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Mechanism, challenges and practical paths of generative artificial intelligence driven educational transformation

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Abstract. In the digital era, on the basis of reconstructing educational content and transforming educational modes, educational fields, as well as the subject-object relations in education, generative artificial intelligence embeds and optimizes the entire process of teaching and learning. At the teacher level, generative artificial intelligence forms an intelligent, interactive and human-machine collaborative teaching form. At the student level, it helps build an immersive, participatory and autonomous learning model. At the educational nurturing level, it strengthens value guidance through data-driven intelligent algorithms. Nevertheless, the transformation of education driven by generative artificial intelligence still faces multiple challenges. Human-computer interaction squeezes the space for real communication between teachers and students; algorithmic bias undermines the effectiveness of education; information narrowing erodes educational fields; and the expansion of instrumental rationality obscures students' subjectivity. Guided by practical problems, this study shall improve the institutional mechanisms for empowering high-quality educational development with digital intelligent technologies, integrate educational resources and optimize educational content via generative artificial intelligence, build sound educational fields for teaching practice, and construct an integrated educational community of "teachers—machines—students".

Keywords: generative artificial intelligence, technological embedding, educational transformation, educational digitization

1. Introduction

With the iterative updating of computer algorithms and the application of general large models, breakthrough progress has been achieved in the field of artificial intelligence. Generative artificial intelligence technologies including ChatGPT, Sora and DeepSeek have sparked a global wave of digital transformation. Generative Artificial Intelligence (GAI) represents a new content production mode that automatically generates content through artificial intelligence technology, following Professional Generated Content (PGC) and User Generated Content (UGC). As a new engine for the innovative development of digital content, generative artificial intelligence brings new opportunities for the high-quality development of education. Since 2022, China has implemented the digital education strategy. Against this strategic backdrop, generative artificial intelligence profoundly influences all elements and processes of education, reshaping educational practice and educational ecology. Generative artificial intelligence transforms the internal elements, operational systems

and external environmental relations of education. Relying on its technical advantages of multi-scenario and personalized services, it delivers opportunities for educational reform and development. Relevant studies have demonstrated that digital intelligent technologies such as generative artificial intelligence play a vital role in optimizing teaching and learning and improving learning outcomes. Scholars including K Porayska-Pomsta argue that human-machine collaboration can effectively facilitate learners' skill training and provide students with interactive learning experiences [1]. Computer scientist Marius Cătălin Iordan has collaborated with psychologist Jonathan D. Cohen and other researchers to link brain-inspired science with cognitive learning activities, and construct computer models from the interdisciplinary perspectives of cognitive psychology and computational neuroscience [2]. Zhu Zhiting et al. have discussed the manifestations of digital educational transformation in three dimensions: high-consciousness learning, skill-based education and smart education [3]. Lv Guangzhu and Shi Miao take Stanford University as a case to illustrate that the empowerment of students by ChatGPT follows the practical path of personalized adaptive learning [4]. Therefore, in-depth research on the holistic transformation of educational processes and educational functions brought by generative artificial intelligence is necessary. From the perspective of basic constituent elements of education, this paper focuses on exploring the following core questions: how generative artificial intelligence embeds and couples with educational practice, how it reshapes educational ecology and improves educational effects, and how to avoid and eliminate its potential risks. In this regard, the researchers must maintain forward-looking thinking, focus on the empowering effect of generative artificial intelligence on high-quality educational development, strive to advance the digital transformation of education, and accelerate the construction of a powerful country through education.

2. Internal mechanisms of educational transformation driven by generative artificial intelligence

In the digital era, generative artificial intelligence adopts an entirely new mode of content production, featuring high interconnectivity, ubiquity, full-time availability and interactivity in content production workflows and information communication. Embedded with generative artificial intelligence, core educational elements including educational content, educational modes, educators and learners undergo remarkable changes, enabling generative artificial intelligence to embed and optimize the full process and full chain of education.

2.1. Teacher dimension: intelligent, interactive and human-machine collaborative teaching forms

Against the backdrop of educational digitization, generative artificial intelligence promotes the shift of teaching forms toward intelligence, interactivity and human-machine collaboration through general large language models, multi-modal deep learning, automatic content generation technologies and other tools.

2.1.1. Innovations in teaching modes via simulacral educational narratives and interactive discursive communication

The primary task of teaching is to help students form correct theoretical cognition of educational content, which requires educational narratives to describe educational content, define theoretical categories, interpret conceptual terms and build knowledge frameworks. In the digital era, as a tool for content production and interaction, generative artificial intelligence possesses universal linguistic capabilities. With the embedding of generative artificial intelligence, teaching activities break away from traditional oral and written narratives. Converting visual, auditory and textual information into digital formats, generative artificial intelligence creates educational content in text, image, video and other forms. Its educational narratives are mainly

expressed as image and textual narratives on digital interfaces, adopting interactive dialogue as the mode of discursive communication.

Instead of knowledge, emotion and verbal expression conveyed by teachers, intelligent systems extract information and knowledge from data and model parameters to form simulacral educational narratives on digital interfaces. Distinct from traditional educational narratives, the image and textual simulacral narratives rely on electrical signal transmission. On the one hand, information and codes on digital interfaces carry educational content, and the simulacral narratives composed thereof bear immaterial attributes. During information production and reception, simulacral narratives can only be completed through the objectification of "general intellect". This process of objectifying "general intellect" forms a bond for the circulation and sharing of cultural concepts and knowledge content. After multiple rounds of circulation and dissemination, the knowledge, information, ideas and emotions embedded in digital image and textual narratives will not diminish; instead, they are reinforced and transformed into shared cultural resources between teachers and students, endowing educational narratives with stronger communicative power. On the other hand, computer multi-modal large models encode visual images, auditory sounds and even tactile sensations of human beings [5]. Supported by multi-modal large models, generative artificial intelligence establishes statistical correlations between linguistic symbols in texts and visualized visual information, enriching human symbolic knowledge systems with abundant visual materials. On this basis, the image and textual symbols generated by generative artificial intelligence stimulate students' senses through light and shadow, delivering hyperreal narrative effects. Nevertheless, the image and textual narratives formed by generative artificial intelligence remain stored on digital interfaces for a short time. Compared with the permanence of traditional educational narratives, simulacral narratives tend to leave only short-term memories in students.

Assisted by general large language models, teaching adopts interactive dialogue as the form of educational communication, further advancing discursive communication practices among teachers, students and computers. Through Reinforcement Learning from Human Feedback (RLHF), generative artificial intelligence models are increasingly aligned with human cognitive and comprehension patterns [2]. For instance, the data rationality of large language model technologies is grounded in the linguistic logic of "predicting subsequent text based on preceding context" [6]. Computers enable students to retrieve relevant knowledge at any time through natural, intelligible dialogue, pioneering an information communication paradigm based on natural language processing. Utilizing generative artificial intelligence for educational narratives constitutes a dynamic process of real-time subject-object verbal interaction. With the embedding of generative artificial intelligence, the "AI + Teaching" model replaces the traditional one-way indoctrination discourse communication mechanism. Teachers engage in multi-round dialogues with students via large language models. From the perspective of educational development trends, the application of generative artificial intelligence will not degrade human thinking; instead, it increasingly approximates the Socratic "maieutics". Teachers leverage intelligent systems to inspire students through dialogue and questioning, while students likewise express their viewpoints clearly with the aid of large language models during discursive communication. The interactive dialogue mode facilitates the transmission and exchange of theoretical knowledge and ideological concepts. Through interaction with information codes, students conduct in-depth thinking, consciously pursue truth and engage in self-exploration.

2.1.2. Improvement of teachers' capacity to construct classroom teaching by generative artificial intelligence technology

In the links of knowledge transmission and internalization, the construction of classroom teaching stands as a core issue. Teachers' capacity to structure classroom teaching directly affects students' comprehension and

acceptance of educational content. Nowadays, supported by generative artificial intelligence, teachers' capacity to construct teaching and learning activities has been significantly strengthened.

A series of technical suites underpin the embedding of generative artificial intelligence in teaching practice. In the text translation stage, generative artificial intelligence adopts digital content twin technology to convert textbook background knowledge and educational content into digital texts or visual resources. Relying on artificial neural networks and digital content twin technology, teachers can better present educational content in digital spaces and reproduce real educational scenarios. Digital content twin technology intervenes in the structure of the real world, creating conditions for two-way interaction between intelligent systems and individual student experiences. In the content production stage, intelligent systems carry out machine learning via digital content generation technology to independently organize teaching content and construct educational fields. Digital content generation technology first extracts and learns from data to form digital content that defines students' cognitive objects or knowledge carriers. Computer systems then adopt agenda-setting and intelligent push mechanisms to introduce theoretical knowledge into students' cognitive domains. Meanwhile, the full-time and multi-space educational scenarios constructed by digital content generation technology amplify the influence of educational environments on students and reinforce the basic semantics of educational narratives. Through human-machine interactive discursive communication, students select and reorganize teaching information, integrate educational content into their existing knowledge frameworks, and form new theoretical cognition. In the content feedback stage, generative artificial intelligence evaluates students' mastery and comprehension of teaching content in real time through multi-modal perception systems. Since digital content editing technology possesses semantic understanding and attribute manipulation capabilities, the design of teaching activities, setup of educational contexts and expression of teaching content are regulated by digital content editing technology, enabling generative artificial intelligence to implement real-time intervention and feedback on teaching processes (see Figure 1).

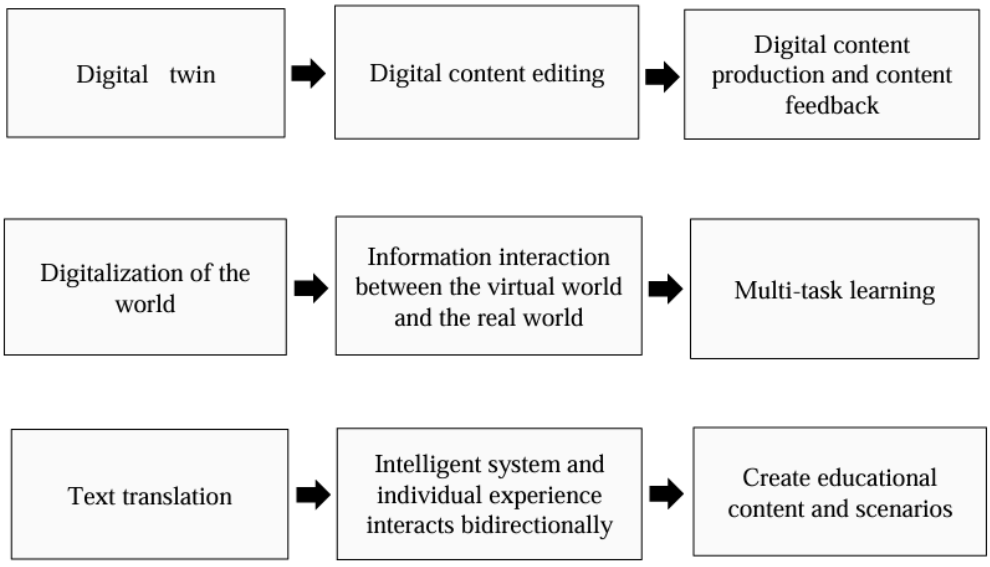

Figure 1. Construction of teaching processes by generative artificial intelligence technology

Through digital content twin technology, digital content editing technology and digital content generation technology, generative artificial intelligence effectively realizes interaction between educational information and individual students, facilitating students' comprehension of theoretical knowledge. Generative artificial

intelligence fulfills positive constructive functions across all stages of classroom teaching, from text translation and content production to scenario construction and teaching evaluation.

2.1.3. Shaping of multi-dimensional subject-object relations in education via human-machine collaboration

Driven by generative artificial intelligence, the generation and dissemination paths of knowledge and information have shifted from the previous centralized radiation of point-to-many to an open network topology. Generative artificial intelligence software interacts with users to acquire multi-faceted data and conduct in-depth machine learning. Especially after blockchain and machine learning models are applied in education, intelligent digital platforms produce knowledge and output educational content through open collaboration. Educational communication between teachers and students on digital platforms, as well as knowledge generation by intelligent systems, integrate information activities of multiple participants. During data processing, generative artificial intelligence creates a pattern of multi-directional information flow, and the intervention of machines breaks the closed loop of original subject-object relations. After the embedding of generative artificial intelligence, multi-dimensional subject-object interaction replaces the previous one-way information communication model dominated by educational subjects. The traditional binary "teacher–student" subject-object structure in education has evolved into a ternary "teacher—machine—student" structure under human-machine interaction and collaboration.

The multi-dimensional subject-object relations under generative artificial intelligence differ markedly from those in traditional education. Under the traditional binary "teacher–student" structure, students obtain information from a single source, mainly the educational content integrated by teachers. The multi-dimensional subject-object relations embedded with generative artificial intelligence alter teachers' role as the sole producers and interpreters of educational content, breaking the traditional dichotomous teacher-student subject-object relationship. Supported by massive data in corpora and databases, intelligent systems integrate relevant theoretical achievements and student data into teaching. New subject-object relations drive the transformation of educational models. On the one hand, the multi-dimensional "teacher—machine—student" subject-object relations under generative artificial intelligence incorporate educational processes into the horizon of intersubjectivity. The supply of educational content no longer relies solely on teachers, but originates from integrated information of multiple parties including students and other educators. The selection of educational content and production of knowledge are grounded in interactive relations and shared meanings among teachers, students and other educators. On the other hand, the interactivity and sharing of knowledge production are intrinsically linked to the interpretation of educational content. During teaching, teachers rely on specific contexts and interconnected interpretive rules to explain educational content. Wittgensteinian scholars argue that the rationality of applying isolated single rules by interpreters carries high uncertainty, while interconnected interpretive rules within discursive contexts can mitigate such uncertainty [7]. The multi-dimensional subject-object relations embedded with generative artificial intelligence expand the intersubjectivity of teaching and promote the application of public reason. Assisted by generative artificial intelligence, teachers can interpret educational content more accurately in accordance with the purposes and concepts embedded therein, drawing on textbooks and established understandings within the education community.

2.2. Student dimension: immersive, participatory and autonomous learning modes

Leveraging technical advantages including multi-modal content generation and collaborative perception, generative artificial intelligence constructs immersive and participatory learning scenarios, stimulates students'

cognitive initiative and learning motivation, and forms immersive, participatory and autonomous learning modes for students.

2.2.1. Integration of rational cognition and emotional factors via digital intelligent communication

In the link of educational information communication, image narratives, textual narratives and interactive dialogue modes driven by generative artificial intelligence shape students' cognitive structures. Australian education scholar Neil Selwyn emphasizes that artificial intelligence exerts positive effects on users' theoretical cognition [8]. The simulacral discursive narratives and interactive dialogue modes of generative artificial intelligence further accelerate the flow of information codes and strengthen students' perception of the external environment. Students correlate existing memories and materials in their minds with newly received information, classify, compare, analyze, synthesize and abstract information following logical relations. Through information reception and discursive interaction, students transition from concrete thinking to abstract thinking, and their cognitive structures are continuously adjusted. Students engage in rational thinking through exchanges of information codes in teaching and participate in educational interaction, with their self-awareness taking shape alongside the dissemination of information codes.

Learners' knowledge systems and self-awareness capabilities develop through the integration of sensibility and rationality. Teaching aims not only to improve students' cognitive capacity for educational content but also to guide their emotions. Distinct from rational cognition, emotion constitutes a pre-reflective, semi-conscious layer preceding behaviors, and emotional experience complements rational cognition to stimulate students' internal learning motivation. If emotional experiences arise within dynamic, specific scenarios, generative artificial intelligence serves as a medium for emotional experience. Pure verbal narration of knowledge by teachers sometimes fails to convey subtle emotions. In contrast, textual and image narratives generated with generative artificial intelligence adopt vivid, concrete expressive forms that touch students' subjective feelings through immersive scenarios. Intellectual emotions circulate among teachers, computers and students. Meanwhile, interactive discursive communication on digital interfaces enables precise emotional transmission in classroom teaching and provides emotional support for students. Positive emotional experiences not only enhance students' learning initiative but also facilitate the development of their thinking and creativity. With generative artificial intelligence, students' emotional experiences are integrated into their rational cognitive processes, narrowing the gap between students and educational content and fostering ideological resonance with teachers.

2.2.2. Regulation of embodied cognition by virtual-real integrated educational fields

An educational field refers to the venue where teachers and students conduct dialogues and communications centering on teaching topics. Education cannot exist without specific spaces and scenarios, with educational fields serving as practical arenas for teaching activities. Within educational fields, teachers interpret educational content, and all elements including educational subjects, educational objects, educational content and educational tools converge. Through verbal interaction and emotional communication within educational fields, students accurately comprehend educational content and construct theoretical knowledge.

In the digital era, as a tool for constructing virtual worlds and even the metaverse, generative artificial intelligence possesses the capacity to participate in building educational fields. When delivering teaching activities to students, generative artificial intelligence integrates and constructs contextual relations for teaching practice according to practical demands. It transcribes real-world objects and reproduces real scenarios via digital content twin technology and AI-generated text, sound and image materials. Built upon general large models, educational activities break the physical spatial constraints of discursive fields, enabling information codes, virtual worlds and the real world to coexist within the same spatial dimension.

Educational fields constructed with the assistance of generative artificial intelligence exert positive impacts on students' embodied cognition. In traditional teaching, students rely on teachers' verbal narratives or textbook textual narratives to construct specific scenarios through imagination. Today, generative artificial intelligence can generate 3D models for educational scenario demonstration, presenting educational content and narrative processes intuitively. The reproduction of real scenarios by generative artificial intelligence helps students construct diversified educational contexts on digital interfaces. Educational fields supported by generative artificial intelligence not only enhance the vividness and interactivity of teaching processes but also broaden students' perceptual channels for educational content, enabling multi-channel perception of educational materials. Students no longer need to mentally process imagery described by educational discourses, as educational scenarios can be intuitively constructed through digital content generation.

Based on human-machine interactive teaching modes, computer multi-modal large models can recognize and respond to students' language, movements, facial expressions and other signals, allowing students to fully immerse themselves in educational fields through human-machine interaction. During information communication, the interactive relations between learners' bodies and environments play a pivotal role in cognitive activities. Virtual-real integrated educational fields in teaching and near-real communication interactions in digital spaces boost learners' sense of participation in teaching activities. Through situational immersion and interactive experience, educational fields constructed by generative artificial intelligence regulate students' cognitive processes. Different time domains overlap and intersect, infinitely extending educational fields temporally. Students' physical sensations, psychological activities, thinking capacities and behavioral motivations are fully mobilized by educational fields, triggering a chain reaction of "sensory stimulation—psychological resonance—emotional identification".

2.2.3. Stimulation of students' subjectivity via educational intersubjectivity

Due to the embedding of generative artificial intelligence, the multi-directional information flow in educational processes shapes multi-dimensional interactive relations among teachers, machines and students, expanding the intersubjectivity of education. Intersubjective relations between teachers, computers and students facilitate the exertion of students' subjectivity and encourage autonomous exploratory learning modes.

Generative artificial intelligence adopts open collaboration to produce and output educational content, granting students opportunities to participate in knowledge creation, and their learning demands can be reflected through intersubjective interaction within educational fields. Teachers leverage the constructive functions of generative artificial intelligence in teaching practice to set specific teaching topics within virtual-real integrated discursive fields. Students enter educational fields to raise questions and share viewpoints centering on theoretical knowledge and value connotations. In this context, learning processes are generative, real-time and open, supporting student participation and communication. Generative artificial intelligence constructs infinite "possible worlds" for learners, encouraging them to select and negotiate topics within variant scenarios. During interactive educational communication, students must respond rapidly to received information, conduct thinking and take initiative to explore. Real-time communication and interaction among teachers, machines and students transform students from "onlookers" to "participants" in classroom teaching, requiring students to recognize their identity as learning subjects. Teaching activities trigger contradictory movements of students' psychological factors including cognition, emotion, belief and volition, prompting active reflection on educational content. Upon completing teaching topics, students not only acquire new knowledge, but also cultivate thinking and creative capacities through interactive learning behaviors, improving individual self-efficacy.

2.3. Educational nurturing dimension: value guidance driven by data and intelligent algorithms

Beyond transforming teaching and learning activities, generative artificial intelligence integrates educational nurturing concepts into educational processes. Against the backdrop of digital educational transformation, generative artificial intelligence delivers critical technical support for the construction of students' learning capacities and cultivation of moral competencies.

2.3.1. Aggregation of moral education content via AI content production modes

Media and carriers are required for information transmission and ideological communication between teachers and students. Through curriculum carriers, educational content is conveyed between teachers and students, enabling the exchange and sharing of their ideas and viewpoints. Curriculum carriers not only determine the external expressive forms of educational narratives but also constrain the internal ideological content embedded within them. Traditional curriculum carriers mainly include textbooks and teaching aids. Based on these traditional carriers, educational content remains relatively stable and is generally processed and organized by teachers, who possess strong autonomy in the selection and arrangement of educational content.

In the digital era, generative artificial intelligence revolutionizes content production modes, with data emerging as a vital carrier of education. Two fundamental prerequisites underpin the embedding of generative artificial intelligence in educational practice: first, intelligent systems take data as a medium and convert real-world educational content into computational problems in virtual spaces via digital content twin technology; second, intelligent systems realize intelligent creation of educational content through machine learning and data computation. During education, an interconnected network of data, technology and information forms within digital spaces. Data-driven intelligent systems engage in information exchange and interaction with the real world, and teaching and learning activities are grounded in data interaction.

When data serve as educational carriers, educational practice tends to adopt formalized, intelligent knowledge production modes. Embedded with generative artificial intelligence, the selection and organization of educational content bypass deductive thinking from hypothesis to verification. Instead, a foundational framework for content production is built through data collection and preprocessing, model selection and training, sampling and decoding, as well as model evaluation and optimization. This provides a new paradigm for scientific discovery based on massive data in education. After machine learning, intelligent systems mine data correlations via algorithms and create educational content in accordance with tasks assigned by teachers. At this stage, all operational links of generative artificial intelligence revolve around machine learning, data computation and logical reasoning, endowing it with robust knowledge extraction and updating capabilities. Originally discrete data, information and knowledge are classified and integrated based on machine learning and data computation, and organized into systematic, structured educational content following internal logical threads. Formalized, intelligent knowledge production consolidates scattered moral education resources at the content level, enabling greater focus on core themes. During the output of educational content, intelligent systems continuously conduct machine learning through repeated human-machine interaction. Via iterative human-machine interaction and machine learning, intelligent systems gradually grasp students' psychological conditions and moral levels, and better understand teachers' nurturing requirements. Under such circumstances, the production of moral education content becomes more precise, and educational resources and theoretical knowledge embedded with moral connotations output by intelligent systems achieve higher aggregation.

2.3.2. Bearing of educational nurturing values by intelligent algorithms

Although the organization of knowledge resources and production of educational content by generative artificial intelligence rely on hierarchical data computation, the data selected for computation, algorithm models set and algorithm parameters adjusted remain controllable. The vertical hierarchical data computation

workflow determines that generative artificial intelligence itself can carry specific educational nurturing values. When applied throughout teaching and learning, generative artificial intelligence can exert positive effects on cultivating students' moral cognition, moral emotions and moral behaviors.

In the preliminary stage of educational practice, large language models first interact with knowledge bases and professional databases to acquire data resources. Generative artificial intelligence then obtains knowledge through algorithms and unsupervised learning, laying foundations for document parsing or generating multi-chain discourses. During data capture and machine learning by generative artificial intelligence, the scope of knowledge bases and professional databases is limited and controllable, and teachers can even independently select knowledge bases. For example, DeepSeek has launched independent knowledge base construction services for individual teachers. Since the data sources of generative artificial intelligence mainly consist of knowledge bases and professional databases, and data within knowledge bases can be screened and selected by teachers, data quality in professional fields is guaranteed, ensuring that educational practices adhere to correct value orientations in moral cultivation.

Under generative artificial intelligence, algorithms constitute the core components supporting intelligent auxiliary educational practice. Based on algorithms, generative artificial intelligence automatically conducts information screening and knowledge organization, assisting teachers in generating educational content and constructing educational scenarios. Centered on intelligent algorithms, educational workflows become computable, predictable and operable. Algorithms can be further adjusted and refined according to educational demands; in particular, algorithm weighting enables output educational content to better align with practical moral education needs and achieve ideal educational effects. In accordance with the statistical importance of data points, algorithm weighting assigns weights to different data items, features or models, adjusting the influence of these features in computational processes. After algorithm weighting, computational models attach greater attention to specific features. If high algorithm weights are assigned to the ideological and value attributes of texts, intelligent algorithms will abandon pure traffic logic and prioritize the value orientation embedded in texts. During education, algorithm weighting improves the quality of educational content and integrates core moral education values into educational materials. Built upon intelligent algorithms, generative artificial intelligence enhances the cultivation of students' moral character through educational practice, strengthening the nurturing functions of education.

3. Challenges facing educational transformation driven by generative artificial intelligence

Media ecologist Neil Postman argues that different media forms favor specific types of content, and media define the world through concealed yet powerful metaphors [9]. Media themselves are not entirely neutral. Encoding and decoding information in symbolic forms inevitably incur media influences. As "AI synthetic media", generative artificial intelligence carries inherent media biases shaped by its content production modes, bringing challenges to educational transformation in the digital era.

3.1. Squeezing of real teacher-student communication space by human-machine interaction

Real educational communication between teachers and students not only fulfills information transmission functions but also delivers genuine emotional exchange and ideological collision throughout educational processes. Face-to-face real communication often amplifies the influence of teachers and peer students on individual learners.

In the digital era, clear boundaries between human beings and computers have faded, merging the real world with cyberspace. Embedded with generative artificial intelligence, computers occupy a pivotal position within the "teacher—machine—student" educational subject-object relations, making educational communication inseparable from human-machine interaction. Nevertheless, if data interaction in educational processes replaces tangible interpersonal relations in the real world, the expansion of human-machine relations will inevitably crowd out the real space for educational communication. Excessive expansion of human-machine relations in educational practice risks alienating students from the real world and collapsing students' reliance and sense of belonging toward teachers. Once authentic interpersonal educational communication is replaced by virtual information interaction and human-machine dialogue, students will only interact with machines devoid of rationality and emotion. Though generative artificial intelligence can set specific educational scenarios to trigger student reflection and emotional responses, it can only complete educational interaction through repetitive, mechanical data computation. Intelligent systems can never achieve genuine ideological and emotional resonance with students. Education centers on human beings, cultivating human thought, emotion, morality, will and other spiritual attributes. Excessive reliance on machines in education prevents students from forming personal cognition and perception within the real world, binding students' rational cognition and value shaping exclusively to machines.

3.2. Reducing the educational effectiveness by algorithmic bias

The technical embedding of generative artificial intelligence into educational workflows revolves primarily around algorithms. The opaque "black-box operation" of algorithmic decision-making may give rise to algorithmic bias. If program settings of generative artificial intelligence contain algorithmic bias, distortions will emerge in auxiliary educational work, causing educational narratives to deviate from sound logic and impairing educational effectiveness.

Computer scientists Friedman and Nissenbaum categorize algorithmic bias into three types: pre-existing bias, technical bias and emergent bias. Pre-existing bias originates from real social relations. Values deviating from mainstream ideology or biased ideological perspectives held by system designers are embedded into machine learning corpora and databases and acquired by machines. Algorithms ultimately absorb biases embedded in human language and behaviors through data input. Technical bias and emergent bias stem mostly from operational factors, referring to explicit discrimination or restrictions in data collection by generative artificial intelligence, or program designs where computer interaction only covers partial user groups. Under such circumstances, educational content generated by intelligent systems carries obvious one-sidedness. Once programs with algorithmic bias are incorporated into software systems, conclusions derived by computer models tend to be unfair. Generative artificial intelligence may put forward one-sided viewpoints or incorrect solutions, and even provide contradictory discursive statements to students. Algorithmic bias misguides the dissemination of educational content, making educational practice assisted by generative artificial intelligence incapable of delivering correct guidance to students.

3.3. Erosion of educational fields by information narrowing

Data integration, information distribution and other core functions of generative artificial intelligence are determined by algorithms. Regarding educational content production, algorithms can only conduct statistics and computations based on existing data. Texts generated by generative artificial intelligence are covered by pre-existing data, and newly created texts may become data sources for repeated machine learning. In terms of educational content distribution, information repeatedly pushed by algorithms following user preferences generates the Matthew effect, forming a centralized information communication pattern.

Within educational practice, repeated reuse of AI-generated data and the Matthew effect in information distribution lead to information narrowing, restricting the scope, depth and precision of transmitted information. When algorithms conduct statistics and computations on existing data, learners are more likely to access established educational content and data consistent with their personal preferences. However, educational content untransformed into computer data or information inconsistent with user preferences are excluded by algorithms. Under such conditions, generative artificial intelligence simultaneously produces and segregates information. Influenced by narrowed information, educational fields constructed and presented by generative artificial intelligence evolve into highly homogenized educational environments. Homogenized educational environments present students with a "symbolic reality" processed by media, and students may continuously immerse themselves within information cocoons. Constrained by information narrowing and homogenized educational fields, students struggle to access comprehensive, objective educational content from discursive fields, which further distorts their theoretical cognition and value judgment and deconstructs the internal normative attributes of educational fields.

3.4. Obscuring of students' subjectivity by the expansion of instrumental rationality

Possessing constructive capacities including educational content production and educational field construction, generative artificial intelligence assists real-time educational interaction between teachers and students and thus assumes the role of an educational "actor". Its efficient knowledge extraction and reasoning decision-making capacities surpass human teachers and individual natural brains in response speed and personalized support [10]. Nevertheless, growing machine agency risks the inflation of instrumental rationality. Within human-technology interaction, the expansion of instrumental rationality may elevate digital intelligent technologies to the dominant position in education, triggering instrumental inversion of human and machine roles in education. Intelligence is no longer defined by human beings but reduced to symbolic machine operations. Students, originally the subjects of learning, are digitized by generative artificial intelligence into data objects and algorithmic targets. During content mining, material retrieval and reproduced editing, generative artificial intelligence determines educational content, and students' knowledge objects are shaped by materials generated by intelligent systems. Students' cognition, concepts and behaviors throughout educational processes are defined by technology, making it difficult to manifest students' subjectivity.

The expansion of instrumental rationality reduces students to a passive state governed by technology, hiding latent risks of superficial learning. In teaching and learning, students tend to directly seek standard answers through discursive interaction with intelligent systems. Excessive reliance on generative artificial intelligence may degrade learning processes that require in-depth analysis, critical innovation and self-exploration into simplistic, rapid knowledge Q&A. Instant information feedback from intelligent systems encourages students to neglect thorough analysis and internalization of theories. Under educational modes highly dependent on human-machine interaction, students' critical thinking, rational cognition construction and knowledge transfer capacities cannot be adequately cultivated, and students gradually lose learning initiative and independent knowledge construction abilities.

4. Practical paths of educational transformation driven by generative artificial intelligence

Promoting educational digitization constitutes a key task for accelerating the construction of a powerful country through education. Guided by practical problems, this paper shall unlock the potential of generative artificial intelligence in educational resource integration, educational content production, agenda-setting and

educational interpretation, facilitating innovative educational models empowered by generative artificial intelligence.

4.1. Improving institutional mechanisms for empowering high-quality educational development with digital intelligent technologies

The capabilities of generative artificial intelligence grow exponentially alongside technological advancement, and digital intelligent technologies represented by generative artificial intelligence have become vital driving forces for educational transformation. Faced with iterative updates of generative artificial intelligence, high-precision core technology research and development must be prioritized. The researchers must firmly grasp strategic initiative in technological development, advance high-performance computing and intelligent computing through the construction of computing power infrastructure. Relying on intelligent computing power and high-quality data resources, this study shall accelerate the research and development of general large models to achieve comprehensive leaps in generative artificial intelligence's complex language comprehension and generation, knowledge reasoning and multi-modal capacities. From the perspective of high-quality educational development, this study shall further construct and refine corpora and knowledge bases for generative artificial intelligence, strengthen algorithm model design and data training to satisfy the demands of digital educational development. Mastering initiative in technological research and development enables risk avoidance and ensures that technological research and application better serve educational undertakings.

Against the backdrop of the digital education strategy, relevant policies for educational reform shall be continuously improved, framing the promotion of educational model innovation as a core task of educational digitization. Organizational leadership for educational reform shall be strengthened, management systems and regulatory procedures shall be perfected, and innovative paths for generative artificial intelligence to empower educational practice shall be encouraged through exploration. Through policy support, incentive guidance and pilot construction, digital intelligent technologies can be introduced into classrooms to realize organic integration between generative artificial intelligence and educational processes.

4.2. Integrating educational resources via smart education platforms

In response to the trend of educational digitization, generative artificial intelligence can be systematically combined with cloud computing, big data, blockchain and other technologies to build integrated smart education platforms incorporating multiple technical elements. On the one hand, smart platforms serve as hubs for aggregating educational resources. Oriented toward society, they provide information resource services for all types of schools, institutions and individuals. Breaking barriers to information flow, smart platforms supply massive, diversified and real-time data information for generative artificial intelligence, hence their utilization shall be advanced to promote the integration of educational resources. During education, data acquisition, knowledge organization and teaching content design by generative artificial intelligence are situated within the digital space of platforms. Teachers and students can log into platforms to access valuable information and share educational resources. On the other hand, smart platforms consist of modular architectures, platform interfaces and standardized module rules, providing diverse application scenarios for the education sector. Smart platforms reconstruct all links of education to form a compact, intelligent operational workflow. Generative artificial intelligence can be connected to smart platforms to develop demonstration courses combining online and offline teaching. Leveraging the interconnected technical advantages of smart platforms, schools and teachers expand the scope of information communication in teaching and learning, enabling students nationwide to access high-quality boutique and demonstration courses.

4.3. Constructing sound educational fields within intelligent communication

Contextual setup and experiential learning constitute critical links for knowledge internalization, laying foundations for educational content to be fully absorbed, understood and applied by students. Teachers can rely on generative artificial intelligence to assist with contextual setup for teaching. On the one hand, in terms of teaching modes, generative artificial intelligence delivers new information communication media for teachers. Within educational practice, teachers utilize image narratives, textual narratives and interactive dialogue forms of generative artificial intelligence to exert the symbolic expressive functions of intelligent systems, enriching expressive forms of educational content and transforming abstract, flat educational materials into concrete, three-dimensional forms. On the other hand, educational content embedded with generative artificial intelligence adopts a presentation mode of "scenarios + media". Teachers can construct virtual-real integrated educational fields via digital content twin technology and AI-generated text, sound and image materials, enabling students to participate in discussions on social hot topics and role-playing activities. Virtual-real integrated educational fields strengthen the communication effect of "subjective reality", stimulate students' capacity to perceive and respond to knowledge, and help students transfer theoretical knowledge to real-life scenarios. In addition, new educational fields constructed by generative artificial intelligence take students' learning, living and growth as temporal and spatial dimensions. Breaking temporal and spatial constraints, educational practice extends to broader mobile spaces. Intelligent systems assist teachers and students in remote connections to enable information interaction at any time and location.

When educational content adopts the "scenarios + media" presentation mode of generative artificial intelligence, ensuring information authenticity is paramount. To prevent algorithmic bias and false information from disrupting educational ecology, algorithm governance for generative artificial intelligence shall be strengthened. At the source management stage, a sound legal and regulatory system shall be established, and a classified and hierarchical algorithm governance system shall be implemented. Algorithms shall be guided toward benevolent applications that uphold correct value orientations in educational services. At the process supervision stage, safety assessments and supervisory inspections shall be carried out, focusing evaluation on data sources, scale, annotation rules and algorithm mechanisms of generative artificial intelligence. To guarantee transparency in data sources, data content and data application throughout education, multi-stakeholder educational supervision bodies composed of government authorities, schools, teachers and parents can be established to review algorithmic programs. At the result control stage, sound disposal mechanisms for early warning, detection, tracing, identification and elimination of false information shall be perfected to ensure reliable information sources. For educational practice, multi-pronged information management and field purification are prioritized to safeguard standardized and effective educational fields.

4.4. Optimizing educational content based on digital intelligent decision-making

Throughout education, full play shall be given to the knowledge extraction and content generation capacities of generative artificial intelligence, promoting learners' internalization and construction of theoretical knowledge and value concepts embedded in educational content based on data-driven digital intelligent decision-making.

First, generative artificial intelligence shall be utilized to accurately set educational content. The design of teaching content must fully consider students' cognitive levels, psychological conditions and learning demands. Individual students differ in thinking capacities and behavioral patterns. The integration of generative artificial intelligence and big data enables precise output of educational content. Teachers can leverage generative artificial intelligence to conduct personalized analyses of each student's growth patterns, psychological demands and cognitive development processes, establishing individual multi-modal data models

to provide decision-making references for educational content design. Mastering students' comprehensive qualities and individual conditions via generative artificial intelligence enables educational content to better align with students' internal demands, realizing personalized and optimized production of educational content.

Second, the intelligent recognition and algorithmic recommendation functions of generative artificial intelligence shall be leveraged to set agendas focusing on core educational topics. Supported by data mining and data content comprehension capacities, generative artificial intelligence possesses sharp observation and guidance capabilities in educational content production. Teachers can utilize the agenda-setting functions of generative artificial intelligence to capture student learning interests and actively retrieve hot information related to educational content. After capturing hot information, intelligent systems push educational content to students via algorithmic recommendation. Emphasis placed by generative artificial intelligence on specific educational content draws students' attention, turning such materials into central educational topics and triggering active student interaction and in-depth reflection.

Since the application of generative artificial intelligence is associated with big data mining, algorithmic recommendation and other functions, intelligent systems may repeatedly reuse AI-generated data or trigger the Matthew effect in information distribution, leading to information narrowing. To address such risks, technical governance of generative artificial intelligence shall be strengthened. In terms of data supervision, prevention mechanisms for information cocoons formed by intelligent push shall be constructed, limiting the collection of student personal information to reasonable scopes of educational data utilization and avoiding mandatory selection of interest labels for targeted information push. In terms of technical supervision, technical specifications for generative artificial intelligence shall be formulated to mandate diversity and completeness of AI-generated content and prevent generative artificial intelligence from being dominated by single information sources. Strict technical regulation of generative artificial intelligence safeguards the objectivity and richness of educational content to deliver favorable educational outcomes.

4.5. Constructing an integrated "teacher—machine—student" educational community based on multi-dimensional subject-object relations

Under generative artificial intelligence, human-machine integration deepens, and computers embed themselves within the "teacher–student" subject-object relations. Faced with multi-dimensional educational subject-object relations, the researchers shall fully exploit the collaborative educational nurturing functions of human teachers and machine tutors to construct an integrated educational community of "teachers—machines—students".

Within educational practice, teachers occupy a leading position. On the one hand, proficiency in utilizing generative artificial intelligence constitutes an essential competency for teachers in the digital era. Teachers must continuously upgrade their teaching capacities and digital literacy, thoroughly understand the functions and mechanisms of generative artificial intelligence in empowering teaching and learning, and explore innovative teaching paths grounded in practical instruction. On the other hand, teachers must grasp an appropriate scale in applying generative artificial intelligence. The humanistic nature of education can only be manifested through teachers' care, instruction, communication and inspiration toward students. Therefore, teachers shall adapt to role transformations brought by embedded generative artificial intelligence, shifting their work focus from educational content organization and teaching process design to educational content interpretation and educational communication, devoting themselves to student guidance to foster comprehensive development of students' intelligence, literacy and personality. Teachers shall prioritize optimizing educational models to meet students' intellectual and value demands in education. During teaching,

teachers can further refine educational scenario construction to trigger student emotional resonance, stimulate creative thinking, and cultivate students' independent critical thinking and judgment capacities.

In the digital era, educational spheres have expanded from the real world to virtual spaces, and educational subjects composed solely of natural human beings sometimes fail to fully satisfy practical educational demands. Virtual digital humans generated by intelligent systems can assist teachers in supplying educational content. Supported by generative artificial intelligence, virtual teachers join human teachers as co-educational subjects to produce educational content through human-machine collaboration. The participation of virtual teachers broadens information communication channels for educational content and highlights the role of machine intelligence within the "teacher—machine—student" educational community. Meanwhile, generative artificial intelligence provides diverse application scenarios for digital human auxiliary teaching. Virtual teachers can be deployed for current affairs news broadcasting, launching teaching topics and explaining educational content. After inputting prompts defining educational content scope, logical connections and teaching objectives, generative artificial intelligence presents virtual teacher lecture images to deliver authentic teaching effects. Beyond conventional auxiliary teaching, digital humans support multilingual and sign language broadcasting, broadening the audience scope of educational content and bridging knowledge gaps among different student groups.

Constructing the integrated "teacher—machine—student" educational community requires strengthening communication between virtual spaces and the real world, promoting multi-dimensional interaction between students and human teachers, students and machine tutors, as well as students and peers, and expanding the public nature of education. The public nature of education serves as the communal bond linking teachers, machines and students organically. Today, generative artificial intelligence further transforms the one-way theoretical indoctrination mechanism of education. Equal, interactive communication modes are adopted among human teachers, machine tutors and students within generative artificial intelligence frameworks. While maintaining leading roles in education, teachers shall utilize generative artificial intelligence to inspire students through dialogue and questioning, granting students more opportunities for participation, interaction and expression. The collision and integration of viewpoints within the "teacher—machine—student" educational community not only mitigate the subjectivity crisis triggered by excessive expansion of instrumental rationality and reshape students' subjective value, but also deepen students' theoretical cognition and motivate them to pursue truth and engage in conscious exploratory practice.

5. Conclusion

Built upon big data, computing algorithms and deep learning, generative artificial intelligence achieves alignment with human thinking through learning from training models and massive datasets. Its technical characteristics create intrinsic connections between generative artificial intelligence and education, enabling mutual integration of the two. Generative artificial intelligence can directly intervene in learners' information exchange, theoretical internalization and practical application, embedding itself within the full educational process and upgrading information communication paradigms while reconstructing relational rules and real scenarios. Rooted in the mutual embedding mechanisms between digital intelligent technologies and educational transformation, exploring innovative paths for high-quality educational development through in-depth research on the principles of digital intelligent technologies will constitute a direction for further expansion and extension of research on educational digitization in the future.

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