Journal of Science Education and Technology
https://doi.org/10.1007/s10956-025-10200-9

Intersections of Mind and Machine: Navigating the Nexus of Artificial Intelligence, Science Education, and the Preparation of Pre-service Teachers

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Accepted: 24 January 2025

Abstract
The rapid advancement of generative artificial intelligence (GenAI) is reshaping various sectors, including education. This editorial explores the intersections of AI, science education, and the preparation of pre-service teachers (PSTs), questioning whether GenAI represents a truly transformative technology or merely the latest iteration of an educational hype cycle. While previous technological innovations—such as radio, television, and computers—were initially heralded as revolutionary, their impact on education has varied significantly. The emergence of GenAI, particularly large language models, introduces new possibilities for personalised learning, digital tutoring, and adaptive content generation, yet its integration into educational practice remains uneven. Despite growing societal reliance on GenAI, a substantial proportion of in-service teachers report limited use, citing a lack of training and institutional policies as key barriers. In contrast, research suggests that PSTs are already engaging with GenAI tools for lesson planning, content summarisation, and assessment preparation. This editorial underscores the need for initial teacher education (ITE) programmes to provide structured support, ensuring that PSTs develop both technical proficiency and critical AI literacy. Ethical concerns—such as data privacy, algorithmic bias, and epistemic authority—must also be central to teacher training. Focusing on science education, this special issue examines the opportunities and challenges of GenAI integration. The contributions explore PSTs' perceptions, competencies, and preparedness to implement AI-driven tools in their teaching, addressing themes such as inquiry-based learning, pedagogical content knowledge, and the evolving role of educators in AI-powered classrooms. The discussion highlights the necessity of balancing technological innovation with critical reflection, equipping future teachers to navigate the complexities of AI in education responsibly. This editorial aims to advance the dialogue on GenAI's role in teacher preparation, urging educational institutions to proactively support PSTs in harnessing its potential while fostering a critical, ethical, and pedagogically sound approach to AI integration in science education.

Keywords Generative Artificial Intelligence · Science Education · Pre-service Teachers · Teacher Education · AI LiteracyPedagogical Integration · Inquiry-based Learning

Introduction

Overhyped? Or Truly Transformational?

The increasing digitalisation of societies is influencing an ever-growing range of sociocultural, economic, and geo-political spheres (Darics & Poppel, 2023; Mohamed et al., 2020; Wang, 2019). As part of this increasing digitalisation, generative artificial intelligence (GenAI) utilises advanced neural networks to produce various outputs, such as text, image, and video (Cooper, 2023). GenAI represents a shift from other forms of artificial intelligence that simply process data within limited contexts, to output of content that mimics

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Published online: 10 February 2025

human-like creativity and complexity. The tech industry's 'move fast and break things' philosophy has evolved into a mindset focused on the unrestricted and rapid advancement of GenAI (Roose, 2023). Large language models (LLMs), a subset of GenAI, have seen widespread adoption worldwide. ChatGPT, for instance, has an estimated 100 million active weekly users at the time of writing (Brandl, 2024). The emergence of GenAI in education has ignited fierce debate in some circles. Is it truly transformational or just the latest overhyped technology?

Historically, educators have seen this before (Cuban, 1986). For instance, the humble radio was once predicted to be a transformational tool that would revolutionise education. 'Educators, government officials, and the public envisioned a future where the airwaves would bring the world's greatest teachers to students, making high-quality education universally accessible' (Dieterle, 2024, para.2). Proponents predicted that broadcasts would supplement or even replace traditional classroom instruction, offering lectures, courses, and educational programmes directly to students. Although radio made a significant contribution to distance education, it fell short of the transformative expectations some predicted. Likewise, when television was a new technology, it was also expected to revolutionise education. In the mid-twentieth century, television was seen as a transformational tool that could bring visual and auditory learning experiences to students in a way that books and radio could not (Kent & McNergney, 1999). Advocates believed that television could make learning more engaging and accessible, reaching a wide audience and uniform quality of instruction across different regions (Dunham et al., 1957). Like the radio, television did not transform the education system as predicted.

The introduction of computers into classrooms in the late twentieth century has had a much larger impact. When used effectively, computers have, for instance, helped learners grasp complex concepts through simulations, facilitated collaboration among learners online, and adaptive software has adjusted the difficulty of content based on learner progress. However, despite their widespread adoption, many classrooms have remained remarkably resistant to change (Leahy et al., 2019). This exemplifies the cycle of technological hype in education. As Cuban and Jandrić (2015) argued,

> "cyclical patterns have accompanied new technologies for nearly a century, reform-minded policymakers surround the innovation with extravagant claims followed by academic studies showing limited or unimaginative classroom use of devices followed by disappointment and then blame heaped upon teachers rather than those who made the initial claims" (p.426).

In a similar way, once again, stakeholders are questioning the potential of GenAI in education. Is this just another hype cycle for educators to navigate or is this time truly different? Some argue that AI's wider impact has the potential to bring about societal changes on a scale greater than previous technological waves, including the internet (Gruetzemacher & Whittlestone, 2022). In terms of education, some argue that its capacity to, for instance, personalise learning, provide tailored feedback, and act as a digital tutor means it can be classified truly as a transformational technology (Chen et al., 2023; Giannakos et al., 2024). GenAI systems are not only capable of analysing vast amounts of data to provide individualised learning pathways, but they can also evolve with each interaction, learning from users and adapting responses over time. GenAI-powered tools can function as 'on-demand tutors', giving each student the attention they need in areas where they need support. Advocates of GenAI envision an education system where learning is truly a collaborative effort between humans and machines. For those who see GenAI as co-creator, the technology supports students in generating ideas, refining their work, and ultimately leveraging human potential.

Against the backdrop of bold claims that GenAI will radically transform education, a recent nationally representative survey of over 900 educators in the USA reported that 59% of educators are not currently using ChatGPT or other GenAI tools (Klein, 2024). In addition, over a third of teachers (36%) mentioned that a lack of knowledge about how to use GenAI tools was a key reason for not integrating them into their teaching. Likewise, 33% indicated that they were not using GenAI tools because their districts had not yet established policies for their use. Is GenAI just the latest technology caught up in the hype cycle of new technologies we mentioned earlier, where in-service teachers are provided with limited support, yet are later blamed when the technology is not effectively integrated into their teaching practices? In contrast, exploratory research into GenAI usage among pre-service teachers (PST) suggests that students are already actively engaging with GenAI tools for their university studies. The range of GenAI engagement includes practical applications such as generating lesson ideas, summarising content, and using it for assessment preparation (e.g. Cooper et al., 2024; Park et al., in press). For instance,

> …ChatGPT has rapidly emerged as a commonly used platform, and in some instances, a favoured choice for university students (all PSTs)…[they]…were using ChatGPT and Google interchangeably, depending on the question or need. For more nuanced queries, ChatGPT often appeared to be the go-to choice. Its ability to engage in an ongoing dialogue allowed users to interact conversationally with the GenAI, clarify with follow-up questions, and create differ-

> ent cultural artifacts (e.g. résumés, code, charts etc.). Google at present tends to be the favoured choice when students wish to quickly ask a simple question or fact check, search a specific website, or find images and video…. GenAI literacy is becoming an increasingly crucial skill for graduates…charting a course through this terrain will likely call upon universities, educators and students to embrace a reimagined space where learning is increasingly a collaborative endeavour between human and machine (Cooper et al., 2024, p.116).

The extent to which PSTs' experience with GenAI at university will shape their future teaching practices in schools is still unclear. However, their use of GenAI is expected to continue, and this early adoption at university likely lays the foundation for broader integration of these technologies in school settings.

GenAI Experiences, Perceptions, and Training for PSTs

As societal reliance on these technologies grows, GenAI literacy is becoming an increasingly important part of initial teacher education (ITE). PSTs commonly showed a strong intention to integrate digital technology into their teaching practices, though effective integration often required structured support (Duan et al., 2024). This underscores the essential role universities play in equipping PSTs for the responsible, ethical, and effective use of GenAI. PSTs need to develop a comprehensive toolkit that equips them with both the technical skills and the critical acumen to assess GenAI outputs effectively, discerning trustworthy information from misleading content (Cooper et al., 2024). They need critical thinking skills to engage with GenAI outputs responsibly, questioning their validity and recognising the broader socio-political narratives they may convey, especially when they exhibit biases favouring dominant Western perspectives that marginalise minority groups (Cooper & Tang, 2024). Ethical concerns surrounding privacy and data security further complicate the adoption of GenAI. These tools collect user data to improve functionality, raising questions about how this data is stored, who has access to it, and how it might be used in the future. Inadequate safeguards could expose both educators and students to risks such as data breaches or misuse of personal information. Institutions should prioritise structured, ongoing professional development to ensure that PSTs are prepared to use GenAI responsibly and ethically. This includes discussions about bias, ethics, and data privacy in ITE programmes and creating opportunities for PSTs to critically reflect on the broader implications of these technologies in educational settings (Cooper et al., 2024).

Implications of PSTs' Use of GenAI Use in Science Education?

GenAI presents transformative potential to reimagine science education. GenAI tools can, for instance, simulate experiments, generate data for analysis, and support creative problem-solving, offering new avenues for students to explore scientific concepts and processes. This involves understanding how to integrate these tools into science curriculum, ensuring alignment with learning objectives, and selecting appropriate platforms for specific educational outcomes. To this end, PSTs need to cultivate a type of GenAI literacy that allows them to critically assess AI-generated content, recognising when and how it aligns with the principles of scientific inquiry and where it falls short.

Integrating GenAI into science education necessitates a thoughtful examination of the discipline's epistemic foundations. Science education is deeply rooted in the materiality of empirical evidence, hands-on experimentation, and the iterative processes that define scientific inquiry (Tang & Cooper, 2024). Therefore, the use of GenAI must be complemented by practical, inquiry-based learning experiences that allow students to test and validate AI-generated insights through direct experimentation and observation. However, effectively integrating GenAI requires a deeper understanding of how PSTs perceive and approach these tools, as well as their preparedness to incorporate them into their teaching practices. Current literature highlights significant gaps in these areas, underscoring the need for targeted research. In response, this special issue brings together studies that address these gaps, exploring PSTs' technical competence and their understanding of GenAI's societal and educational implications. These six contributions collectively provide a roadmap for equipping PSTs with the skills and perspectives necessary to navigate and leverage GenAI in science education.

Arantes (2024) begins the collection by examining how notions of objectivity and evidence in science education are shifting in a post-truth era shaped by GenAI. The author frames this dilemma through the concept of technical agonism, a model for fostering critical awareness of the biases, hallucinations, and inaccuracies that GenAI introduces. By examining GenAI's limitations alongside its potential, Arantes' study challenges the assumption that GenAI can serve as an authoritative source in science education. The work calls for more focus in ITE that highlights the importance of equipping PSTs with skills to navigate an information landscape rife with GenAI-induced ambiguities and misinformation.

By embedding AI chatbots within a guided discovery learning framework, Huang et al. (2024) illustrate how GenAI can foster PSTs' engagement, motivation, and personalised learning in science education with a focus on global warming. The study revealed that PSTs found this AI-supported learning nurtured their confidence in navigating scientific content and fostered skills in facilitating inquiry-based learning. This work reinforces GenAI's potential to foster motivation and enhance relevance within science education, contributing valuable insights into the special issue's theme on AI-embedded teaching practices and supporting PSTs' development as future teachers.

Using Ajzen's Theory of Planned Behaviour, Ramnarain et al. (2024) identified several factors associated with science PSTs' intentions to adopt GenAI in inquiry-based teaching. Despite a generally favourable view of GenAI, many PSTs expressed concerns over skill readiness and ethical implications, which act as barriers to adoption. The study's findings reveal the complexity of integrating GenAI within inquiry-based learning, a model that emphasises critical thinking, experimentation, and student-driven discovery. Ramnarain et al. suggest that institutions must anticipate the diverse readiness levels of teachers and invest in a structured, gradual integration of GenAI competencies across the pre-service curriculum.

Li and Ironsi's (2024) work examines the use of GenAI to support PSTs' writing skills in science education. Their findings reveal that while tools like ChatGPT offer a level of convenience for generating content and supporting revision, they may not substantively improve PSTs' writing abilities over the long term. Li and Ironsi point out that students often lean towards AI-generated responses as final answers rather than as starting points for deeper analysis, which can lead to superficial learning outcomes. The authors warn that over-reliance on GenAI can undermine the development of foundational writing skills and discourage students from actively engaging in the cognitive work that human mentorship and personalised feedback typically cultivate. This study serves as a cautionary counterpoint to more optimistic views of GenAI, emphasising the need for an approach that incorporates human mentorship that leverage GenAI tools.

Zhai's (2024) paper presents a framework for understanding GenAI's transformative impact on teachers' roles and agency within educational contexts. By categorising teachers into four roles—observer, adopter, collaborator, and innovator—based on their engagement with GenAI, Zhai illustrates a developmental trajectory where educators move from initial exposure to active co-creation of educational content alongside AI. This progression not only highlights the growing importance of professional development in GenAI literacy but also underscores the need for ongoing institutional support to address the ethical and relational complexities GenAI introduces to classroom dynamics. His findings emphasise the dual necessity of empowering teachers to harness AI's potential while also fostering the critical oversight and ethical sensitivity needed to manage the challenges GenAI poses.

Concluding the issue, Blonder et al. (2024) work examines how GenAI can serve as both a diagnostic and developmental tool for pedagogical content knowledge (PCK) in science teacher education. Blonder et al. argue that GenAI holds unique potential for facilitating the practical application of theoretical knowledge in PST education. The paper highlights GenAI's diagnostic power, showing how personalised, real-time feedback can facilitate the kind of reflective practice that is central to effective teaching. This application of GenAI offers a unique way to enhance PCK development in teacher education programmes, presenting an innovative solution to persistent challenges around assessing and developing teachers' pedagogical knowledge.

Each of these six papers contributes to a deeper understanding of GenAI's role in PST education, with a particular focus on the context of science education, illustrating both the opportunities and areas that warrant further attention. As teacher education programs consider the most effective approaches to incorporating GenAI technologies, these findings provide critical insights into supporting educators who are both discerning users and effective integrators of GenAI. The insights offered here underscore the need for educational models that balance innovation with critical reflection, preparing science PSTs to navigate AI-powered classrooms effectively. Together, these papers contribute to a vision of science education that equips teachers with the skills and perspectives necessary to engage with GenAI in ways that prioritise both educational integrity and transformative learning.

As a whole, this special issue represents an important step towards addressing the significant gap in the literature concerning PSTs' use, understandings and experiences of GenAI in science education. By foregrounding these intersections, we aim to advance a dialogue that bridges theoretical insights and practical applications in preparing the next generation of science educators. As we move forward, the convergence of GenAI, science education, and teacher preparation will demand new pedagogical frameworks, empirical insights, and a commitment to fostering critical GenAI literacy, so that PSTs are not only equipped to engage with these powerful tools but also prepared to question, adapt, and guide them in ethically responsible ways. This special issue, therefore, aspires to be a catalyst for research that enriches our understanding of how best to harness the transformative potential of GenAI while preparing PSTs to be leaders in navigating the complex intersections of mind and machine.

Author Contribution All three have equal contributions.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions.

Data Availability All raw data published in paper.

Declarations

Ethical Approval Not applicable.

Consent to Participate Informed consent was obtained from all individual participants included in the study.

Consent for Publication The participant has consented to the submission of the case report to the journal.

Competing Interests The authors declare no competing interests.

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ChatGPT 4o was used during the writing process of this editorial between July and December 2024. The tool was used to rewrite sentences for improved phrasing, flow, and word choice (e.g. ChatGPT prompt: rewrite: [sentence], or reword: [sentence]). We acknowledge that we have carefully reviewed and edited the text, and take full responsibility for the manuscript, regardless of the extent to which GenAI contributed to its creation.