

The Application of Generative AI in Education

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Abstract. As artificial intelligence technology advance rapidly, the rapid development of Generative Artificial Intelligence (GenAI) technology has brought subversive innovation in the field of education, promoted the further deepening of education reform, and provided strong technical support for improving the quality of teaching and education. This paper systematically explores the core application modes of generative AI in education scenarios, including personalized learning, teaching design, teaching evaluation, etc., and analyses the advantages of generative AI in education through the three dimensions of data-driven decision-making, optimization of teaching costs, and cultivation of cross-disciplinary capabilities. Meanwhile, this paper reveals the challenges faced by generative AI in educational applications, such as data privacy and security, ethical risks and teacher training issues. Finally, this paper gives an analysis of the future development direction of generative AI in education. In conclusion, this paper provides an in-depth analysis and discussion on the application of generative AI in education, and the results show that generative AI can significantly improve the efficiency and fairness of education through the mechanism of human-machine synergy, and it is important to provide theoretical support and practical guidance for education reform.

Keywords: Generative Artificial Intelligence; Educational Reform; Educational Development

1. Introduction

According to the United Nations Educational, Scientific and Cultural Organization (UNESCO) Global Education Monitoring Report 2022, the digital transformation of education has become a core strategy to address the global education crisis. Currently, the problem of global education inequality is getting more and more serious, more than 260 million children and adolescents are out of school, the gap between developing and developed countries' investment in education resources is as high as 20:1, and only 10 per cent of students in low-income countries have stable access to the Internet, whereas the proportion in high-income countries is more than 90 per cent. the COVID-19 epidemic has further exposed the vulnerability of the education system, and 150 million students around the world have been forced to interrupt their studies due to the lack of digital devices, highlighting the traditional education model's technological infrastructure and adaptation. lack of digital devices has forced interruptions in learning, highlighting the shortcomings of traditional education models in terms of technological infrastructure and adaptability [1].

Generative AI technologies have made breakthroughs in recent years, for example, technologies such as DeepSeek and Diffusion Modelling have shown great potential in several areas. DeepSeek extends the Transformer structure through the Multi-Headed Latent Attention (MHSA) mechanism, enabling the model to extract latent features more efficiently and improve multimodal understanding and generation. Its Multi-Token Prediction technique implements parallel Token prediction to improve the coherence and efficiency of text generation. In addition, DeepSeek optimizes computational efficiency and resource utilization through dual-pipeline technology and mixed-precision computing.

As the IT revolution continues to deepen, the education field is experiencing a technology-enabled paradigm shift at an unprecedented pace. The new generation of digital technologies represented by generative artificial intelligence is gradually reshaping the underlying architecture of the education ecosystem. This technological innovation not only stays on the surface of the application of tools, but also deeply touches the essence of education, giving rise to a new model of education adapted to the needs of the intelligent era.

It is worth paying attention to the fact that technological innovation has a forcing effect on the established education system. The education governance system needs to establish an ethical framework for the application of technology, the role of teachers is changing from knowledge transmitters to learning designers, and the curriculum structure needs to adapt to the new teaching mode of human-machine collaboration. The digital transformation of education brought about by generative AI is essentially a deep dialogue involving technological rationality and the nature of education, requiring us to seek a dynamic balance between technological empowerment and the true nature of education [2]. This technology-driven educational innovation not only provides new possibilities for cracking the problems of resource distribution and educational equity, but also brings potential risks such as the widening of the digital divide and the alienation of the human-machine relationship. How to build a benign interactive mechanism between the instrumental rationality of technology and the rationality of educational value, and realize the deep integration of technological empowerment and humanistic care, has become a major proposition that needs to be broken in the new era of educational innovation [3].

2. State of the Art of Generative AI in Education

Traditional education tends to be teacher-centered, with relatively fixed teaching content and methods that lack individuality and flexibility. These limitations of traditional education limit the fairness, efficiency and quality of education to a certain extent, and it is also difficult to meet the needs of modern society for diversified, personalized and innovative talents.

The application of generative AI breaks this limitation, adopting the ‘teacher-student-machine’ ternary combination, providing students with a more personalized learning experience, and also providing teachers with professional teaching feedback and guidance suggestions, which can help teachers to quickly design teaching plans, enrich classroom activities, and finally help teachers to correct assignments, Evaluation of teaching indicators, providing reference value for subsequent class teaching. The current status of the application of generative AI in education presents multifaceted features and trends. As shown in Fig. 1.

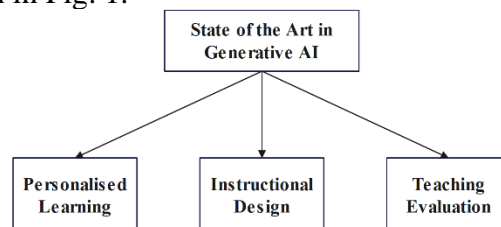


Figure 1. State of the art in generative AI

2.1 Personalized Learning. Generative AI technology is deeply reconfiguring students' personalized learning paradigm through multi-dimensional innovative applications. It has innovated to a great extent in the field of intelligent content generation, where the AI engine has broken through the static limitations of traditional question banks and is able to dynamically generate stepped learning resources based on the learner's cognitive level, error patterns and interest preferences [5]. For example, after collecting students' learning data, an online education platform uses machine learning algorithms to construct a model of student roles. When a student logs into the platform, the system recommends personalized course videos, learning materials and practice questions for him/her based on the student model. For students who have a weak foundation in mathematics and have difficulties in learning geometry, the system recommends animated videos that specifically explain geometric concepts, properties and problem-solving skills, as well as geometric practice problems from easy to difficult, and adjusts the recommended content in real time according to the students' feedback on their practice, so that the learning resources are always tailored to the students' learning needs and the learning effect is improved.

Generative AI technology is also involved in the construction of knowledge graphs, for example, the model based on the Transformer architecture is able to analyze textbook content and student

interaction data in real time, generating a 3D visualized personalized knowledge network graph, intelligently annotating mastery levels, knowledge relevance, and suggesting learning paths. The cross-modal content generation capability is particularly outstanding, as a single knowledge point can be transformed into interactive micro-lesson videos, immersive VR experimental scenes, voice-interactive thinking training, etc. For example, 3D models of chemical molecular structures, animations of chemical reactions, and voice prompts for laboratory safety can be generated synchronously.

Some advanced systems have already realized the integration of interdisciplinary knowledge, for example, when explaining the history of the Renaissance, they automatically correlate the artistic presentation of scientific discoveries of the same period, and generate AI painting creation tasks. The dynamic updating mechanism of learning materials makes it possible to adaptively adjust the coefficient of difficulty of content with the growth of students' abilities, forming a real-time matching closed loop of "ability-content", which improves the adaptation accuracy of traditional educational resources by more than 40%. This intelligent content ecosystem not only solves the contradiction between standardization and personalization of educational resources, but also significantly improves the knowledge retention rate through multi-sensory stimulation. Especially in the field of special education, the haptic feedback learning package for students with visual and hearing impairments has achieved breakthroughs in the application of results.

2.2 Instructional Design. Generative AI can not only provide convenient learning resources for students, but also facilitate teachers in instructional design by using AI technology to build online learning and communication platforms. Teachers can learn how to use AI tools for teaching design, classroom management, and homework correction by participating in AI-enabled teaching training [6]. For example, through 'Rain Classroom' and other intelligent teaching tools, teachers can master the functions of classroom interaction, homework release and online examination. In addition, participating in workshops and case sharing sessions can help teachers better understand the practical application scenarios of AI tools.

Khan Academy, founded by Salman Khan, the champion of personalized education, has been at the forefront of educational innovation. In 2023, Salman Khan joined forces with OpenAI and Microsoft to launch Khanmigo, an AI-powered tutoring tool, as shown in Fig. 2. It aims to provide highly personalized learning paths for students, while bringing unprecedented ease of teaching to teachers.

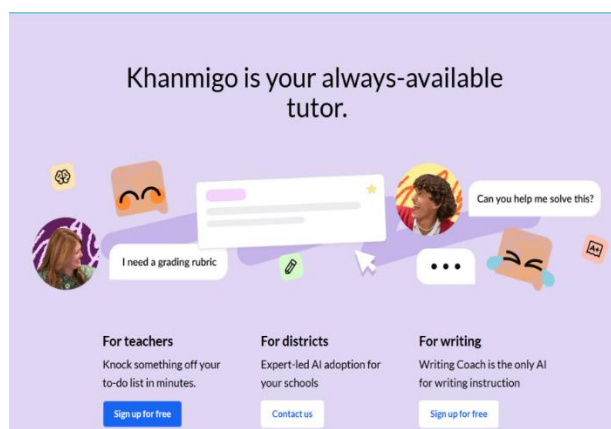


Figure 2. Khanmigo

The tool not only frees up teachers' workload, but also shows amazing results in improving teaching efficiency, fully demonstrating the unlimited potential of AI in education. For example, by simply inputting core information such as the theme of the lesson, the target grade and specific teaching objectives, Khanmigo can quickly present a well-planned and clearly structured lesson plan. The plan not only covers the core content in detail, but also incorporates a wide range of activities and effective assessment methods.

This intelligent function acts as an experienced teaching assistant, providing teachers with comprehensive support. For example, a lesson plan on the topic of ‘Identifying points, lines, segments, rays, parallel and perpendicular lines’ has been developed for the Grade 4 Mathematics programme.

2.3 Evaluation of Teaching and Learning. Generative AI technology can also assist teachers in teaching evaluation; it will automatically assess and diagnose the learning situation according to the specifics of student learning [7]. For example, based on natural language processing (NLP) and knowledge mapping technology, AI can analyze students' classroom discussions, online collaborative documents and lab report texts in real time. For example, the classroom speech analysis system developed by KU Xunfei can automatically identify logical gaps in students' speeches, generate a competency matrix containing dimensions such as critical thinking and argumentation quality, and visually present cognitive development trajectories.

Teachers' after-school summarization work has been greatly facilitated by the development of Critique.com (Pigai), a composition evaluation engine built using generative AI that not only identifies grammatical errors, but also assesses dimensions such as text logic and depth of thought. Its latest version (2024) can generate guidance programmed that include suggestions for rhetorical optimization and restructuring of argumentation, with a very significant increase in accuracy over traditional algorithms.

Generative AI technology is upgrading from unimodal analysis to multimodal fusion, such as the Multimodal Assessment AI developed by Google, which can synchronously parse programming code, 3D designs models and experimental report text to generate a comprehensive evaluation of engineering thinking. In the future, we will focus on breaking through key technologies such as cross-cultural evaluation adaptability and real-time feedback delay optimization, and promote the formation of an intelligent closed-loop system of ‘teaching-evaluation-intervention’. The collaborative innovation between educational institutions and technology enterprises is redefining the teaching evaluation paradigm in line with the characteristics of the digital era.

3. Advantages of Generative AI in Education

The application of generative AI in the field of education significantly breaks through the limitations of traditional education and reconfigures the education model through technological innovation, thus continuously promoting educational equity. Its core advantages are reflected in the following key dimensions, as shown in Fig. 3.

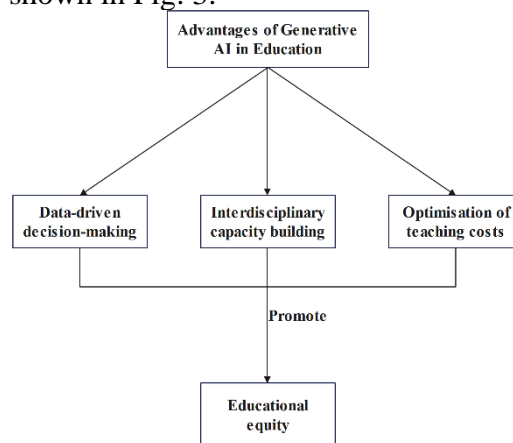


Figure 3. Advantages of generative AI in education

3.1 Data-driven Decision-making. Data-driven precision education is a teaching model based on big data and artificial intelligence technology. The concept of precision education was first proposed by Ogden Linsley in the 1960s, which initially relied on paper and pencil to record students learning behaviors, but was limited by technological means, making it difficult to analyze students’ personalized characteristics in depth [8].

With the advent of the big data era, massive amounts of learning behavior data have been generated in the education system, which have become a strategic asset for transforming education. Data-driven precision education makes use of information technology to track and record and analyze data from the whole process of student learning, mining personality traits, and generative AI can collect and analyze a large amount of educational data to provide a basis for educational decision-making and help educational institutions optimize resource allocation and teaching strategies.

In data-driven decision-making, teachers play more of a role as guides and facilitators, while in traditional education, teachers are the main transmitters of knowledge. As for student learning, teachers can integrate AI tools into their daily teaching and explore their application in lesson planning, delivery and evaluation through practice, thus reducing their reliance on textbooks. For example, AI tools such as DeepSeek are used for intelligent Q&A, learning tracking and personalized learning advice generation. Students are better able to learn to think and learn on their own, and to solve problems with the help of their teachers' guidance.

3.2 Optimization of Teaching Costs. Within the framework of the traditional education system, the pattern of distribution of high-quality educational resources shows significant geographical differences. For a long time, educational resources have been highly concentrated in large and medium-sized cities, creating a phenomenon of city-centered educational resource concentration. In sharp contrast, the supply of educational resources in remote rural areas is seriously inadequate, and the problem of imbalance in the teacher-student ratio is particularly prominent. This unbalanced distribution of educational resources directly leads to a significant gap in the knowledge reserve, cognitive ability and comprehensive quality of students in different regions, forming the ‘urban-rural divide’ in the quality of education [9].

With the breakthrough development of artificial intelligence technology, generative AI technology provides an innovative path to solve the problem of education resource distribution. Rural educators can use the intelligent education platform to break through the geospatial limitations and systematically obtain cutting-edge education concepts and teaching methods. Through AI-assisted virtual teaching and research rooms, online course libraries and other tools, teachers are able to access high-quality teaching resources in real time, participate in cross-regional teaching seminars, and realize the sharing and iteration of educational experience. This technological empowerment not only enriches the means of teaching, but also tailors the teaching programmed for each student through intelligent diagnostic systems, personalized learning path planning and other functions.

This technology-driven educational change has greatly optimized the cost of teaching, shifted the distribution logic of educational resources from “physical space agglomeration” to “digital space sharing”, and bridged the gap between urban and rural education, which no longer relies purely on the number of teachers, but rather on a substantial improvement in the quality of education through technological empowerment.

3.3 Interdisciplinary Competence Development. There is an essential difference between generative AI and traditional education in the paradigm of interdisciplinary ability cultivation. The traditional education system is constrained by the disciplinary division system and standardized cultivation mode, and its knowledge transfer presents obvious disciplinary compartmentalization characteristics, and the curriculum resources are scattered and lagging behind, making it difficult to adapt to the demand for multi-dimensional cognitive integration for complex problem solving [10].

Generative AI constructs a dynamically reconfigured interdisciplinary cognitive network through semantic understanding and knowledge mapping technology, which is able to break through the artificially delineated disciplinary boundaries and realize the organic integration of multi-domain knowledge. This technological empowerment is not only reflected in the generation mechanism of personalized learning paths, but also through simulation and multimodal reasoning to provide learners with scaffolding for complex problem solving.

Compared with the traditional classroom “one-size-fits-all” knowledge instillation model, the AI-driven virtual collaboration space supports global learners to develop distributed cognition based on shared problem domains, and to form innovative solutions in knowledge transfer and thinking collision. The transformation of this educational paradigm is essentially an evolution from static

knowledge transfer to dynamic cognitive empowerment, and generative AI not only makes up for the structural deficiencies of traditional education in cross-disciplinary training by building an open, collaborative, and adaptive learning ecology, but also provides a technological fulcrum for cultivating future talents with systematic thinking and innovation, demonstrating the revolutionary power of promoting changes in the form of education.

4. Challenges of Generative AI in Education

The deep application of generative AI in education is encountering multidimensional real-world challenges that are reconfiguring the evolutionary path of the education ecosystem on a number of levels, from data privacy and security, to ethical issues, to teacher training, as shown in Fig. 4.

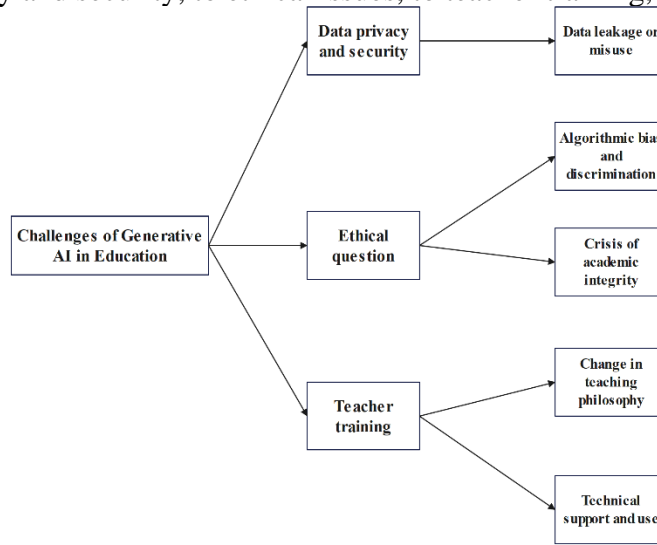


Figure 4. Challenges of generative AI in education

4.1 Data Privacy and Security. In the educational application scenario of generative AI, the privacy and security protection of students' data constitutes a key challenge for the implementation of the technology. The in-depth application of this technology requires the collection of multi-dimensional learning behavior data, covering sensitive information such as knowledge mastery, cognitive style preferences and personalized learning trajectories, and its full lifecycle management involves a number of links such as collection, storage, transmission and analysis. The lack of a rigorous data governance mechanism may lead to unauthorized access, data leakage or misuse risks, which may seriously damage students' rights and interests and shake the foundation of trust in education [11].

To address the challenges of data privacy and security, a two-pronged approach of “technology + system” is needed, as shown in Fig. 5.

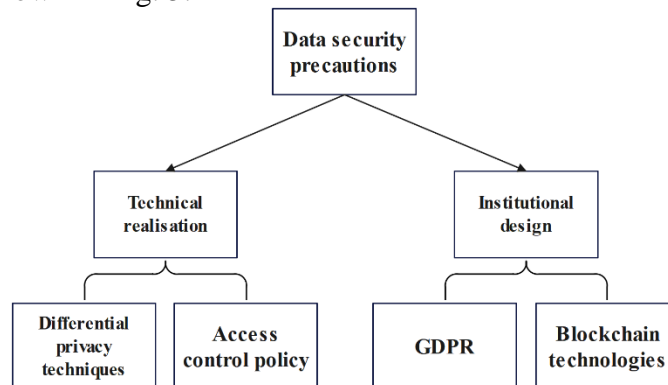


Figure 5. Challenges of generative AI in education

From the dimension of technical implementation, strengthening data security requires the construction of a multi-layer encryption protection system and the use of differential privacy technology to anonymize data, as well as the implementation of strict access control policies and operational audit mechanisms. At the institutional design level, a data ethics review framework that complies with international standards such as GDPR should be established to clarify the ownership and use boundaries of data and realize traceable management of data flow.

4.2 Ethical Issues. The application of generative AI technology in education has raised multidimensional ethical issues, the complexity of which has gone beyond the scope of technological instrumentality and touched deeply on the value of education. First and foremost is the crisis of academic integrity, as the automated content generation capability of the technology may weaken the process of students' critical thinking cultivation, blurring the boundary between knowledge acquisition and intelligent assistance. When technological tools are used to complete course papers or creative works, the traditional evaluation system faces the risk of deconstruction, and the nature of knowledge construction in the educational process may be alienated into a technological game [12].

Deeper ethical challenges stem from the risks. Structural imbalances in the training data may cause the model to replicate or even amplify social biases in dimensions such as gender, race, and geography. For example, in the educational resource recommendation scenario, if the algorithm inherits the urban-rural differences inherent in the historical data, it may exacerbate the unequal distribution of educational opportunities. This kind of technological discrimination is characterized by covertness and systematic exclusion through a seemingly neutral decision-making mechanism, with an amplifying effect on its social impact.

The construction of an ethical governance framework needs to unfold in three dimensions, as shown in Fig. 6.

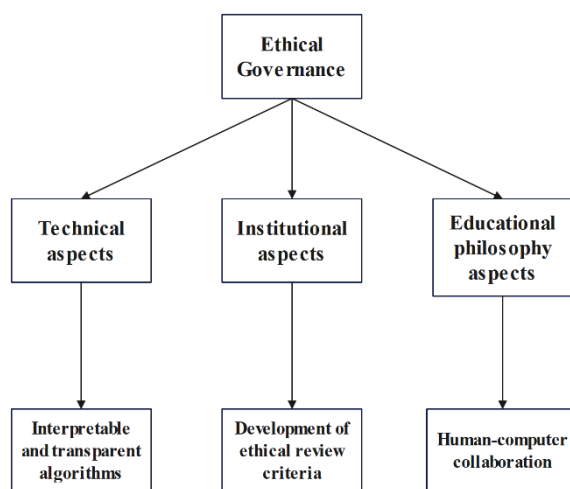


Figure 6. Ethical governance

Firstly, at the technical level, we should establish transparent algorithms that can be interpreted, and set up bias detection and correction modules; secondly, at the institutional level, we should formulate ethical review standards and clarify the prohibited areas of technological application, and at the level of educational concepts, we should reshape the cultivation paradigm of ‘human-machine synergy’, stressing the value of the complementarity between technological tools and human intelligence. At the same time, it is necessary to establish a dynamic monitoring and ethical impact assessment mechanism, so as to maintain the evolutionary capacity of the governance framework in response to new ethical challenges arising from technological iterations.

4.3 Teacher Training. The in-depth application of generative AI in the field of education has led to structural challenges in teacher training. The contradiction between the acceleration of technology iteration and the lag of education has led to a ‘catch-up dilemma’ in the improvement of teachers' intelligent literacy [13]. The technological evolution of generative AI follows Moore's law, while the teacher training system is limited by the cycle of educational resource allocation, forming a significant development time lag. This difference in the rate of knowledge updating makes some teachers need

to cope with the demand for pedagogical applications of the new generation of tools before they have mastered the current technology.

Cognitive paradigm shift poses a profound challenge. While traditional education emphasizes the linear logic of knowledge transfer, generative AI supports a non-linear, generative process of knowledge construction. Teachers need to transform from ‘knowledge authorities’ to “learning collaborators”, a role shift that requires breaking through existing cognitive frameworks and establishing a collaborative human-computer pedagogical mindset. According to the study, more than half of the teachers who encountered generative AI at the initial stage had the tendency to simply superimpose technological tools on traditional teaching, reflecting the difficulty in transforming the educational paradigm.

The practice transformation gap has become a key bottleneck. Technical training often focuses on the operational level of tools, while ignoring the creative application in teaching scenarios. Teachers need to transform algorithmic logic into educational wisdom, which cannot be achieved through simple technology transfer.

Lagging evaluation system increases the difficulty of implementation. The current teacher evaluation system lacks the dimension of intelligent educational literacy, resulting in the lack of a results-oriented feedback mechanism for training. This lack of evaluation creates a “training-application” gap, and teachers lack the motivation for continuous improvement. The construction of a multi-dimensional evaluation framework for intelligent education literacy, including technological understanding, collaborative innovation, and ethical awareness, has become an urgent need to improve the effectiveness of training.

To solve these challenges, it is necessary to build a three-in-one teacher training ecosystem of “dynamic resource supply-scenario-based learning-developmental evaluation” [14], as shown in Fig. 7.

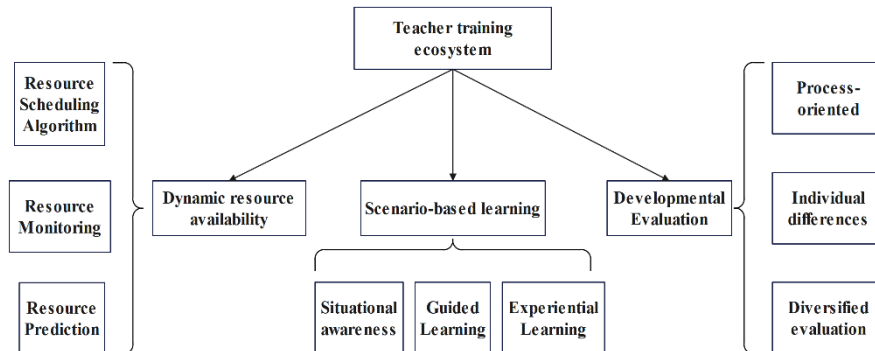


Figure 7. Teacher training ecosystem

Through the establishment of a technology interpretation community, the development of immersive training courses, and the implementation of concomitant evaluation support, we can help teachers realize the role of leaping from technology applicators to educational innovators, and provide human support for generative AI-enabled educational innovation.

5. Summary and Directions

5.1 Summary. Generative AI technology is profoundly changing the field of education, and its application has penetrated into the core links of personalized learning, teaching design, teaching evaluation, etc., showing a significant technology empowerment advantage. In terms of personalized learning, generative AI realizes real-time matching of ‘ability-content’ by dynamically generating ladder learning resources, constructing three-dimensional knowledge maps, and transforming multimodal content (e.g., VR experiments, haptic feedback learning packages), with a great improvement in adaptation accuracy compared with traditional resources, and effectively improves the learning experience of special education groups. Learning experience of special education groups has been effectively improved. In the field of teaching design, AI tools represented by Khanmigo can quickly generate structured lesson plans, provide massive teaching resources, save teachers'

preparation time, and support personalized adjustment to promote teaching innovation. In teaching evaluation, generative AI promotes evaluation from result-oriented to process and developmental assessment through multimodal data analysis (e.g., classroom speech logic recognition, in-depth assessment of essays) and dynamic assessment systems, with typical cases such as KDDI's classroom competency matrix and Batch.com's rhetorical optimization suggestion system.

The core advantages of generative AI are reflected in three aspects: first, data-driven decision-making optimizes resource allocation and teaching strategies by analyzing massive learning behavior data; second, teaching cost optimization breaks the geographical limitation, bridging the gap between urban and rural education with the help of the able education platform and AI tools (e.g. DeepSeek, etc.), reducing the cost of a single classroom hour in rural areas to 1/5 of that of traditional education, and continuously realizing education fairness; Thirdly, interdisciplinary ability cultivation breaks through disciplinary barriers, fostering systematic thinking and innovation through dynamic knowledge networks and virtual collaboration spaces. However, the application of technology still faces multiple challenges: data privacy and security risks need to be addressed through differential privacy and blockchain technology; ethical issues such as academic integrity crisis and algorithmic bias require the establishment of transparent algorithms and a dynamic ethical review mechanism; the teacher training system needs to shift from a tool-based operation to an educational paradigm transformation to address the cognitive lag and practical gap; and the teacher training system needs to shift from a tool-based operation to an educational paradigm transformation to address the cognitive lag and practical gap. The teacher training system needs to shift from tool operation to education paradigm transformation to solve the “cognitive lag” and “practice gap”.

Overall, generative AI improves the efficiency and fairness of education through the mechanism of human-machine collaboration, but its full-scale implementation needs to balance technological innovation and ethical governance to build a sustainable educational ecology.

5.2 Directions. The future development of generative AI in the field of education will deeply integrate technological innovation and ethical governance, and promote the continuous evolution of the education system in the direction of intelligence and inclusiveness. With the in-depth combination of multimodal technology and cutting-edge technologies such as meta-universe and brain-computer interfaces, educational scenarios will break through physical limitations and build learning environments that integrate reality and reality. For example, augmented reality (AR) technology can restore immersive scenes of historical events, brain-computer interfaces can capture students' cognitive state in real time and dynamically adjust the teaching content, and the training of large models in vertical domains will enhance the accuracy of interdisciplinary problem solving. At the same time, ethical challenges such as data privacy and algorithmic bias require the construction of a globally unified data governance framework through federated learning and blockchain technology, so as to realize the ‘usability and invisibility’ of educational data and the traceability and authentication of academic results. The dynamic ethical review mechanism and transparent practices of the open-source community will ensure the fairness and inclusiveness of the AI system, for example, automatically detecting geographic discrimination in the recommendation of resources and generating corrective solutions, so as to eliminate educational inequality from the bottom of the technology.

The core of the future education ecosystem will revolve around the reshaping of teachers' roles and social collaborative networks. Teachers will shift their role from knowledge transfer to emotional guidance and innovation stimulation, and master human-computer collaboration strategies through the dual-track training model of ‘AI literacy + education innovation’. Immersive classroom simulation and AI collaborative design tools will help teachers cope with complex teaching situations, while the collaborative network formed by the government, enterprises, schools and the community can realize the dynamic deployment of educational resources through intelligent contracts. In addition, generative AI will accelerate the process of inclusive education, develop adaptive interactive interfaces (such as brainwave-controlled learning systems) for disabled groups, and build a lifelong learning platform with global coverage.

In short, generative AI will deeply reconfigure the education paradigm, but its success depends on the synergy of technological innovation, ethical constraints and social consensus. Only by building a “human-centered” intelligent education ecosystem can we truly achieve the double improvement of education equity and quality.

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