andachievements can result in severeand far-reaching ethical questions.The European Union(Hickman & Petrin, 2021) is taking the lead so far in initiatingserious attempts to regulate AI and big technology companies. Any potential monopoly has to be broken downtoensure theethical and safe use ofAI and related technologies.

5.10 Future Directions-

The future of science pedagogy is gradually moving toward intelligent, adaptive, collaborative, and technology-supported learning ecosystems. AI-supported educational systems are expected to further enhance personalised learning, competency-based education, virtual experimentation, and interdisciplinary learning practices.Future educational environments may increasingly utilise AI for curriculum design, multilingual learning support, and lifelong learning opportunities. Integration of AI with immersive technologies such as AR and VR is likely to further transform science learning experiences.

When days pass, educators will need to embrace the potential of AI as a complementary tool for enhancing teaching and learning experiences. There will be a focus on developing a symbiotic relationship between human educators and AI, though both parties have the power to go on. As AI excels in handling repetitive tasks, data analysis, and content generation, utilise it to create personalised and adaptive learning experiences for students. At the same time, educators should emphasise their irreplaceable role in fostering critical thinking, creativity, empathy, and ethical decision-making, which are essential human qualities that AI cannot fully replicate. By integrating AI into pedagogy and adopting a growth mindset, educators can

empower themselves and their students to thrive in an increasingly technology-driven world. I could not have said it better myself (Mattalo, 2024).

6.0 Conclusion:

Today AI has emerged as a transformative force in contemporary science education. Pedagogical practices in the 21st century need to be reshaped. AI-supported science pedagogy has tremendous benefits. At the same time, we must be very sure ofethical concerns, digital inequality, academic integrity, teacher preparedness, and data privacy, which require careful consideration.The effective integration of AI into science pedagogy should therefore focus on balanced, ethical, inclusive, and pedagogically meaningful educational classroom practices. AI should function as a supportive instructional tool that enhances human teaching rather than replacing the role of teachers.

References:

- Abumusab, S. (2024). Generative AI and human labour: Who is replaceable? *AI & Society*, 39, 3051-3053. https://doi.org/10.1007/s00146-023-01773-3
- Afzaal, M., Shanshan, X., Yan, D., & Younas, M. (2024). Mapping artificial intelligence integration in education: A decade of innovation and impact (2013–2023) - A bibliometric analysis. *IEEE Access*,12,113275-113299. https://doi.org/10.1109/ACCESS.2024.3443313
- Akhmadieva, R. S., Udina, N. N., Kosheleva, Y. P., Zhdanov, S. P., Timofeeva, M. O., &Budkevich, R. L. (2023). Artificial intelligence in science education: A bibliometric review. *Contemporary Educational Technology*, 15(4). https://eric.ed.gov/?id=EJ1406974
- Alkhatlan. A, & Kalita, J. (2019). Intelligent Tutoring Systems: A Comprehensive Historical Survey with Recent Developments. *International Journal of Computer Applications*. 181, 43, 1-20. DOI=10.5120/ijca2019918451
- Barbhuiya, R. K. (2023), Introduction to Artificial Intelligence: Current Developments, Concerns and Possibilities for Education. *Indian Journal of Educational Technology*, 5 (2), July 2023.
- Barbhuiya, R. K., Mustafa, K., & Jabin, S. (2011). Design Perspectives of Intelligent Tutoring Systems. In IICAI (pp. 1484-1495).
- Efe, R. & Efe, H. A., (2025). Science Teachers' Perceptions of the Artificial Intelligence in Science Education: Challenges, Readiness, Benefits, and Impact on Student Learning. *Journal of Baltic Science Education*, 24 (4), 2025.ISSN 1648-3898 & ISSN 2538-7138, https://doi.org/10.33225/jbse/25.24.655
- Hajam, K. B., & Purohit, R. (2024). The ethics of artificial intelligence: A critical examination of moral responsibility and autonomy. *Indian Journal of Educational Technology*, 6(2), 398–407. https://journals.ncert.gov.in/IJET/article/view/513
- Higgs, J. M., &Stornaiuolo, A. (2024). Being human in the age of generative AI: Young people's ethical concerns about writing and living with machines. Reading Research Quarterly, 59 (4), 632-650. https://doi.org/10.1002/rrq.552
- Kanvaria, V. K., & Ritika. (2024). Exploring the integration of artificial intelligence in lesson planning for pre-service teachers. *Indian Journal of Educational Technology*, 6(2), 340 345. https://journals.ncert.gov.in/IJET/article/view/455
- Kapoor, V., & Bakhshi, A. K. (2025). Artificial intelligence and the future of education. *Indian Journal of Educational Technology*, 7(1), 389–397. https://journals.ncert.gov.in/IJET/article/view/837
- Karampelas, K. (2026). Artificial Intelligence in Inquiry-Based Science Teaching: A Bibliometric Study. *European Journal of Science and Mathematics Education*, 14 (1) p104-116 2026.ISSN:2301-251X (Online). http://creativecommons.org/licenses/by/4.0/
- Karan, B. (2024). Integration of artificial intelligence by the Central Board of Secondary Education in India: Towards innovative teaching and learning practices. Teaching, Pedagogy and Education, 33(4). https://doi.org/10.1080/1475939X.2024.2337924
- Kavitha, K. & Joshith, V. P. (2024). Pedagogical incorporation of artificial intelligence in K-12 science education: A decadal bibliometric mapping and systematic literature review (2013-2023). *Journal of Pedagogical Research.* 8 (4), 2024 https://doi.org/10.33902/JPR.202429218

- Kavitha, K., & Joshith, V. P. (2024). The transformative trajectory of artificial intelligence in education: The two decades of bibliometric retrospect. *Journal of Educational Technology Systems*, 52(3). https://doi.org/10.1177/00472395241231815
- Kesgin, K. Bibliometric analysis and predictive modeling map the role of artificial intelligence in science education from research trends to classroom integration. *DiscovEduc* 4, 464 (2025). https://doi.org/10.1007/s44217-025-00906-8
- Lopez, S., Sarada, V., Praveen, R.V. S., Pandey, A., Khuntia, M., &Haralayya, B. (2024). Artificial intelligence challenges and role for sustainable education in India: Problems and prospects. Library Progress International, 44(3), 18261-18271. https://dx.doi.org/10.2139/ssrn.5031316
- Mattalo, B. (2024). 'Artificial Intelligence: The Future of Pedagogy'(2024)41JLSE49. https://doi.org/10.1111/jlse.12146
- Mattalo, B. (2024). Artificial Intelligence: The Future of Pedagogy. *Journal of Legal Studies Education*, 41 (1), p. 49-71 2024, https://doi.org/10.1111/jlse.12146
- NCERT (2023, June 03). DIKSHA. https://diksha.gov.in/. Accessed on 03 June 2023.
- Schleicher, A. (2019). Artificial intelligence in education: Challenges and opportunities for sustainable development. *OECD Education Working Papers*.
- UNESCO. (2021). AI and education: Guidance for policy-makers. *UNESCO* Publishing.
- Webb, M. &Galamba, A. (2026). Transforming Pedagogy with GenAI-Supported Formative Assessment: Challenges for Teacher Education. *British Journal of Educational Technology*, v57 n3 p690-706 2026, https://doi.org/10.1111/bjet.70051
- Yun, G., Lee, K. M., & Choi, H. H. (2024). Empowering student learning through artificial intelligence: A bibliometric analysis. *Journal of Educational Computing Research*, 62 (8). https://doi.org/10.1177/07356331241278636

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