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Research on the Educational Application of Generative Artificial Intelligence Based on CiteSpace: Hotspots, Trends, and Cross-National Comparisons

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Abstract: The transition of generative AI from an analytical to a creative tool is profoundly reshaping global education. This study employs CiteSpace for a scientometric analysis of relevant literature, identifying key research domains—"higher education," "human-AI collaboration," and "educational innovation"—and tracing their evolution. A comparative examination of approaches in the UK, US, and Australia highlights international variations in governance, assessment, and pedagogical integration. The analysis details GenAI's transformative impact on key educational processes (teaching, learning, assessment, tutoring) via its core capabilities, while also addressing associated risks like data privacy, ethical dilemmas, and over-reliance. Concluding with a China-specific perspective, the paper proposes a forward-looking framework emphasizing human-centric principles, robust accountability, sustainable data ecosystems, and synergistic development, offering insights for intelligent education development worldwide.

Keywords: Generative artificial intelligence; Educational application; CiteSpace; Educational risks; Human-AI collaboration

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1. Introduction

The advent of the intelligent age has witnessed the rapid rise of generative artificial intelligence (GenAI) and its transformative impact on the educational ecosystem. Education, serving as the cornerstone of social development and the primary arena for talent cultivation, has become a central focus for the application and transformation of GenAI. Since 2022, representative models like ChatGPT have marked a paradigm shift from "analytical" to "creative" intelligence. Their powerful capabilities in content generation and contextual understanding have triggered a wave of technological innovation and industrial transformation on a global scale.

The growing importance of generative artificial intelligence in education is marked by its significant im-

pact on teaching landscapes and reform processes. Addressing this global shift, UNESCO issued the *Guidance for Generative AI in Education and Research* in September 2023 [1]. This document was groundbreaking in its systematic outline of eight fundamental controversies related to GenAI—after first elucidating its core mechanisms—and their critical impact on educational applications. It further proposes targeted public governance strategies, educational policies, and a practical framework for human-AI interaction [2]. However, the Guidance's proposed strategies and framework necessitate adaptation. Given the vast differences in national contexts and digital readiness, it is imperative for governments, institutions, and researchers within each country to collaborate in tailoring and co-constructing frameworks that suit their specific realities.

Generative artificial intelligence has become a pivotal direction for the digital transformation of education in countries around the world. In 2023, the U.S. Department of Education released *Artificial Intelligence and the Future of Teaching*, highlighting the significant opportunities AI presents for addressing educational policy priorities and outlining the clear need for AI policy development. The U.K. Department for Education published *Generative Artificial Intelligence (AI) in Education*, clarifying its stance on the application of GenAI and emphasizing its positive effects when used properly. Japan's Ministry of Education, Culture, Sports, Science and Technology issued the *Interim Guidance on the Use of Generative AI in Elementary and Secondary Education*, recommending that schools proceed with small-scale trials and carefully verify the outcomes of its application. Australia released the *Australian Framework for Generative AI in Schools (Draft)*, encouraging school staff, teachers, and students to use GenAI "safely and ethically." In China, seven departments, including the Cyberspace Administration of China, jointly promulgated the *Interim Measures for the Management of Generative Artificial Intelligence Services*, encouraging the innovative application of GenAI technology across various industries and fields. UNESCO published the *Guidance for Generative AI in Education and Research*, calling on governments to regulate its educational use through measures such as legislation and teacher training. The release of these policies demonstrates that the orderly and limited opening of GenAI applications in education, within defined policy boundaries, is an inevitable trend [3].

2. Related work

2.1. The role of generative AI in education

The application of GenAI in education has consistently been a key focus of global attention. The central aim is to direct technological advancement towards serving educational needs, consequently freeing teachers from heavy workloads of routine tasks. Therefore, the integration of AI technologies in education is of paramount importance.

Generative AI's importance in education stems from four core capabilities: inspirational content generation, conversational context understanding, sequential task execution, and programming language parsing.

Inspirational content generation: This capability allows the AI to produce creative and stimulating text (e.g., poems, stories, critiques) based on a provided prompt or the context gleaned from a multi-turn conversation. Conversational context understanding: This involves synthesizing information throughout a dialogue to understand meaning and reason semantically. It identifies user intent and the context to formulate coherent, logical replies, ensuring a smooth interaction. Sequential task execution: The technology can understand the connections within a sequence of user instructions, manage task progression step-by-step, and accomplish complex tasks involving combined commands, thus reliably handling multi-step processes. Programming language parsing: Adhering to the syntax, data structures, algorithms, and conventions of multiple programming languages, it can

analyze code structure and logic, and automatically generate code snippets to fulfill tasks or debug errors based on user requirements [4].

In conclusion, generative AI's advanced capabilities in processing long-form text, audio, code, and other modalities are ushering in a new intelligent era. This technology is set to disrupt established fields, become a significant new domain in its own right, and bring transformative changes to all sectors of society.

Nevertheless, alongside these benefits, the opaque "black box" nature of its operational mechanisms poses significant data security risks. When applied to scientific research, generative AI introduces potential dangers, including privacy breaches, the amplification of biases, integrity issues, and challenges for effective oversight [5].

The primary risks associated with generative AI in education include: Data provenance and privacy vulnerabilities: This refers to the use of vast, billion-scale datasets often sourced through non-compliant or illicit means. User interaction data is also collected, creating risks of unauthorized access and misuse of private information. Unmanageable data governance: This stems from the technology's rapid iteration cycle, which outpaces the development of synchronous legal frameworks globally. Compounding this, inadequate user data literacy can cause data devaluation or leakage beyond model boundaries, disrupting effective governance. Dissemination of inauthentic content: This risk arises when students, potentially becoming overly dependent, accept AI-generated content without verification. This can result in the acquisition of misinformation, stifle the development of discernment and critical thinking, promote intellectual inertia, and hinder creative and sustained cognitive development.

2.2. Application trends in education

Leveraging the four core capabilities previously outlined, generative AI is now commonly applied across teaching processes, learning processes, instructional assessment, and educational tutoring.

2.2.1. Innovating the teaching process

Generative AI serves as a valuable tool for teachers. It aids in lesson preparation by sourcing materials and creating customized exercises and interactive activities. In subjects like programming, it can efficiently troubleshoot common student errors using its extensive data processing capabilities, which enhances classroom efficiency by alleviating the teacher's burden.

Crucially, teachers must guide students to use this technology appropriately. This involves developing the skills to critically assess AI-generated content, integrate it effectively, and exercise independent judgment. The objective is for students to use AI as an aid for their work, not as a crutch that replaces their own critical thinking and problem-solving abilities [6].

2.2.2. Reshaping the learning process

Generative AI acts as a powerful aid in the learning process. It helps students overcome learning obstacles by providing hints that expand their perspectives and lead them to solutions, promoting both efficiency and independent problem-solving skills. Its interactive nature allows it to deliver increasingly systematic and accurate responses through iterative dialogue. For specialized subjects, it produces context-aware, discipline-specific explanations. When tackling challenging topics like programming, it offers scaffolding—such as code snippets or analogous logic—enabling students to comprehend core principles and deconstruct complex problems until they achieve mastery.

2.2.3. Optimizing teaching assessment

Generative AI can track data throughout the entire instructional process, providing evaluative feedback and descriptions of the teaching implementation. It analyzes student problem-solving behaviors and records data from various activities such as in-class tests, homework assignments, and group work. This data is used to assess student engagement and learning interest, thereby supporting the development of tailored teaching models. By leveraging the data generated from teaching activities, generative AI can record and analyze student participation, the iterative process of their solution development, and their performance in group collaborations, ultimately offering more objective and formative evaluations. Implementing teaching assessment powered by generative AI facilitates efficient intelligent assessment, enables the monitoring of dynamic changes in affective states, allows for the precise capture of authentic classroom dynamics, and permits the tracking of growth trajectories for both teachers and students. Future in-depth development and widespread application of AI-driven classroom assessment will require further exploration in constructing specialized evaluation metrics, enhancing personalized feedback on teaching behaviors, and addressing the developmental challenges facing future education [6].

2.2.4. AI-powered tutoring

For students working on homework assignments, generative AI serves as an on-demand resource for immediate help. It addresses the time lag often associated with teacher availability by providing timely hints and diverse solution strategies from multiple perspectives. This fosters a more comprehensive understanding and helps students develop their own unique problem-solving approaches. Furthermore, it can summarize and synthesize provided literature or documents, distilling lengthy inputs into concise outputs. This alleviates the burden of tedious administrative tasks, allowing students to complete their work more efficiently and focus on deeper learning. Since the fundamental purpose of education is to cultivate individuals, education should be student-centered. AI technology demonstrates significant advantages in structurally representing knowledge related to character development, mapping the connections between knowledge points, and performing personalized knowledge inference. This has led to the proposal of building a personalized educational assistant system—an "AI Good Teacher"—to leverage technological power in addressing educational challenges. This system is characterized by its ability to contextually solve educational problems, offer personalized tutoring on formative knowledge, structurally organize this knowledge, enable its collaborative evolution, and intelligently reason through educational cases. It acts as a professional guide for teachers and parents, and a personal advisor for students' self-diagnosis, thereby achieving highly effective character education through human-AI collaboration [7]. In summary, AI-powered tutoring breaks the constraints of time and space, offering students instant, multi-faceted academic support and assisting with tedious tasks like document summarization and outlining. This enables students to concentrate on constructing core knowledge and developing higher-order thinking skills.

3. Literature review analysis

3.1. Literature analysis tool: CiteSpace

3.1.1. Data sources

The literature analyzed in this study was sourced from the China National Knowledge Infrastructure (CNKI) database. A search was conducted using "Generative Artificial Intelligence" and "Educational Research Application" as key themes, which yielded an initial set of 285 publications. All identified records were collected and compiled. This data was then imported into CiteSpace to generate keyword co-occurrence maps. After processing, 275 records were found to be valid and usable by the software, which subsequently produced the desired

visualizations.

3.1.2. Visual analysis of research hotspots in the application of generative AI technology in educational research

3.1.2.1. Analysis of the keyword co-occurrence map

Keywords represent a highly condensed summary of a research publication and hold significant research value. We performed a high-frequency keyword analysis on the valid literature using CiteSpace. The resulting keyword co-occurrence map for the application of generative AI in educational research from 2021 to 2025 is shown in **Figure 1**. This map contains 107 nodes and 112 links, with a network density of 0.0197.

In **Figure 1**, the nodes are presented in the form of rings. The size of a ring indicates the frequency of the keyword's occurrence—a larger ring signifies a higher frequency. The color of the rings represents the time period of the keyword's activity, with the color gradient from the inside to the outside indicating the publication timeline from earlier to more recent years [8].

The analysis reveals that "Higher Education," "Artificial Intelligence," "Human-AI Collaboration," "Vocational Education," "Educational Innovation," and "Education" form the most significant keyword nodes. Among these, "Artificial Intelligence," "Higher Education," and "Human-AI Collaboration" occupy absolutely central positions within the literature corpus. Furthermore, an extensive network of radiating links extends from these core keywords, forming a complex structural network primarily connected to terms such as "Educational Application," "Educational Transformation," and "Coping Strategies." This pattern indicates that a coherent knowledge structure has already been formed regarding the application of generative AI technology in educational research.

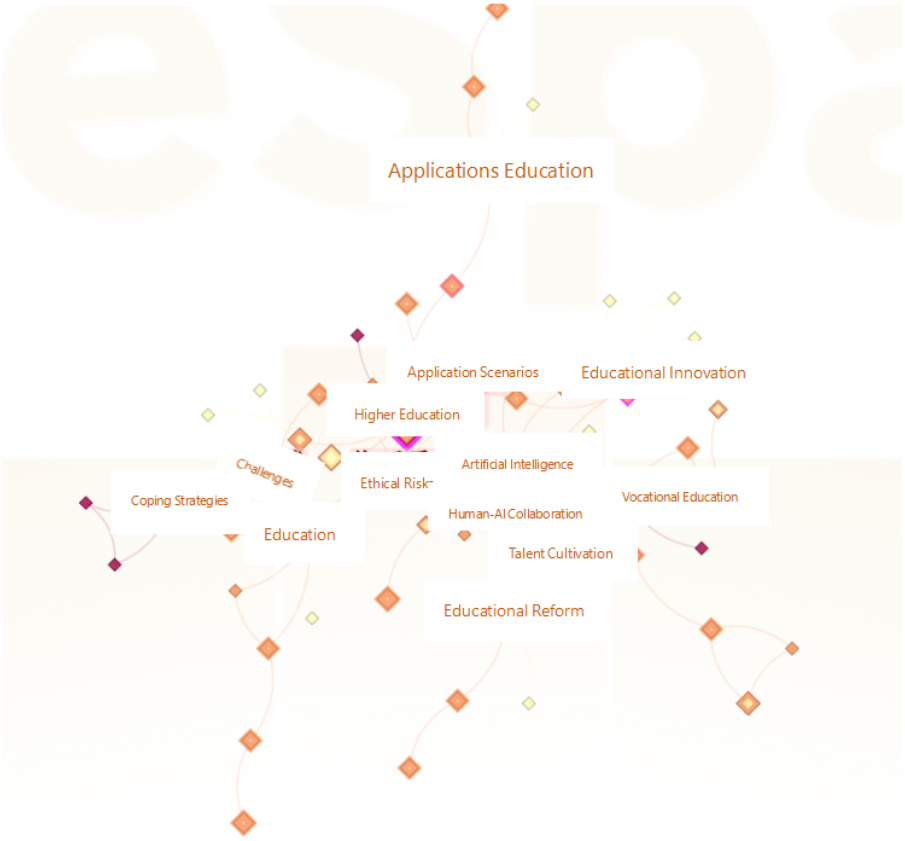

Figure 1. Keyword co-occurrence map of research on generative AI in education

3.1.2.2. Analysis of the keyword cluster map

A keyword cluster analysis was performed using CiteSpace, grouping terms with significant common characteristics into clusters. The resulting keyword cluster map for the research domain is shown in **Figure 2**. The analysis formed seven distinct keyword clusters, labeled #0 through #6. These clusters are: #0 Artificial Intelligence, #1 Education, #2 Educational Reform, #3 Educational Innovation, #4 Coping Strategies, #5 Educational Application, and #6 Vocational Education. This clustering provides a foundation for further analyzing the thematic classification of generative artificial intelligence technology within educational research.

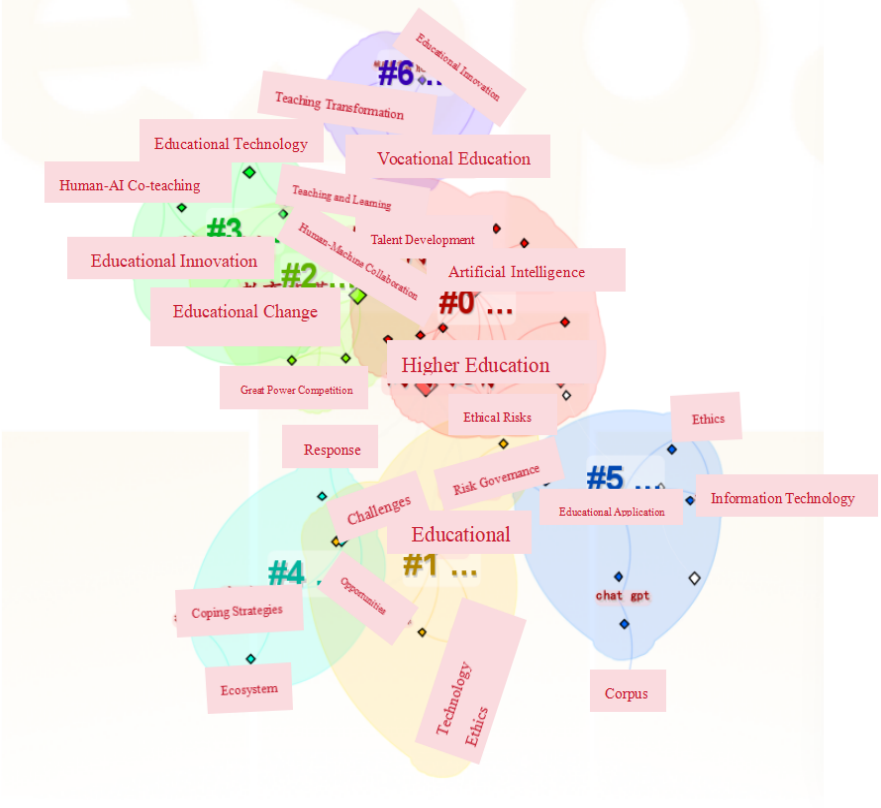

Figure 2. Keyword cluster analysis map

Given that the seven cluster labels shown in **Figure 2** exhibit a degree of overlap—with some containing similar or identical terms—similar cluster labels were consolidated to better summarize key research hotspots. This process, combined with an analysis of high-frequency and high-centrality keywords, led to the identification of primary knowledge domains in the application of generative AI in educational research, as summarized in **Table 1**. Six major themes emerged: Artificial Intelligence, Educational Innovation, Education, Coping Strategies, Vocational Education, and Educational Application.

The labels "Educational Innovation," "Educational Reform," and "Artificial Intelligence" are closely interconnected. In particular, the "Educational Reform" and "Educational Innovation" labels demonstrate the highest degree of coupling, with very little substantive distinction between them. Additionally, the "Artificial Intelligence" cluster is strongly linked to the themes of Higher Education and Human-AI Collaboration, forming the largest cluster in the entire literature analysis.

Table 1. Primary knowledge domains in the application of generative AI technology in educational research

No.	Research theme	Major cluster labels
1	Artificial Intelligence	Talent Cultivation; Higher Education; Ethical Risks; Application Scenarios; Human-AI Collaboration; Ethical Issues
2	Educational Innovation	Educational Reform; Educational Technology; Human-AI Co-teaching; Future Education; Digital Literacy; Development Opportunities; Teaching and Learning
3	Education	Challenges; Risk Governance; Opportunities; Instrumental Rationality; Ethics of Technology
4	Coping Strategies	Educational Impact; Ecosystem; Response
5	Vocational Education	Teaching Reform; Intelligent Technology; Teaching Innovation
6	Educational Application	Legal Regulation; ChatGPT; Information Technology; Ethics

3.1.2.3. Statistical analysis of keywords

Using the CiteSpace tool, a bibliometric analysis of keywords was conducted on the collected valid literature to identify the main research areas in the application of generative AI technology in educational research. The summary results indicate that a total of 107 keywords were identified, with the specific distribution shown in **Table 2**.

The most frequently occurring keyword was "Higher Education," appearing 20 times with a centrality of 0.33, representing the largest proportion among all keywords. This was followed by "Artificial Intelligence," with a frequency of 16 occurrences, and then "Human-AI Collaboration," with a frequency of 9 occurrences. It is noteworthy that the aforementioned high-frequency keywords all emerged in 2023. The keyword "Legal Regulation" first appeared in 2024, indicating a growing focus on addressing the social anxieties and potential misconduct associated with generative AI through legal means.

Table 2. Keyword statistical analysis

Keyword	Frequency	Centrality	Year of first appearance
Higher Education	20	0.33	2023
Artificial Intelligence	16	0.29	2023
Human-AI Collaboration	9	0.2	2023
Education	9	0.12	2023
Educational Innovation	6	0.1	2023
Legal Regulation	2	0.1	2024
Ethical Risks	6	0.09	2023
Vocational Education	9	0.08	2023
Educational Application	7	0.08	2023
Challenges	6	0.08	2024
Educational Reform	10	0.06	2023
Higher Education	2	0.06	2024
Coping Strategies	4	0.04	2024
Value Alignment	2	0.04	2024
Instrumental Rationality	2	0.04	2024

Table 2 (Continued)

Keyword	Frequency	Centrality	Year of first appearance
Risk Governance	5	0.03	2023
Application	4	0.03	2023
Digital Literacy	2	0.03	2024
Talent Cultivation	4	0.02	2023
Educational Assessment	3	0.02	2023
Application Scenarios	3	0.02	2024
Chat GPT	2	0.02	2024
Future Education	2	0.02	2024
Ethics of Technology	2	0.02	2024
Opportunities	3	0.01	2024
Teaching Reform	2	0.01	2024
Educational Field	4	0	2024
Ideology	4	0	2023
Basic Education	4	0	2023
Educational Technology	3	0	2023
Medical Education	3	0	2024
Educational Governance	3	0	2023
Intelligent Political Education	3	0	2024

3.2. Summary of literature analysis

Since its emergence in 2022, GenAI has attracted widespread attention and exploration from various sectors. The analytical maps derived from the selected literature provide a more detailed, intuitive, and concrete representation of the research hotspots and domains in this field. The charts and data above indicate that, starting in 2024, the perception of GenAI has shifted from being solely optimistic and positive to including significant concerns and calls for restraint. The international community is attempting to use model frameworks, laws, and regulations to confine its application within effective boundaries, aiming to control potential negative feedback loops. Regarding the guidance proposed by the United Nations, it presents both the advantages and disadvantages. While acknowledging its powerful capabilities, it also explicitly lists the associated risks, encouraging a critical approach towards its generated content to reduce illegal and transgressive behaviors.

In the field of educational research and application, GenAI has replaced the previous human-centered paradigm, creating a new educational model of “Teacher-Student-Machine” and placing greater emphasis on human-AI collaboration and intelligence augmentation. However, its application in basic education faces risks such as the immaturity of the AI technology itself, the risk of alienation in the teaching and learning process, and challenges in adaptation for both teachers and students. Furthermore, the emergence of new keywords has brought issues like educational innovation and ethical concerns directly into public focus, with calls for educational reform echoing these concerns. This situation requires users not only to view GenAI technology rationally but also to recognize it primarily as an educational tool. It is crucial to critically evaluate its generated content. The education sector must proactively develop coping strategies to counter potential adverse impacts and

address deeper issues such as data privacy and security threats.

In today's highly technological society, generative AI, as a key force, is reshaping educational objectives, theories, and models, and posing new requirements for educational governance. Exploring innovative pathways for governing the educational application of generative AI reveals that educational governance requires regional collaborative innovation strategies. By facilitating cross-regional policy coordination and resource sharing, a more flexible and adaptive governance system can be formed. This study proposes a dual-wheel drive mechanism for the application and governance of generative AI, emphasizing the mutual reinforcement and support between technological application and governance innovation to effectively control potential risks. Optimizing educational governance through generative AI technology is a critical pathway towards achieving governance modernization.

Compared to existing research, this analysis suggests employing a multi-dimensional governance framework that emphasizes the dynamic and adaptive nature of governance strategies. It necessitates the collective participation of governments, various regions, and schools. Through cross-sector communication and coordination, and while safeguarding technological development, stakeholders should jointly explore and address potential risks. The goal is to formulate a set of widely acceptable, operational, and flexibly adjustable governance strategies. These strategies will contribute to achieving agile governance, avoiding regulatory paralysis, and effectively responding to the risks and challenges posed by generative AI technology [9].

4. Case studies of educational applications

4.1. Drawing on international cases

Based on innovative governance models and their coverage across educational levels, this section analyzes and considers three international cases: the UK government, the Australian Tertiary Education Quality and Standards Agency (TEQSA), and the Massachusetts Institute of Technology (MIT) in the United States. The aim is to provide insights and directions for developing a generative AI technology management framework in China.

4.1.1. The UK government's approach

Through top-down policy measures, a relatively flexible and resilient dynamic monitoring framework should be established at the national level [10]. It is essential to encourage a context-specific and baseline-oriented framework philosophy, enabling accurate risk anticipation and prevention regarding the challenges posed by generative AI. This involves avoiding both overestimation of risks and neglect of drawbacks, while conducting reasonable and precise risk assessments for critical areas. Such an approach can significantly enhance public confidence in the technology without creating unnecessary panic. Furthermore, the establishment of an open and transparent accountability system—where data and procedures are clearly linked to responsibilities, and a reward-and-punishment mechanism ensures that specific parties are held accountable for specific matters—will guarantee the efficient operation of the technology. Users and institutions should be encouraged to experiment boldly and innovate, embracing hypothesis-driven exploration and rigorous verification. Within rigorous processes, space for expansion should be sought to stimulate creativity at all levels. Multi-stakeholder participation in governance should be promoted: the government sets policies to safeguard baseline requirements, while industry and educational practitioners actively engage in transformation and innovation, providing methods and strategies for the governance of generative AI [11].

4.1.2. Australia's high-standard assessment strategy

Australia's Tertiary Education Quality and Standards Agency (TEQSA) promotes the effective application of generative AI in education through stringent, high-quality standards for higher education. It encourages the adoption of risk assessment strategies based on authoritative data standards. Relevant government departments promptly formulate policies according to the latest developments, imposing strict regulations on all aspects of higher education to ensure effective implementation within the framework. Significant emphasis is placed on cultivating the ethical literacy of both teachers and students. Quality requirements are appropriately elevated or revised based on practical circumstances, ensuring that educators and learners meet international benchmarks and adhere to new ethical demands [11]. Concurrently, a more diversified evaluation model is adopted, which extends beyond mere academic performance assessment. This model encompasses the entire educational process, monitors each component, empowers the educational journey, assigns value to various stages, and implements multiple forms of evaluation, specifically in segments where generative AI technology is involved.

4.1.3. Massachusetts Institute of Technology (MIT)

MIT leverages its vast repository of high-quality resources to support teaching innovation, utilizing technology and resources to underpin the development of its overall teaching strategy. A resource search engine powered by generative AI technology enables all faculty and students to complete tasks more efficiently by drawing upon these premium resources. The institute encourages a bidirectional interaction between knowledge and practice, integrating theoretical knowledge into concrete educational practices. This allows practice to inform and refine knowledge, creating a mutually reinforcing cycle that continuously optimizes and updates both the knowledge base and practical methodologies.

4.2. Forming a characteristic framework based on national conditions

The introduction of technology into the educational field consistently aims to enhance educational equity, improve quality, and narrow disparities. In China, generative AI technology can be integrated into all aspects of classroom teaching. For instance, in mathematics instruction, it can instantaneously generate in-class exercises to consolidate key knowledge points, and leverage its advantages in generating problems for various subjects, providing automated solutions, and offering homework tutoring.

However, the application of generative AI in education also risks creating new digital divides and exacerbating educational inequity. Therefore, the state should establish unified research, development standards, and models. By integrating these resources into the national Smart Education platform, all teachers and students can share the benefits of high-quality generative AI educational applications.

China could aggregate all resources onto the national Smart Education Platform for primary and secondary schools, making them available for all teachers and students to share and utilize. Competitions focusing on integrating generative AI into classroom teaching could be held regularly to efficiently embed the technology into primary and secondary education and leverage its core capabilities. Organized digital literacy training for teachers and students should be conducted periodically to enhance teachers' technical proficiency and application skills, facilitating faster alignment with international standards [12].

Furthermore, at the government level, China can formulate a specific and detailed indicator framework for generative AI to standardize its development. Establishing uniform development and research standards across industries, along with universal data sharing protocols, can help break through data bottlenecks and address data privacy and security concerns more rapidly, striving to make the technology more accessible and user-friendly.

Academic institutions and researchers in universities should promptly establish robust monitoring mechanisms to detect data vulnerabilities and misuse, exercising strict supervision across sectors to safeguard user data security and ensure that the data used by generative AI technologies in operation is open and transparent [13].

5. Insights and reflections

5.1. Key revelations

The rapid advancement of GenAI has injected new momentum into the digital transformation of education in China. It is imperative to correctly recognize the dual nature of GenAI. While it possesses significant potential to promote educational equity, drive educational innovation, and enhance educational quality, it simultaneously brings risks and challenges such as data security concerns, over-reliance on technology, resource disparities, and communication barriers. Therefore, when applying GenAI, we must maintain a clear perspective, carefully consider its potential risks and consequences, and ensure its healthy development. Hence, proactive measures from various aspects and dimensions are required to address the impact of the GenAI wave on the education sector.

5.1.1. Always ensuring the "human-centric" core position in the education sector

Being people-oriented is the fundamental goal of education. As generative AI technology impacts education, the central role of humans is being challenged, while human agency is being re-emphasized. Education must safeguard the subjective status of people; all tools should serve human growth and progress.

5.1.2. Building an "accountability" mechanism for generative AI technology

Strictly control the responsibility system of generative AI-related software in education, implementing high-standard oversight at every stage of usage, and assigning dedicated personnel to be accountable for the software. In terms of ethics and digital literacy, establish a comprehensive monitoring mechanism to prevent risky behaviors, ensure proper use of the product, prohibit personal gain or trafficking of user data, and maintain societal trust and transparency [14].

5.1.3. Forming a data ecological cycle in the education field

Establish large-scale models or mechanisms dedicated to the education sector, applying user data to educational contexts and directing data flow to more efficient channels. Ensure that educational data serves student development by implementing data locks on student and teacher information, and establishing an accountability system where third parties can access educational data only with user authorization. Engage educational experts to design data tracking mechanisms that monitor the real-time location and usage of data, with unauthorized data transfers being immediately intercepted to prevent exploitation for profit [15].

5.1.4. Fostering a two-way drive between education and technology

Technology serves teaching, while new teaching demands spur technological innovation and improvement. The relationship between the two is not antagonistic but mutually reinforcing. Education must actively adapt to the rapid development of AI technology, maintaining a more open and inclusive attitude towards it. Educators should be encouraged to uphold the principle of "technology for good" by researching and utilizing relevant technologies and tools to collaboratively complete various teaching tasks. Furthermore, the education sector must pay close attention to the potential security and ethical risks of generative AI. For its application scenarios within education, relevant laws and regulations should be promoted to form a double-helix model of mutual ad-

vancement between technology and education [16].

5.2. Future prospects

Based on the analysis of research hotspots, case studies, and risk assessment in the relevant literature, the future trajectory of generative AI in the educational field is becoming increasingly clear. Its development represents not merely a superficial technological upgrade but a profound revolution in educational paradigms. Looking ahead, we aim to construct a forward-looking and inclusive new ecosystem for intelligent education, which can be advanced through the following four dimensions:

(1) Paradigm shift: From "instrumental rationality" to a new "human-centric" paradigm

Future education must adhere to the fundamental purpose of cultivating individuals. The ultimate goal of applying generative AI is not to replace teachers, but to empower people, freeing educators from repetitive tasks and allowing them to focus on work that embodies humanistic qualities—such as emotional care, stimulating creativity, and shaping values. The core metric for technological development should shift from "efficiency gains" to "holistic human development," ensuring that technology consistently serves the intrinsic value of education, safeguards the agency of learners and the humanistic warmth of education, and ultimately constructs a new form of educational civilization characterized by human-machine symbiosis and AI for good [17].

(2) Governance upgrade: From "reactive regulation" to a new "proactive and agile" framework

Confronted with the exponential iteration of technology, traditional linear governance models have become obsolete. The future necessitates the establishment of an agile governance system characterized by a "dual-wheel drive" mechanism. On one hand, clear accountability systems for technology application and dynamic risk assessment models must be implemented to delineate safe boundaries for innovation. On the other hand, governments, enterprises, schools, and research institutions should be encouraged to form collaborative governance alliances, enabling the proactive design and rapid adaptation of policies, regulations, and standards. This approach aims to foster a sense of educational data sovereignty, refine mechanisms for data circulation and protection, and thereby create a trustworthy, transparent, and responsible application environment.

(3) Ecosystem construction: From "data silos" to a new cycle of "smart ecosystem"

A high-quality, large-scale foundational model dedicated to the education sector should be constructed. Leveraging public infrastructure such as the national Smart Education Platform, the orderly sharing and value cycling of educational data can be promoted. This will effectively break down data barriers, bridge the digital divide, and allow every teacher and student to benefit from technological dividends. Meanwhile, through data tracking and empowerment, generative AI will not only assist teaching but also deeply analyze learning trajectories, providing personalized growth support for each student. Thereby, a virtuous closed-loop smart education ecosystem is formed: data-driven decision-making optimizes teaching, and teaching outcomes in turn feed back into data refinement [18].

(4) Pathway innovation: Shifting from "technology application" to a new path of "educational transformation"

Future exploration should transcend superficial tool "application" and penetrate deeper into reshaping curricula, assessment, and management models. Educational innovation should be actively encouraged, involving the design of new curriculum systems aligned with human-AI collaborative capabilities and exploring reforms for comprehensive competency assessment based on AI-driven process analy-

sis. Concurrently, a national strategy for digital literacy and ethics education should be implemented, placing critical thinking and human-AI collaboration skills at the forefront. Ultimately, this will forge a developmental path characterized by mutual reinforcement and a co-evolutionary spiral between "technological iteration" and "educational needs," collectively paving the way for a more equitable, high-quality, and dynamic educational future.

Disclosure statement

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