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Bringing Teachers in the Loop: Exploring Perspectives on Integrating Generative AI in Technology-Enhanced Learning

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Abstract

In education, the utilization of EdTech tools diverges notably between developed and developing nations, a dichotomy attributed to multiple factors like Technological Infrastructure, Digital Literacy, Digital Pedagogy, Tools, and Content. Recent research studies highlight that Generative AI's potential use and integration might exacerbate this gap. One possible and first-hand suggested solution is to involve the educational stakeholders in the early phase of any shift caused by a technological wave. This study explores the potential of Generative AI use and integration in STEM education by capturing the perceptions of digitally literate Indian High school teachers. Through a purposive sampling approach, it includes 67 teachers as participants, soliciting their perceptions labeled under SWOT verticals through open-ended questionnaires. Employing thematic and content analysis, this research delves deeper into the perceptions of Technological, Pedagogical, Content, and Contextual potentials of Generative AI in Indian High school TEL-based STEM education. The findings reflect strengths like Personalized Learning Experiences, Content Enrichment, and Interactive Learning Experiences. Opportunities such as Differentiated Instruction Enrichment, Inclusivity, Access Expansion, and Active Learning Integration are pathways toward a more inclusive and engaging educational paradigm.

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Introduction

In the digital age, Educational Technology (EdTech) refers to incorporating digital tools, software, and devices in educational practices like learning, teaching, and curriculum planning to improve corresponding outcomes like deep learning, contextualized teaching, and effective student-centered curriculum (Johnson et al., 2016). Integration of EdTech tools in learning and teaching has shown numerous benefits like increased student engagement, improved information retention, enhanced critical thinking skills, and better performance (Carmichael et al., 2018). For example, teachers can create more interactive and personalized learning environments catering to diverse student needs and learning preferences through Technology-Enhanced Learning (TEL) (Song et al., 2012). As TEL studies continue to validate EdTech integration in authentic learning situations longitudinally, its widespread adoption is becoming increasingly prevalent.

The scope of TEL varies significantly between developing and developed countries due to conducive conditions such as robust technological infrastructure, widespread internet access and fast speed, and stakeholders' (like teachers, curriculum designers, and school principals) generic digital literacy (Nye, 2015). Developing countries face challenges accessing and maintaining TEL infrastructure and providing adequate initial training for stakeholders (Adarkwah, 2021). Moreover, socioeconomic disparities like varying cultural attitudes towards technology and geography-based budget constraints add more complications (Burns, 2013). Acknowledging these differences and leading to the tailored strategies to maximize the potential of EdTech through TEL would bring one step closer to promoting equitable and effective quality education worldwide (Sustainable Development Goal 4; SDG4) (Unterhalter, 2019).

The rapid emergence of new technologies in Information and Communication Technology (ICT) directly impacts EdTech from a technical standpoint, often resulting in waves of change in TEL (Deaney et al., 2003). Unfortunately, in many cases, educational stakeholders in developing countries are neither adequately consulted nor asked for collaboration during the early phase of these technological shifts (Oke & Fernandes, 2020). This technocentric approach significantly hampers the integration and adoption not only in the practical aspect but also from the policy-level (Burch & Miglani, 2018). For instance, when AI-based Chatbots were introduced, numerous EdTech companies followed the wave. They came with educational robots but their use and adoption could not be sustained due to insufficient consultation and late collaboration with educational practitioners (Pedro et al., 2019). To bridge this gap, educational stakeholders need to be in the loop from the early wave phase to cover the specific needs and deal with context-specific challenges of authentic TEL situations (Thomas & Knezek, 2008).

The emergence of Generative Artificial Intelligence (GAI), particularly Large Language Models (LLMs), is an ongoing new technological wave in EdTech and TEL community (Mhlanga, 2023). LLMs have revolutionized natural language processing, enabling machines to understand and generate human-like expressions, leading to the development of futuristic EdTech tools such as automated essay graders and assistants for assignment design and evaluation (Khosravi et al., 2023). However, despite this remarkable technical advancement, the challenges of using such tools from context-aware, human-centered, values-sensitive, and culturally-aware lenses might persist, mirroring past waves of EdTech journey (Yan et al., 2023). Therefore, it is required to keep educational stakeholders in the loop of the design and development journey from the early phase (Khosravi et al., 2023).

History seems to be repeating - ongoing GAI integration in EdTech is again mostly technocentric, and teachers are hardly consulted from the earliest phase in this development iteration (Smith & Hayman, 2016). This study takes the initial step to bridge this gap with the educators-in-the-loop approach. It collects the early perceptions of digitally literate Indian high school STEM teachers on the potential of using and integrating GAI in authentic TEL situations. To conceptualize their viewpoints effectively, the study employs a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis [1] (Gurl, 2017). SWOT is a strategic planning framework used in business contexts to assess internal and external factors affecting an organization's objectives. Its instantiation in educational research provides valuable insights to stakeholders about intervention and its potential implications by systematically examining the Strengths (S), Weaknesses (W), Opportunities (O), and Threats (T).

In this study, to ensure concise and focused responses, the teachers' perceptions under SWOT are further structured around the main verticals of the TPACK framework - Technology, Pedagogy, Content, and Context (Mishra & Koehler, 2008). The TPACK [2] is a widely recognized framework in EdTech and TEL, emphasizing the intersection of technology, pedagogy, and content knowledge within a specific educational context. It offers a comprehensive lens through which stakeholders can understand the complex interplay between these critical components and understand the requirement of TPACK skills for effective teaching and learning in TEL (Papanikolaou et al., 2017).

The main Research Question (**RQ**) is - ***What do digitally literate Indian high school STEM teachers perceive as the Strengths, Weaknesses, Opportunities, and Threats of GAI in TEL situations?*** The rest of this paper is structured as follows: Section "Related Work" briefly presents similar works in this direction, and Section "Methodology" presents the overall methodology of this study. Further, we present the teachers' demographics and profiles in Section "Teachers' Demographics and Institutional Profiles", and their perceptions are briefly presented and summarized in Section "Results". Finally, the implications of teachers' perceptions are discussed in Section "Discussion", and the paper is concluded in Section "Conclusions".

[1] For the operationalization of the SWOT framework's definition in this paper, authors adopt one of the SWOT variants used as a pedagogical tool for teaching critical thinking'(AlMarwani, 2020)

[2] The operational version of TPACK where authors used to understand the teachers' knowledge to ethically integrate AI-based tools in education (Celik, 2023) is used as a conceptual lens in this paper

Related Work

The requirement of educational stakeholders' involvement in the co-design and co-development of an EdTech tool from the early phase has been extensively examined and analyzed through various lenses like human-centered (Renz & Vladova, 2021), context-aware (Laine, 2011), educational theories-based (Ouyang & Stanley, 2014), and values-sensitive (Papendieck & Hughes, 2022). The human-centered design emphasized the active involvement of teachers and students throughout the development process to ensure that the resulting tools cater to their specific needs and preferences (Viberg & Grönlund, 2021). Context awareness highlighted the inclusion and accountability of different educational environments' unique settings and circumstances, recognizing that a one-size-does-not-fit-all (Gašević et al., 2016; Shankar et al., 2023). Educational theories provide valuable insights into the learning processes and instructional strategies, guiding the design of EdTech tools that align with established pedagogical principles (Giannakos & Cukurova, 2023). Similarly, adopting a values-sensitive and culture-aware approach helps identify and address ethical and societal implications within different cultures (Chen & Zhu, 2019).

Several critical aspects demand particular attention in planning, designing, and developing EdTech tools. For example, Diversity, Equity, and Inclusivity (DEI) considerations are vital to ensure that tools cater to the needs of diverse learners, bridging educational disparities and promoting equal opportunities for every learner across developed and developing countries (Pham & Sampson, 2022). Second, although the use and integration of EdTech tools in TEL situations are gaining momentum globally, adoption remains a significant hurdle (Sharples, 2021). Some reasons include - resistance to change, lack of awareness and self-efficacy among teachers, and less or almost no technical infrastructure in most schools of developing countries compared to the developed ones (Shibani et al., 2020). Finally, addressing ethical concerns and privacy issues is imperative to safeguard students' data and uphold democratic standards (Ifenthaler & Tracey, 2016).

Integrating AI in education brought the next generation of EdTech tools like Chatbots and intelligent computer support for teachers and students (Schiff, 2021). Several research studies involved educational stakeholders as experts in the development process. For example, researchers interviewed teachers to gain valuable insights into the Strengths, Weaknesses, Opportunities, and Threats surrounding EdTech integration (du Plessis & Webb, 2012). Another study tried to find the acceptance level of AI-based evaluation tools from the students' perspective because evaluation as a process in universities has always been highly correlated with the tool (Balickis, 2022). These research endeavors have contributed to a deeper understanding of the complexities of leveraging AI in existing or future EdTech tools (Ifenthaler, 2021).

As GAI-based EdTech tools are emerging, researchers are actively investigating the challenges and opportunities associated with their implementation (Ruiz-Rojas et al., 2023; Cukurova et al., 2023). Few studies explored the possibilities of novel and futuristic tools to enhance students' engagement in online classrooms (Hao & Cukurova, 2023) and support in content generation at scale for adult learning (Leiker et al., 2023). Concurrently, research also focuses on probing the ethical and privacy implications of integrating GAI into TEL settings by engaging with experts and practitioners (Lodge

et al., 2023). Similarly, research (Limna et al., 2023) has explored the perspectives of Thai teachers and students on a ChatGPT-based chatbot through interviews. The findings included seven themes: positive perception, reduced workload, the accuracy of the information, loss of personal interaction, data privacy interaction, data privacy issues, and ChatGPT as resources for the classroom toolkit.

Another study (Sullivan et al., 2023) explored the specific potential of ChatGPT on higher education while acknowledging the concerns surrounding academic integrity and plagiarism. The authors discussed its potential benefits in enhancing students' learning and highlighted the need for teachers to adopt this evolving technological space in their daily teaching and assessment practices. Similarly, Bahroun et al. (2023) examined the potential of GAI in education by analyzing 207 research papers. The authors explored how GAI can be used for assessment, personalized learning, and intelligent tutoring systems across disciplines like medicine and engineering. They also highlighted the ethical considerations while using GAI and suggested responsible usages like transparent models and addressing bias. Another study (Ali et al., 2023) explored the knowledge and innovation challenges presented by ChatGPT and GAI-based tools, highlighting the need for further research to address them. Through a systematic literature review, authors analyzed existing research on the model and identified four critical areas (user, operational, technological, and ethical) for further exploration based on user satisfaction and knowledge generation.

Methodology

The central objective of this study was to explore teachers' perceptions on the potential of using and integrating GAI in authentic TEL situations within the realm of Indian high school STEM education (see Fig. 1). It entailed examining how these tools can enhance various dimensions of TEL situations like Technology, Pedagogy, Content, and Context (four main verticals of the TPACK framework (Mishra & Koehler, 2008)). This study employed a qualitative approach to achieve the objective (Kishun & Vashishtha, 2019).

The study aimed to gather insights from a targeted group of STEM teachers working in Indian high schools (in-service teachers) through a purposive sampling approach (Kgosi et al., 2023). The rest of this section outlines the participant selection process, communication methods, exclusion criteria, data collection procedure, and initial data cleaning.

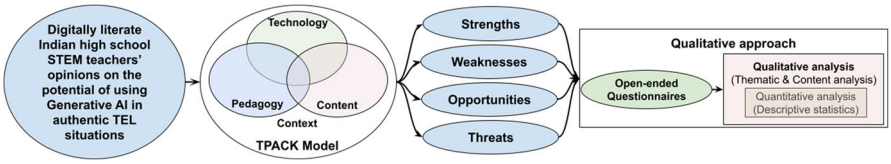

Fig. 1 The main objective, conceptual lens, structuring framework, and overall methodology of this study

1. **Purposive Sampling Approach:** This study deliberately selected teachers who are in-service, digitally literate, working in high schools, have implemented few TEL situations, and have experience using GAI-based tools like ChatGPT.
2. **Communication Medium and Participant Recruitment:** 1235 STEM teachers were initially contacted to participate in the study through WhatsApp and Email. Out of 1235 participants, 1078 teachers' details were collected from the researchers' local academic network. The rest of the 157 teachers joined this study through social media posts.
3. **Participant Filtering Process:** The selection process involved a multi-stage filtering approach to ensure that the final sample consisted of participants with relevant experience and expertise within STEM education. The filtering process occurred in multiple stages(see Fig. 2):
   (a) ***Teaching Experience:*** This study included only teachers with equal or greater than ten years of in-service teaching experience. Through this filtering process, 374 teachers were excluded.
   (b) ***Digital Literacy:*** Another level of filtering included the level of digital literacy of the teachers by following the European Union's digital literacy scale (Redecker & Punie, 2017). Notably, to the best of our knowledge, the authors of this study did not find a validated and evaluated digital literacy framework for teachers from an Indian context. After this step, this study had 579 teachers who reported a literacy level of 4 or 5.
   (c) ***Experience of EdTech tools in TEL:*** 258 teachers who had no experience using and integrating EdTech tools in TEL situations were excluded in this step.
   (d) ***Familiarity with TPACK:*** To ensure a certain level of amalgam knowledge of combining technology with pedagogy, participants were asked to self-report familiarity with TPACK (Balacheff et al., 2009; Agyei & Voogt, 2011). This resulted in a population size of 137 teachers.
   (e) ***Familiarity with GAI-based tools:*** The scope of familiarity was defined as teachers have heard of and used the GAI-based tools. For instance, if they have used ChatGPT for at least five queries. This level of filtering resulted in a population of 76 teachers.
4. **Data Collection Process:** A set of 16 open-ended questions[3], motivated from Mohebi and Meda (2021), targetting each of the main verticals of TPACK (Technology, Pedagogy, Content, and Context) for all four dimensions of SWOT was designed. They were internally validated for their ease of understanding by the researchers of this study. Finally, they were presented to the 76 teachers using Google Forms based on their language of instruction, such as English, Hindi, and Tamil. Before presenting these questions, a detailed SWOT analysis in a scenario was presented with an explanation of all its components so that participants get familiar with SWOT. The data collection process spanned over four weeks (23, 24, 25, and 26) of April 2023. The collected responses were stored securely on Google Drive within the organization's protected Google Suite environment.

[3] https://tinyurl.com/GAIQuestions

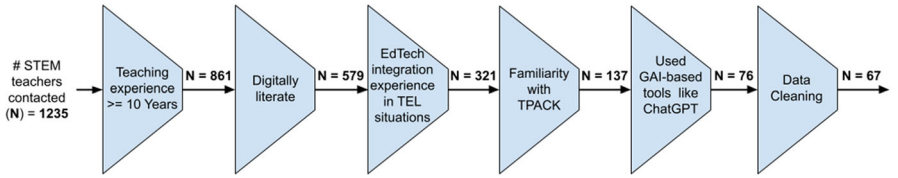

Fig. 2 Selection of teachers by following seven steps

5. **Data Management and Initial Cleaning:** The collected responses were accessible on the researchers' organizational laptop only. An initial data cleaning process (like removing incomplete, duplicate, and redundant data) was done. This stage considered 9 participants' responses insufficient because perceptions were either incomplete or absent. Finally, data from 67 teachers was processed and analyzed.

The study included Thematic analysis, which helped to identify recurring themes and subthemes using deductive reasoning. Further, it applies Content analysis to get patterns and specific quotes for each of them. Additionally, the study employed a quantitative analysis technique (Descriptive analysis) to enhance the findings' comprehensiveness numerically. It provided numerical findings like the number of themes, corresponding subthemes, and their frequencies against 67 participants. This nested approach (quantitative analysis on qualitative findings) enriched the results by presenting the depth of teachers' perceptions and the breadth of their prevalence.

Teachers' Demographics and Institutional Profiles

This section presents the demographic and institutional profile of the 67 participants.

1. **Gender:** 39 participants reported their gender as female (F), 26 as male (M), and two chose not to disclose.
2. **Age:** There were 22 teachers (F - 10 and M - 11) aged in the range of 31 to 40 years. 19 female and 11 male participants were from the range of 41 to 50 years. The third range (51 to 60 years) comprised 15 teachers (F - 10, M - 4).
3. **Teaching Experience:** 33 teachers reported having 10 to 14 years of in-service teaching experience, whereas 13 fell into the second category (15 to 19 years). The rest of the 21 participants reported experience of 20 to 24 years.
4. **School's Geographic Area:** The geographical area of the schools where participating teachers work was in five categories: Rural, Urban, Semi-rural, Semi-urban, and Neither Rural nor Urban. Five teachers were associated with Rural schools, while the Urban category included 18 teachers. 26 participants were from Semi-rural, and 11 teachers from the Semi-urban schools. Lastly, seven teachers indicated that their schools were neither rural nor urban.
5. **Educational Board Affiliation:** Indian educational boards are mainly categorized between union- and state-run bodies. For example, the Central Board of Secondary Education (CBSE) and the Indian Certificate of Secondary Education (ICSE) are two union boards. Moreover, different Indian states run their boards, like the Chhattisgarh Board of Secondary Education. 16 teachers belonged to CBSE-affiliated

schools, whereas 12 were from ICSE, 34 were from state boards, and five chose not to report.

6. **Digital Literacy:** 38 teachers self-reported their digital literacy on a Level of 4, whereas the rest of the participants reported a Level of 5.
7. **Representation of Indian States:** The total number of participants states-wise are as follows - Kerala: 7, Arunachal Pradesh, Chhattisgarh, Gujarat, Odisha, and Tamil Nadu: 5 each, Chandigarh, Karnataka, and Sikkim: 4 each, Bihar, Madhya Pradesh, and Rajasthan: 3 each, Assam, Haryana, Jharkhand, Punjab, and Uttarakhand: 2 each, and Himachal Pradesh, Maharashtra, Uttar Pradesh, and West Bengal: 1 each.

Results

This section presents the main themes and subthemes deducted from the Thematic analysis of teachers' perceptions on the envisioned S, W, O, and T of using and integrating GAI. They are situated under each of the four main verticals of TPACK with a brief explanation found from Content analysis and enriched with the quantitative findings from Descriptive analysis.

1. **Technology:** Teachers state that GAI can capitalize on interactive learning experiences, efficiency improvements, and personalized learning journeys in TEL situations.

   (a) ***Strengths: Human Augmentation Technologies -*** Teachers remark that GAI can technically help students and teachers improve their productivity in their respective practices. In this theme, three subthemes (***ST1-3***) emerge that cover most of the participants' perceptions (please refer to Table 1 for the frequencies and a sample quote from the participants for each subthemes).

   - **ST1: Interactive Learning Experiences -** Teachers suggest that GAI can bring future EdTech tools that may offer a transformative learning approach by providing dynamic and interactive experiences. Moreover, they point out the integration of simulations, virtual experiments, and multimedia presentations with such envisioned futuristic tools. This can further capture students' attention and deepen their understanding of complex STEM concepts.

Table 1 Potential strengths of GAI for improving technological aspect

Subtheme	Frequency	A sample quote
ST1	17	"... can help learners in interactive dialogue after classroom hours without my presence"
ST2	28	"... can automate administrative tasks, grading, or data analysis, saving my time"
ST3	18	"... technically tailoring content and experiences to each student's unique needs and learning preferences"

- **ST2: Efficiency and Time Savings -** With GAI integration in TEL situations, teachers can redirect their efforts toward meaningful teaching and personalized student interactions by automating administrative tasks such as grading and attendance tracking.
- **ST3: Personalized Learning Journeys -** The adaptability of GAI-based EdTech tools might facilitate personalized learning journeys for students. Teachers can tailor content delivery to meet each student's unique needs by analyzing individual learning patterns and preferences.

(b) ***Weaknesses: Uneven Technical Infrastructure -*** Teachers highlight that the limited and heterogeneous existing technical infrastructure in schools across different geographical locations would play one of the main weaknesses in using and integrating GAI. Three subthemes (***ST1-3***) emerge in this theme (please refer to Table 2 for summarized findings).

- **ST1: Access Limitations -** The digital divide in Indian high schools across different geographical locations poses a significant challenge to harness the potential of GAI equitably in STEM education. The uneven distribution of technology access and reliable internet connectivity could perpetuate educational disparities. Students lacking technical resources might be deprived of the potential benefits.
- **ST2: Need Technical Support -** Implementing and sustaining GAI usage and integration in STEM education would demand technical proficiency. Teachers might encounter difficulties troubleshooting technical issues or optimizing GAI-based EdTech tools utilization in regions with limited IT support.
- **ST3: Reliability Concerns -** The dependency on technology exposes teachers and students to potential disruptions caused by power outages and erratic internet connectivity.

(c) ***Opportunities: Experiential Learning Integration -*** Teachers highlight that GAI has the technological potential to promote experiential learning among students in virtual environments. There are three subthemes (***ST1-3***) in this direction (please refer to Table 3 for a summary).

Table 2 Potential weaknesses of GAI for improving technological aspect

Subtheme	Frequency	A sample quote
ST1	23	"... the potential for increased dependence on technology, may lead to a digital divide among students and exacerbate existing inequalities"
ST2	17	"Teachers may require additional skills and resources to effectively use and integrate GAI into their daily teaching"
ST3	29	"... technical glitches and reliability issues with AI tools can disrupt the teaching and learning and hinder smooth classrooms"

Table 3 Opportunities that GAI might bring to education from a technological perception

Subtheme	Frequency	A sample quote
ST1	24	"... can create options to combine experiential learning strategies with technology-enabled instructions"
ST2	23	"... might help my students who come from remote villages and marginalized families to visualize science experiments using a Socratic dialogue"
ST3	22	"... supports creativity, problem-solving, and digital literacy skills among students"

- **ST1: Blended Learning Approaches -** GAI-based tools can open avenues for blended learning strategies, harmonizing online and offline resources. Moreover, it can accommodate students' varying levels of technological access, enabling teachers to create a balanced learning experience that combines digital tools with traditional methods.
- **ST2: Real-world Contexts -** GAI can potentially engage students with real-world scenarios. For example, virtual simulations and field trips can help students explore situations that may otherwise be out of reach due to geographic constraints or resource limitations. This exposure to authentic experiences might enhance contextual understanding.
- **ST3: Skill Enhancement -** Proficiency in digital tools is essential for students' future success. By using and integrating GAI in school education, teachers empower students to navigate the digital world with the current trend.

(d) ***Threats: Data Privacy and Ethical Concerns -*** Teachers point out several concerns about using and integrating GAI in education from the technological perception. Most converge toward data privacy and ethics and lead to three subthemes (***ST1-3***) (findings summary can be referred to Table 4).

- **ST1: Data Privacy Risks -** Teachers point out that using GAI would most likely collect and store students' personal and profiling data. In countries like India, inadequate data protection measures could jeopardize students' privacy and might lead to data breaches.

Table 4 Threats that GAI might pose to education from a technological perception

Subtheme	Frequency	A sample quote
ST1	21	"... might collect and analyze sensitive student information that is an alarm for me because unauthorized access and misuse"
ST2	11	"... presents a threat to algorithm design in TEL by potentially perpetuating biases and reinforcing inequalities ..."
ST3	28	"... might diminish students' critical thinking skills and discourage reliance on traditional learning methods"

- **ST2: Ethical Algorithm Design -** The algorithms underpinning these tools have the potential to perpetuate biases present in the data they learn from. As India is a country with a diverse and mammoth student population, algorithmic biases could inadvertently reinforce inequalities.
- **ST3: Digital Dependency -** Overreliance on technology might unintentionally detract from traditional teaching methods, especially when most in-service teachers are in their mid-career and have not been retrained to continue teacher education. Moreover, it could potentially overshadow the importance of interpersonal interactions and human guidance in learning.

2. **Pedagogy:** Teachers find strengths in GAI for improving personalized learning, active engagement, and multimodal instruction.

   (a) ***Strengths: Pedagogical Enhancement -*** Teachers believe that GAI-based tools can support their pedagogical strategies to deliver personalized learning experiences to a diverse group of learners and encourage active learning engagement through multimodal instruction and formative assessment. Four subthemes (***ST1-4***) cover most of their perceptions, and for a summary of them, please refer to Table 5.

   - **ST1: Personalized Learning Experiences -** Teachers highlight that GAI could provide the platforms for personalized learning experiences tailored to individual student needs. Through adaptive assessments and content delivery, teachers can engage students in a manner that aligns with their learning pace and preferences.
   - **ST2: Active Learning Encouragement -** GAI can promote active learning by offering interactive activities, simulations, and gamified elements for even those students who belong to the lowest strata of society. Teachers can leverage its features to encourage student participation and engagement, transforming the learning process into an active and dynamic endeavor.
   - **ST3: Multimodal Instruction -** Teachers point out that future GAI-based EdTech tools might help them incorporate various media formats with diverse pedagogical strategies to meet diverse learning preferences.

Table 5 Potential strengths of GAI for improving pedagogical aspect

Subtheme	Frequency	A sample quote
ST1	33	"... can help in technically orchestrating pedagogical practices so that students engage in self-paced learning ..."
ST2	24	"... can support innovative pedagogical approaches that promote active learning and critical thinking"
ST3	27	"... might support learning anytime and anywhere using instructional videos, interactive tutorials, and online discussion platforms"
ST4	13	"... supports formative assessment and personalized feedback with students' pace"

Moreover, it might offer content through visual, auditory, and interactive channels.

- **ST4: Formative Assessment Facilitation -** Teachers highlight that students would leave their activity logs while using GAI in TEL situations, and the same can be analyzed for formative assessments. Moreover, teachers can identify areas where students struggle and promptly adjust their teaching strategies to address such challenges effectively.

(b) ***Weaknesses: Pedagogical Adaptation Challenges -*** The central theme concerns the challenge of pedagogical adaptation across technological waves. There are four subthemes (***ST1-4***) found across participants' perceptions (please refer to Table 6 for summarized findings).

- **ST1: Requires Paradigm Shift -** Teachers report that they face challenges adapting basic TEL-related pedagogical approaches because of technological infrastructure inequalities, the digital divide, and diverse students' socioeconomic and respective parents' educational backgrounds. Building on their experience, when it comes to using and integrating GAI in STEM education, they envision a paradigm shift.
- **ST2: Lack of Pedagogical Training -** The effective use of these tools would demand a high degree of technological proficiency, pedagogical understanding, and technological pedagogical knowledge. Teachers might struggle to maximize the tools' potential without adequate training, leading to underutilization or inappropriate or ad-hoc applications.
- **ST3: Standardization vs. Customization Dilemma -** Balancing standardized curriculum requirements with the customization potential of GAI-based EdTech tools can be challenging. Teachers point out that they must find a middle ground that aligns with educational standards while catering to individual student needs. However, they argue that achieving

Table 6 Potential weaknesses of GAI for improving pedagogical aspect

Subtheme	Frequency	A sample quote
ST1	22	"... can pedagogically compromise the importance of practical, real-world learning experiences because students would never come out of the digital world"
ST2	20	"... would hinder my limited digital pedagogical approaches that I acquired through COVID-period because there is almost no training ..."
ST3	13	"Effective teaching often requires tailoring instruction to meet the diverse needs of learners but with GAI, I do not how this process would work where anyone can do anything"
ST4	27	"... the potential for reduced opportunities for social-emotional learning and the development of interpersonal skills"

Table 7 Opportunities that GAI might bring to education from a pedagogical perception

Subtheme	Frequency	A sample quote
ST1	23	"... would feel enabled to orchestrate personalized instructional strategies...allowing me to design learning experiences to individual student needs"
ST2	11	"...to access a wide range of educational materials and tools tailored to meet different categories of learners..."
ST3	8	"I can analyze student performance data and reflect on my teaching strategies and interventions"

such a common ground is complicated while dealing with diverse stakeholders in an educational setting running a top-down approach.

- **ST4: Loss of Human Connection -** An overreliance on technology could reduce direct teacher-student interactions. The interpersonal dynamics essential for mentorship and holistic education from the pedagogical perception might diminish, affecting the development of socio-emotional skills.

(c) ***Opportunities: Individual Learner-centered Instructions -*** Teachers speculate one main opportunity: GAI can help plan individualized instructional strategies for diverse learners. It comprises three subthemes (***ST1-3***; please refer to Table 7 for a summary of findings).

- **ST1: Individualized Learning Plans -** Teachers believe that GAI integration can enable the creation of individualized learning plans. Moreover, they can harness it to analyze student performance data and tailor content and activities to address individual strengths and areas for growth. This approach might support differentiated instruction, catering to diverse student needs.
- **ST2: Resource Diversification -** These tools might expand the resource pool available to teachers. Teachers can leverage a variety of multimedia and interactive resources to enrich their lessons, making learning more engaging and relevant.
- **ST3: Data-Informed Instruction -** The data of students captured by GAI-based tools might inform teachers' instructional decisions. By analyzing student performance trends, teachers can adjust their teaching strategies to ensure each student receives the required support.

(d) ***Threats: Pedagogical Transformation Pitfalls -*** Most teachers are concerned about over-emphasis and -reliance on technology, especially the nature of GAI to answer any query, which might disrupt the teachers' role and pedagogical strategies. From the perceptions, two subthemes (***ST1-2***) emerge (A summary of findings can be seen in Table 8).

- **ST1: Digital Divide Aggravation -** Teachers feel that GAI might widen the existing digital divide in the future. Students without access to technology, parents with almost no literacy, and no guided navigation in the

Table 8 Threats that GAI might pose to education from a pedagogical perception

Subtheme	Frequency	A sample quote
ST1	22	"Disparities in access to GAI and technological resources widen the gap between privileged and marginalized student population in my school"
ST2	13	"I would lose my control over curriculum customization and classroom decision-making in everyday life once GAI is used and integrated. I feel threatened that I might lose my job because of this"

TEL path might face disadvantages regarding learning opportunities and outcomes.

- **ST2: Loss of Teacher Autonomy -** 13 out of 67 participants find the nature of GAI prescriptive and authoritarian. They highlight that this nature might limit their autonomy in instructional design. Students would shape their understanding of learning and the world with GAI, leading to an individualized- and polarized world. This approach could hinder teachers' creative and innovative pedagogical contributions in guiding learning from a social constructivist perspective.

3. **Content:** Teachers find GAI's potential to enrich learning experiences through cultural context integration, inclusivity, and multilingual adaptability.

   (a) ***Strengths: Enhancing Content Relevance -*** GAI can help bring cultural awareness to the existing learning materials. Moreover, it can bring the content into learners' vernacular local languages. There are three subthemes (***ST1-3***) in this category (please refer to Table 9).

   - **ST1: Cultural Context Integration -** Teachers mention that GAI can redefine educational content with the cultural, linguistic, and societal contexts specific to different geographical locations and cultures of India. By sensitively incorporating local nuances, tools might foster an environment

Table 9 Potential strengths of GAI for improving the content aspect

Subtheme	Frequency	A sample quote
ST1	16	"... can curate and generate a wide range of multimedia resources, ensuring that students encounter diverse perspectives, cultures, and voices"
ST2	25	"... might engage with engaging and interactive content from multiple sources, fostering a deeper understanding of the subject matter"
ST3	22	"... can be used in future to convert text into different formats (such as audio or braille), translate content into multiple languages ..."

Table 10 Potential weaknesses of GAI for improving the content aspect

Subtheme	Frequency	A sample quote
ST1	36	"... can exacerbate the existing digital divide, as disparities in access to GAI-generated learning materials might widen the gap"
ST2	29	"It's a vicious cycle, in my perceptions. Students who have less digital literacy would remain at the lowest in this race"

where students can more deeply relate to and comprehend complex subject matter, leading to better student engagement and interest.

- **ST2: Inclusive Learning -** Most participants believe that GAI can revolutionize educational inclusivity by catering to diverse learning preferences and abilities. This inclusivity and adaptability encourage a more comprehensive understanding of subjects and ensure that no student is left behind due to a mismatch of learning preferences.
- **ST3: Multilingual Adaptability -** In linguistically diverse environments prevalent in India with a high student population, GAI holds the potential to transcend language barriers. With the ability to translate and adapt content into multiple languages, these tools might democratize access to quality education for everyone.

(b) ***Weaknesses: Digital Divide and Illiteracy -*** Participants highlight that the existing digital divide (***ST1***) and digital illiteracy (***ST2***) might bring forward major challenges for GAI use and integration in Indian STEM education. Moreover, they also highlight that unconscious and unguided integration flowing along with the technological wave might enlarge these two weaknesses (please refer to Table 10 for sample perceptions).

- **ST1: Digital Divide -** The unequal distribution of digital resources and infrastructure could perpetuate existing educational disparities. Moreover, students from the lowest strata of society who lack access to technology might be excluded from GAI-based tools' benefits and opportunities, further widening the digital divide.
- **ST2: Digital Illiteracy -** Another weakness centers around the varying degrees of digital literacy among students, their parents, and teachers. In

Table 11 Opportunities that GAI might bring to education from a content perception

Subtheme	Frequency	A sample quote
ST1	15	"... can help me in tailoring educational materials to suit the diverse needs, preferences, and paths of my students coming different societies"
ST2	32	"... the expansion of educational resources for all students, regardless of geographical location or socioeconomic status..."

regions where familiarity with digital tools is low, the implementation of GAI may be met with skepticism or confusion.

(c) ***Opportunities: Tailored Pathways -*** Teachers perceive that GAI can support the tailored learning pathways by considering different aspects of every learner. For example, many students are too shy to ask their doubts to the teachers in the classroom, but with GAI, they can. From their perceptions, two main subthemes emerge in this direction (***ST1-2***; Table 11 presents brief sample perceptions).

- **ST1: Content Customization -** GAI might provide a novel way to optimize and customize learning resources in resource-constrained educational settings concerning different profiles of learners. Teachers may effectively address the challenges of large class sizes and limited teaching materials by delivering personalized content and assessments.
- **ST2: Expanding Educational Resources for Everyone -** Teachers explain that GAI might help students with almost any educational resources in any form, whether descriptive or other modalities. For example, deprived students in their local schools, where only one or two teachers handle all the students, might not feel left out when asking their queries because GAI can answer anytime, anywhere.

(d) ***Threats: Loss of Cultural Localization -*** Most participated teachers report a bigger threat of losing local nuances associated with micro-cultures that India as a big geographical and populous country has. In this main concern, two sub-categories (***ST1-2***) are presented below, and a summary of the respective findings can be seen in Table 12.

- **ST1: Cultural Bias -** While GAI has the potential to enhance the content from the cultural perspective, it might also amplify cultural biases present in algorithms or data sources. In developing countries like India, which are extremely diverse, these biases can perpetuate stereotypes, reinforce inaccuracies, and undermine the inclusive learning environment.
- **ST2: Loss of Local Relevance -** The future content generated by GAI-based tools might lack the local relevance and context necessary for effective learning experiences. Overlooking the significance of local cultural norms, traditions, and socioeconomic contexts could result in a disconnection between the curriculum and students' lived realities, hindering meaningful knowledge acquisition.

Table 12 Threats that GAI might pose to education from a content perception

Subtheme	Frequency	A sample quote
ST1	22	"... lack the depth, personalization, and the ability to incorporate local context and cultural relevance"
ST2	14	"... can generate content that lacks cultural diversity and local context that ..."

Table 13 Potential strengths of GAI for improving contextual aspect

Subtheme	Frequency	A sample quote
ST1	25	"... might support flexible learning options for students who cannot fit into the daily routines of common schools ..."
ST2	17	"... can support students to engage in self-paced learning involving collaboration and problem-solving activities across online peers"

4. **Context:** Teachers highlight that GAI can be harnessed for supporting flexible learning schedules and self-directed learning among students. This can be very useful for students who drop out of school due to socioeconomic reasons.

   (a) ***Strengths: Flexible Self-Learning -*** GAI-based tools might help students learn at their own pace and comfort, unlike following the strict schedule of traditional formal education. This can be very useful for students who are learning and have to do other work, like part-time jobs and helping in the family profession. Two subthemes (***ST1-2***) in this category are presented below, and the summary of findings from the participants' perceptions can be seen in Table 13.

   - **ST1: Flexible Learning Schedules -** Teachers believe that GAI-based tools can accommodate varying schedules and commitments. Students from the lowest socioeconomic group, who might have familial or employment responsibilities, can engage with learning content at their convenience, promoting accessibility.
   - **ST2: Self-directed Learning -** Integration of GAI in TEL-based STEM education can encourage students to take ownership of their learning journey. They can develop valuable self-directed learning skills beyond the classroom by engaging with the content of their interest at their own pace.

   (b) ***Weaknesses: Physical Infrastructure of Schools and Democratization of Education -*** Teachers envision that once GAI-based tools are used and integrated into daily learning and teaching, the concept of physical schools and democratization of quality education might get lost slowly. They relate this vision to similar experiences during the COVID-19 lockdown of schools and the changed behavior of students, parents, and society towards physical schools once they were reopened. The two subthemes (***ST1-2***) are presented below, and a summary of findings is presented in Table 14.

   - **ST1: Less Focus on Physical School Infrastructure -** Teachers express that GAI facilitates the creation of personalized learning experiences tailored to individual student needs, and there may be less reliance on traditional classroom settings. This shift towards virtual and remote learning environments could reduce the emphasis on physical infrastructure such as classrooms, laboratories, and libraries. With GAI-based tools offering interactive simulations, virtual labs, and AI tutors, the need for extensive physical facilities may diminish, leading to a potential decline in

Table 14 Potential weaknesses of GAI for improving contextual aspect

Subtheme	Frequency	A sample quote
ST1	29	"... might detract from the focus on physical school infrastructure, risking neglect of necessary resources and facilities ..."
ST2	15	"... as reliance on GAI-driven solutions may widen the gap between privileged and disadvantaged students due to unequal access to technology and resources"

investment and attention toward maintaining and improving school infrastructure.

- **ST2: Decline in the Democratization of Quality Education -** While GAI promises to enhance learning experiences, its implementation might inadvertently widen the digital divide, disadvantaging students without access to advanced technology or reliable internet connectivity. This could create a disparity between students who can afford access to GAI-driven educational resources and those who cannot, hindering the equitable distribution of educational opportunities. Moreover, the complexity and cost associated with integrating GAI might limit its adoption in schools serving marginalized communities, further exacerbating educational inequalities.

(c) ***Opportunities: Equitable Remote Education -*** Teachers report that GAI integration can bring inclusivity for diverse learners (**ST1**) with immense potential for remote learning expansion (**ST2**). Moreover, they highlight that GAI-based tools can help them continue their professional development (**ST3**). The summary of findings for this category can be seen in Table 15.

- **ST1: Inclusivity -** Teachers report that GAI can offer personalized learning experiences tailored to diverse student needs, accommodating various learning preferences and abilities. For example, it can address the educational challenges faced by students with disabilities by providing accessible learning materials and adaptive assessments. Furthermore, GAI-powered tools can facilitate language translation and localization,

Table 15 Opportunities that GAI might bring to education from a contextual perception

Subtheme	Frequency	A sample quote
ST1	17	"... can provide tailored support and resources to students with diverse backgrounds, abilities, and learning needs, ..."
ST2	20	"... would allow students from remote areas or those unable to attend traditional classrooms to access quality education ..."
ST3	12	"... can facilitate my continuing education through personalized training programs and AI-driven resources ..."

making educational content accessible to students from different linguistic backgrounds.

- **ST2: Remote Learning Expansion -** With GAI, students can access high-quality educational resources and interactive lessons from anywhere with an internet connection, overcoming geographical barriers to education. This expansion of remote learning enables schools to reach students in remote or underserved areas where traditional educational infrastructure may be lacking.
- **ST3: Teacher Professional Development -** Teachers believe that by incorporating GAI into professional development programs, teachers can enhance their pedagogical skills and familiarity with innovative teaching methods. Moreover, it can assist teachers in designing personalized learning experiences, creating tailored instructional materials, and implementing data-driven teaching strategies. Finally, its data can be used for real-time feedback and analytics, enabling teachers to refine their teaching practices continuously.

(d) ***Threats: Balancing Traditions and Technology -*** Teachers express that reliance on GAI might inadvertently prioritize Western-centric educational content, eroding indigenous Indian knowledge systems and cultural heritage (**ST1**). Additionally, the pervasive use of technology may contribute to digital exhaustion among students and teachers, leading to increased stress, anxiety, and burnout. Furthermore, excessive screen time and reliance on digital tools can negatively impact students' physical health and social interactions, exacerbating concerns about overall wellbeing in educational settings (**ST2**; please refer to Table 16 for findings).

- **ST1: Erosion of Indigenous Knowledge -** Overreliance on standardized GAI-generated content might sideline indigenous knowledge systems unique to the Indian context. The dominance of globally curated content might overshadow local wisdom and perspectives.
- **ST2: Digital Exhaustion and the Overall Wellbeing -** The shift to digital learning might result in digital fatigue among students. Prolonged screen time and lack of physical interaction could negatively impact students' mental and emotional well-being.

Table 16 Threats that GAI might pose to education from a contextual perception

Subtheme	Frequency	A sample quote
ST1	27	"... may prioritize standardized Western perspectives, neglecting the richness and diversity of our knowledge systems in Indian high schools"
ST2	20	"Most of the students are already dealing with psychological issues after COVID and this might lead to increased screen time, sedentary behavior, and other mental health concerns on top"

Discussion

This study reveals a multifaceted landscape in each of the verticals of SWOT, which are in correlation with other studies like (Limna et al., 2023; Sullivan et al., 2023; Bahroun et al., 2023; Ali et al., 2023; Bahroun et al., 2023). This section briefly presents their implications in seven points below.

1. **Educational Technology and Innovation:** The strengths of GAI lie in their potential to enrich learning contexts (Limna et al., 2023) by tailoring content to the cultural, linguistic, and regional dimensions (Ruiz-Rojas et al., 2023), fostering inclusivity and engagement; also highlighted in Sullivan et al. (2023). This core strength is foundational to promoting a sense of belonging for students and expanding access to education. However, potential challenges such as the loss of human interaction, dependency on data, and threats to academic integrity underscore the need for a balanced approach that prioritizes ethical considerations and cultural sensitivity (Rof et al., 2022).
2. **Pedagogical Shifts and Adaptation:** GAI may offer transformative potential in promoting inclusivity, expanding access to education, and integrating active learning approaches Rajendran (2023). This paradigm shift paves the way for a more equitable and relevant educational experience (Akhmedov, 2023; Bahroun et al., 2023). However, maintaining the balance between technological innovation and preserving essential aspects of traditional teaching methodologies is crucial to ensuring effective pedagogical adaptation (Woolman, 2001; Ali et al., 2023). Empowering teachers through professional development programs is critical to harnessing the full potential of these tools.
3. **Content Customization and Inclusivity:** The transformative potential of GAI lies in its ability to create personalized learning experiences tailored to diverse student needs, fostering a more equitable and relevant educational experience for all. This inclusivity extends beyond cultural (Giannakos & Cukurova, 2023) and linguistic dimensions to address challenges related to the digital divide and digital illiteracy, ensuring all students have equitable access to quality education.
4. **Societal and Ethical Implications:** Using and integrating GAI responsibly in TEL-based STEM education in Indian high schools necessitates a culture of ethical technology usage and continuous monitoring to protect student data privacy (Bingley et al., 2023), respect cultural nuances and preserve the human element of education. Collaboration among teachers, policymakers, and developers is essential to ensure these tools are ethically designed and aligned with core educational values (Tan, 2022). Addressing concerns related to data privacy, algorithmic biases, and digital exhaustion (Hayak, 2022) is paramount to ensure that the GAI use and integration are ethically and responsibly executed (Bulathwela et al., 2024).
5. **Policy and Implementation Challenges:** Charting a path for the responsible integration of GAI requires a collaborative effort among stakeholders to address policy implications, ensure accessibility using Communities of Practice approach (Shankar et al., 2023), and prioritize ethical considerations (Alexander et al., 2019; Limna et al., 2023; Sullivan et al., 2023). Empowering teachers through professional development programs and equipping students with the skills to thrive

in the digital age are critical steps in realizing the full potential of these transformative tools (Cviko et al., 2013; Ali et al., 2023). Addressing challenges related to policy implications, infrastructure investment, and the digital divide is essential to ensuring that the integration of GAI is successful and equitable (Martha et al., 2023).

6. **Paving the Path for Lifelong Learning:** GAI-based futuristic EdTech tools might present an opportunity to extend learning beyond the boundaries of the traditional classroom, empowering personalized learning experiences and fostering lifelong learning (Şen & Yildiz Durak, 2022; Bahroun et al., 2023). This journey leads to a paradigm shift, where teachers must embrace their role as pedagogical innovators, students as lifelong explorers, and technology as a responsible ally (Rof et al., 2022). However, ensuring these tools are accessible and aligned with core educational values is essential to realizing their full potential.
7. **A Holistic Vision for the Future:** Realizing the full potential of GAI-based EdTech tools demands a collaborative effort among teachers, policymakers, and developers to ensure that these tools are accessible, ethically designed, and aligned with core educational values. Addressing challenges related to policy implications and implementation is essential to ensuring that the integration of these tools is successful. The holistic vision for the future encompasses a balanced approach to technology integration, where ethical considerations, pedagogical innovation, and societal implications are carefully considered (Tuay-Sigua et al., 2023).

Using and integrating GAI in Indian STEM education presents several strengths, weaknesses, opportunities, and challenges. By embracing a balanced approach that prioritizes ethical considerations, pedagogical adaptation, and inclusivity, different educational stakeholders (especially cross-disciplinary ones (Shankar et al., 2018)) can harness the transformative potential of these tools to create a more equitable and relevant educational experience for all students (one more step towards SDG4 (Unterhalter, 2019)).

Conclusions

This study explored digitally literate Indian high school STEM teachers' perceptions of using and integrating GAI to enrich authentic TEL situations from different verticals of TPACK. Our main **RQ** centered on uncovering its envisioned S, W, O, and T of SWOT. Through a qualitative approach involving purposive sampling, thematic and content analysis, and a descriptive analysis of identified themes and subthemes, this study presents the perceptions of 67 teachers and their implications. Our research situated itself within the backdrops of the Indian education landscape, like top-down educational policies and diverse schools with students from different socioeconomic backgrounds, acknowledging their challenges and opportunities.

From a strengths perception, teachers believe that integrating GAI and associated EdTech tools would foster Technological Pedagogical innovation in the future of STEM education (Bahroun et al., 2023). They can potentially personalize learning experiences and offer the prospect of enhancing content delivery by infusing real-

world applications and simulations. Conversely, concerns surrounding the potential displacement of traditional teaching methodologies and the potential hindrance to developing critical thinking skills were acknowledged. A common sentiment among teachers was the fear that an over-reliance on AI tools might dilute the holistic development of students, curbing their ability to analyze, synthesize, and evaluate information independently (Limna et al., 2023).

The opportunities brought to the fore by our research underscored the tools' potential to democratize quality education (SDG4 (Unterhalter, 2019)), transcending barriers in access across varying socio-economic strata (Bulathwela et al., 2024). Furthermore, teachers envisioned these tools as agents of cross-cultural collaboration, preparing students for a globalized future that thrives on interconnectedness and collaboration (Sullivan et al., 2023). However, these opportunities are counterbalanced by critical threats that warrant careful consideration. Chief among these concerns is the issue of privacy and data security, given that AI tool implementation mandates collecting and storing sensitive student information (Bahroun et al., 2023). Additionally, the study pointed to the potential worsening of the digital divide, further marginalizing teachers struggling with digital competencies (Ali et al., 2023).

Despite the insights garnered from 67 teachers, our study has some significant limitations. The sample size (N = 67) might not provide rich qualitative data or fully encompass the vast and heterogeneous Indian high school STEM education landscape. Thus, the generalizability of our findings might be restricted. Moreover, all the participants belong to India, so the extension of the findings can be over-arched to developing countries. Similarly, the question framing was done in a generic way where GAI is considered as one technology. Therefore, some responses might read generic because many participants were new to the GAI for the time being. Further, methodological limitations stemming from data collection, analysis, and interpretation necessitate acknowledgment. The potential for bias in participant selection using Purposive sampling needs to be highlighted. Similarly, the data analysis warrants consideration because the researchers involved in this study (as well as the co-author(s)) did all the data processing steps.

Some indirect findings from this study are worth explaining. First, many Indian high school teachers from different demographics and institutional profiles lack digital literacy (282 out of 1235). Second, teachers cannot practice TEL despite digital literacy because many schools lack the digital infrastructure needed for EdTech. Third, most teachers lack educational training in digital pedagogies training and understanding. It might be the case that teachers find themselves digitally literate by using digital devices on their own. Still, they might lack digital competency to use and implement the same devices for teaching and supporting students' learning. Fourth, almost half of the teachers who self-report are digitally literate, have experience with TEL situations, and are familiar with TPACK but have still not used GAI tools. Fifth, frequencies of subthemes across different themes are not uniform. Findings like data-informed instruction as an opportunity to improve pedagogical aspects are especially reported by urban teachers. Similarly, ethical and data privacy concerns are the same as urban cases. In contrast, rural teachers are the ones who mainly believe in the threat of replacing the teachers. Last, most participants lack continuing education to improve skills like tailored Teacher Professional Development programs.

In conclusion, this study offers a nuanced understanding of digitally literate Indian high school STEM teachers' perceptions on the potential of using and integrating GAI in authentic TEL situations. The convergence of qualitative insights and quantitative patterns envisions a comprehensive and multifaceted picture of the dynamics surrounding it. While our findings contribute significantly to the discourse on education transformation in the GAI era, they also remind us of the necessity for prudent consideration. As teachers, policymakers, and stakeholders navigate the terrain of educational innovation, it is imperative to harness the potential of technology while mitigating its associated challenges.

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Declarations

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