

Human-Computer Collaborative Teaching: A Systematic Review from Theoretical Development to Educational Application

Weilin Huang, Xiuling Yan

Jiangxi Agricultural University, Nanchang Jiangxi, 330000, China

Abstract: Against the backdrop of generative artificial intelligence driving educational transformation, human-computer collaborative teaching has become an important development direction in education. This paper systematically reviews the research trajectory of human-computer collaboration in education: firstly, it clarifies the theoretical research on human-computer collaboration, including its origins, connotations, and theoretical foundations; secondly, it summarizes the practical teaching applications from the perspectives of innovative teaching models and the reshaping of teacher-student roles; thirdly, it deeply analyzes the challenges in data ethics, accountability boundaries, educational equity, and humanistic care, along with strategies to address them. Finally, based on a discussion of existing research, it proposes that future studies should strengthen interdisciplinary integration, conduct long-term empirical research, and build actionable ethical governance frameworks, providing a theoretical reference for subsequently establishing a safe, efficient, and human-centered human-computer collaborative educational ecosystem.

Keywords: Human-computer Collaboration; Generative Artificial Intelligence; Educational Applications.

1. Introduction

The rapid development of generative artificial intelligence worldwide is driving the human-computer relationship to shift from simple 'tool use' to deep 'collaborative cooperation,' bringing unprecedented opportunities to education and making human-computer collaborative teaching an important development direction in the education sector. This trend also aligns with the strategic direction of education in our country. The "Outline of the Plan for Building a Strong Education Nation (2024-2035)", issued by the Central Committee of the Communist Party of China and the State Council, emphasizes promoting the role of artificial intelligence in educational reform and integrating AI into all elements and processes of education and teaching[1]. At the same time, the "New Generation Artificial Intelligence Development Plan" indicates the accelerating trend of artificial intelligence development, showing new characteristics such as deep learning, cross-domain integration, and human-computer collaboration. 'Human-computer collaboration' is a branch of artificial intelligence that leverages both human and computer intelligence to create machine learning models[2], providing a new foundation for the mutually constructive development of human wisdom and computer intelligence in the future.

In an era of rapid technological advancement, the connection between human-computer collaboration and education is becoming increasingly close. Artificial intelligence education products are becoming more widespread, and research on the integration of human-computer collaboration and education is growing. Academia is not only concerned with how technology can enhance teaching efficiency, but has also begun to explore in depth how human-computer collaboration affects cognitive development, reshapes teacher-student roles, innovates teaching models, and the challenges that arise as a result. However, existing research is still in a rapidly growing exploratory stage, with scattered perspectives and a lack of

systematic review of core research directions, theoretical frameworks, and practical approaches. In this background, this paper aims to integrate and analyze the research context of 'human-computer collaboration' in the field of education, focusing on its conceptual evolution, the restructuring of teacher-student roles, teaching applications, and innovation in learning models. It seeks to clarify the current research focus, key findings, and potential challenges, with the goal of providing a reference for subsequent theoretical refinement and practical exploration.

2. Theoretical Research on Human-computer Collaboration

(1) The origin of human-computer collaboration

In short, Human-computer collaboration refers to the mutual cooperation between 'humans' and 'computer.' The term 'collaboration' in ancient Greek is translated as coordination, synchronization, and harmony[3]. The essence of this concept has gradually taken shape alongside the development of artificial intelligence technology, and its evolution process has closely paralleled that of AI. Tracing its intellectual origins, the concept of human-machine collaboration emerged during the Industrial Revolution, initially referring to humans operating machines to complete specific production tasks, with the goal of reducing human labor and improving efficiency. At this stage, humans were still the main actors in the 'human-computer' relationship, occupying a dominant position. With technological advancements, especially the advent of computers, the role of machines gradually expanded from merely replacing physical labor to supporting human thinking, perception, and decision-making. Intelligent entities represented by knowledge bases and expert systems subsequently emerged, enabling computers to reason and make judgments based on expert knowledge and experience, simulating the decision-making processes of human experts, thereby assisting in solving various complex problems. Based on this, the connotation of

human-computer collaboration has gradually shifted from early 'symbiosis' to 'cooperation.' As early as the initial stages of research on artificial neural networks and machine learning, scholars such as Yann LeCun began exploring the possibility of machines assisting human learning. In 1990, Qian Xuesen and his colleagues proposed the concept of "Integrated Engineering," essentially a highly intelligent human-computer interaction system[4]. This system integrates computer technology with expert knowledge and achieves collaboration through human-computer interaction, which can be seen as an early practical form of the "human-computer collaboration" concept. In 1994, Lu Yongxiang and Chen Ying firstly introduced the concept of a "human-computer system," emphasizing that humans and computers should collaborate to leverage their respective strengths in order to improve task completion efficiency. Their research further systematically compared and explored the collaborative relationship between humans and machines from three levels: thinking, perception, and execution[5]. Around the same time, American scholars D. B. Lenat and E. A. Feigenbaum also proposed similar views, advocating that computers and humans could be collaborative colleagues, each playing their respective roles to accomplish tasks together[6].

Subsequently, artificial intelligence technology has continued to develop and has gradually been applied in the education fields of various countries, beginning to be used in educational scenarios such as classroom teaching, personalized learning, examination and evaluation, educational management and decision-making [7]. In the 1920s, Sidney Pressey invented the first intelligent teaching machine capable of conducting automated assessment [8]. In 1958, Skinner Pressey firstly applied artificial intelligence technology to teaching and developed a programmatic teaching machine. This machine could not only store and present knowledge points but also have conversations with learners [9]. Subsequently, intelligent devices and systems such as computers gradually played a role in classroom teaching activities, promoting the emergence of human-computer collaborative education.

(2) The connotation of human-computer collaboration

Human-machine collaboration is not simply the sum of human and machine intelligence, but rather an integrated form of wisdom that combines both[10]. Domestic scholar Liu Buqing argues that a human-computer collaborative system consists of a computer and a human, among which the computer is responsible for data calculation and part of the reasoning work. Humans are responsible for tasks such as selection and decision-making that are beyond the capabilities of computers, exerting their creativity and flexibility. In human-computer collaborative systems, humans and computers closely collaborate and coordinate with each other [11]. Yang Canjun and Chen Ying et al. hold that human-computer collaboration refers to the situation where humans and machines each perform the tasks they are most proficient in, complementing each other's strengths, and jointly recognizing, perceiving, thinking, making decisions, working, understanding, restricting and supervising each other [12].

In the field of education, the concept of "human-computer collaboration" has undergone changes. The "machine" here has been constantly evolving with the development of The Times, from traditional teaching AIDS such as blackboards, chalk, and textbooks to the application of computer technologies like multimedia, hypertext, and network communication, and then to the emergence of intelligent

educational products represented by intelligent guidance systems and educational robots. The concept of "human-computer collaboration" in the field of education is divided into two levels. Firstly, the collaboration between humans and "computers". Traditionally, in "human-computer collaboration", the "machine" mostly refers to a "computer", which means that learners complete some low-level, monotonous and repetitive learning tasks by operating a computer [13], which is significantly different from the computer-assisted teaching adopted by teachers. Computer-assisted Teaching (CAT) is based on information technology to build a more flexible and interactive teaching platform, providing abundant resources and brand-new learning experiences, and helping to improve teaching quality and learning outcomes [14]. Human-computer collaboration focuses on leveraging the computing power of computers to assist learners in completing complex tasks that are beyond human cognitive scope or require a significant amount of human cognitive resources, thereby reducing the burden on learners, such as resource retrieval, assignment correction, text translation, and so on. Secondly, it is the collaboration between people and "intelligent products". With the development and gradual maturation of intelligent technology, the concept of "human-computer collaboration" has been continuously expanding, increasingly emphasizing the modeling, diagnosis and intervention roles of intelligent technology in learners' learning. It advocates the use of intelligent technology to optimize the learning environment, enhance learning efficiency, update learning services and refine learning content. Compared with human-computer interaction, which focuses on the process of information exchange between both parties through interaction [15], human-computer collaboration emphasizes helping learners complete complex learning tasks beyond learner wisdom and computer intelligence through collaborative work, dialogue and negotiation, and joint decision-making between learners and computers, driving the reconstruction of the intelligent learning ecosystem supported by human-computer collaboration.

(3) The theoretical basis of human-computer collaboration

After reviewing the origin and connotation of human-machine collaborative teaching, it becomes clear that its transformation from an industrial auxiliary tool to an intelligent collaborative partner is not merely due to breakthroughs in technical capabilities, but is more deeply supported and developed by a series of cognitive science and systems science theories. These theories provide a fundamental explanatory framework and design basis for how humans and AI can effectively divide labor, deeply integrate and co-evolve in teaching and learning. To deeply understand the research on the direction of human-computer collaborative teaching, theoretical origin tracing is an important perspective that cannot be ignored. Some researchers have pointed out that the theoretical basis of human-computer collaborative teaching mainly includes collaborative theory, distributed cognitive theory, information processing theory and embodied cognitive theory. Essentially, human-computer collaborative teaching is a collaborative process that operates systematically, processes and shares knowledge in a distributed manner, and has the characteristics of self-organizing and orderly development [3].

The theoretical basis of human-computer collaboration not only provides a reference for the design of teaching activities, but also plays an important role in guiding the rational

division of labor between humans and machines, promoting in-depth integration and efficient collaboration. Firstly, in the research based on the collaborative theory, it is advocated to use a unified perspective to rearrange disordered and independent systems according to certain rules, so that the functions of each part collaborate to form a comprehensive whole. From the perspective of collaborative theory, some scholars have conducted research on the design of human-computer collaborative teaching models, arguing that the basic characteristics of collaborative theory, such as system openness, dynamics, and purposefulness, are consistent with those that human-computer collaborative classroom teaching should possess [16]. Another scholar, Huang Jiang, utilized the collaborative theory to explore the framework and path for artificial intelligence to empower the construction of smart campuses [17].

Secondly, when human-computer collaborative teaching is regarded as a cognitive process, cognitive theory is an important research perspective. In human-computer collaborative teaching, complex mechanisms that are difficult to fully explain by traditional cognitive theories will be more suitable with distributed cognitive theories. Distributed cognitive theory is a theoretical paradigm for explaining cognitive phenomena. It holds that cognitive activities are widely distributed throughout the social environment and are realized through symbols, tools, and interpersonal interactions. The distributed cognitive theory holds that through the information flow in the interaction process, scattered cognitive subjects can be effectively integrated to form a cognitive system with overall functions. The distributed cognitive theory provides a solid theoretical foundation for the overall cognitive modeling of human-computer collaborative teaching. Many scholars have conducted research on human-computer collaboration based on the theory of distributed cognition. Guided by the theory of distributed cognition, it explores the path of human-computer collaborative education, innovatively implements five-dimensional optimization, and builds a new data-driven smart teaching ecosystem in the classroom [18]. And by applying distributed cognitive theory, conduct strategy research, practical research on mobile learning, and so on.

Finally, both the information processing theory and the embodied cognition theory are theories about cognition, which play an important guiding and explanatory role in guiding human-computer collaborative teaching. The relevant research mainly focuses on solving learning problems at different stages, improving teaching efficiency, and exploring effective strategies and practical paths.

In conclusion, the theoretical foundation of human-computer collaboration not only encompasses core perspectives such as collaboration theory, distributed cognition theory, information processing theory, and embodied cognition theory, but also includes other related theories like symbiosis theory, collectively forming an interdisciplinary and multi-level theoretical system. These theories reveal the complexity and integrity of human-computer collaboration in terms of structure, process and function from different dimensions such as system coordination, cognitive distribution, information processing and mind-body integration. With the continuous deepening of research, the theoretical framework of human-computer collaborative teaching will be constantly enriched and integrated, thereby providing more systematic and dynamic theoretical support for understanding the evolution of human-

computer relationships, optimizing the design of collaborative systems, and promoting the intelligent transformation of education.

3. Teaching Applications of Human-computer Collaboration

(1) Human-computer collaborative innovation teaching Model

At present, with the rapid development of generative artificial intelligence, the application research of human-computer collaboration in teaching is constantly deepening and expanding, gradually moving from theoretical exploration to multi-level and multi-form practical exploration. Research has not only accumulated rich case studies in areas such as classroom teaching, personalized learning, and teacher professional development, but has also conducted targeted explorations across different educational stages.

The current research on the human-computer collaborative teaching model presents a multi-path and multi-form exploration pattern, and a series of teaching practice models with different styles and structures have emerged. For instance, the "human-computer collaboration and dual-teacher classroom" teaching model integrates online intelligent teachers with offline physical teachers to build a teaching collaboration body that combines virtual and real elements [19]; The "human-computer collaboration and flipped classroom" teaching model relies on intelligent systems to enhance pre-class autonomous learning support and in-depth interaction in the classroom [20]; The "human-computer collaboration and hybrid" teaching model places greater emphasis on establishing a flexible and dynamic human-computer role allocation mechanism in the integrated online and offline environment [21]. In addition, there is a "human-computer collaboration and precision" teaching model centered on data-driven approaches [22]; The "human-computer collaboration and multimodal" teaching mode based on multimodal perception and interaction [23]. Although these models have different focuses, they all reflect the systematic transformation of human-computer collaboration from "auxiliary tools" to "structural elements of teaching", and also provide diverse practical paths for building smart teaching systems that adapt to different scenarios and target different goals.

In addition, scholars have adaptively innovated and restructured the human-computer collaborative teaching model based on the differences in learners' cognitive development laws and teaching goals at different educational stages such as higher education, vocational education, and basic education, making it better fit the teaching reality and educational requirements of each stage. In the higher education stage, scholar Cui Jing, under the background of human-computer collaboration, explored methods to enhance the personalized teaching effect of college English [24]. Researchers Hu Xin and others have proposed a human-computer collaborative teaching model for cultivating innovative practical abilities in response to a series of problems faced by students, such as the disconnection between theory and practice [25]. Some scholars, from the perspective of human-computer collaboration, have specifically studied the teaching mode of the digital media technology major and provided corresponding avoidance and response strategies [26]. In vocational education, relevant

research is more focused on a specific course or a specific major, emphasizing the practical effect of teaching models. For instance, there is a specific teaching model for the logistics major in secondary vocational schools, proposing a human-computer collaborative teaching model based on "AI and" [27]; The human-computer collaborative teaching mode of "teacher-student-computer" for the automotive major in higher vocational colleges aims to achieve the connection between personalized teaching and job capabilities [28]; And starting from the overall perspective of vocational education, it is proposed to construct a three-layer dynamic target ability map, create an integrated content ecosystem, and explore the human-computer dual-mentor teaching method [29]. In the field of basic education, the human-computer collaborative teaching model aims to cultivate students' thinking and abilities in all aspects. For instance, Ren Xujing et al. have developed a set of human-computer collaborative teaching models for primary school science that focus on the cultivation of scientific thinking [30]. There are also scholars who have constructed a human-computer collaborative teaching model of "teacher guidance - student exploration - intelligent study companion collaboration" [31], and so on.

Finally, in the process of exploring the human-computer collaborative teaching model, the role types and functional boundaries undertaken by the "machine" have gradually become important dimensions of the research. Based on different teaching scenarios and collaborative goals, scholars have classified artificial intelligence systems into role categories with differentiated functional positioning, such as "AI assistants", "AI teachers", and "AI study companions" for learners. These roles do not exist in isolation but rather undertake complementary and dynamic functions within the teaching system: "AI assistants" typically focus on instrumental support, such as information retrieval, homework correction, and learning reminders; "AI teachers" take on some of the responsibilities of teaching guidance and explanation, especially in large-scale educational scenarios, they can play a role in personalized explanation and feedback. The "AI Companion" program places more emphasis on emotional companionship, social interaction, and collaborative incentives to promote learners' continuous participation and cognitive engagement.

In conclusion, existing research has systematically sorted out and deeply explored the human-computer collaborative teaching model from multiple dimensions such as the diversity of model forms, the adaptability to different educational stages, and the role and functional positioning of intelligent tools, and has formed research systems with different focuses. These research directions are interrelated and complementary to each other, jointly outlining a complex picture of the human-computer collaborative teaching model, and also providing rich references for its theoretical improvement and practical optimization.

(2) Human-computer collaboration reshapes teacher-student relationships

With the continuous deepening of the application of human-computer collaboration in the field of education, the structure and role positioning of the traditional teacher-student relationship are undergoing significant reconstruction, and this phenomenon has become an important topic in current educational research. Existing relevant studies have pointed out that human-computer collaboration not only changes the organizational form of teaching activities, but also poses systematic challenges to the role connotations,

functional boundaries and interaction patterns of teachers and students.

In terms of the role of teachers, scholars generally believe that they are shifting from the traditional "knowledge transmitter" to "learning guide", "curriculum collaborator" and "designer of human-computer collaborative environment". Scholars Yue Xiaoyang and Zhao Chenyu have conducted research on the role evolution and capability reconstruction of teachers in human-computer collaborative teaching. They argue that teachers are transitioning from "content transmitters" to "learning designers and guides," from "technology users" to "technology enablers," from "one-way instructors" to "interactive collaborators," and from "experience accumulators" to "continuous learners and innovators"[32]. Some scholars, from the perspective of human-computer collaboration, have constructed a ternary structure model of "teacher - computer - student", establishing multiple role positioning of teachers as social responsibility demonstrators, ethical norm formulators, collaborative co-creation designers, teaching model innovators, and learning ecosystem leaders [33], thus achieving the transformation of teachers' roles. In addition to the above discussion on role positioning, scholars have also conducted a systematic study on the core competencies that teachers need in a human-computer collaborative environment from the perspective of professional ability development. For instance, some studies, based on the context of human-computer collaboration, have proposed that teachers need to develop a more diverse and efficient collaborative ability system [34]. Furthermore, from the perspective of practical paths, it is emphasized that teachers should shift from being "tool users" to "collaborative designers". They not only need to master the operational logic of intelligent technologies but also understand the cognitive mechanism of human-computer collaboration. Moreover, they should be able to flexibly design human-computer division of labor and interaction processes based on teaching objectives and student characteristics. These discussions on ability reconstruction and the research on role transformation form a mutual reflection of theory and practice, jointly outlining the new direction and new connotation of teachers' professional development in the digital intelligence era.

In a human-computer collaborative teaching environment, all participating entities exhibit clear functional division of labor and collaborative relationships: in the classroom field jointly constructed by teachers and intelligent systems, machines mainly handle procedural and standardized problems, while teachers focus on dealing with unstructured and highly complex teaching tasks. Students deeply integrate and collaborate with intelligent technologies to form a learning community, achieving the goals of knowledge construction and ability development. The transformation of these roles reflects the structured and hierarchical characteristics of human-computer collaboration in educational scenarios.

4. Challenges and Strategies for Human-computer Collaboration

(1) Data privacy and algorithmic ethics risks

In the human-computer collaborative teaching environment, multi-dimensional information such as learners' behavioral data, cognitive states, and emotional expressions is continuously collected and analyzed to support personalized teaching and intelligent decision-making.

However, the extensive collection and use of data have also raised concerns about privacy breaches and ethical issues. On the one hand, the data boundaries are ambiguous, and learners often do not fully understand or consent to the use of their data for algorithm training and teaching optimization. On the other hand, the algorithmic decision-making process usually exhibits a "black box" characteristic, with opaque reasoning logic, which may lead to the solidification of biases or discriminatory output. For instance, recommendation systems trained based on historical data may unintentionally reinforce gender, regional or cultural biases, affecting the fairness of educational resource allocation.

To address the above-mentioned risks, the academic community advocates the establishment of a hierarchical and classified protection mechanism for educational data, clearly defining the minimum necessary scope of data collection and usage rights, and adopting technologies such as privacy computing and federated learning to achieve "data available but not visible". Meanwhile, by developing explainable artificial intelligence tools, the transparency and credibility of algorithms can be enhanced, enabling teachers and students to understand and question the decision-making basis of intelligent systems, thereby establishing a trust-based collaborative relationship in human-computer collaboration.

(2) Blurred boundaries of human-computer responsibility

In the human-computer collaborative teaching model, teachers and intelligent systems jointly participate in teaching design, process implementation and learning evaluation, resulting in the gradual blurring of the responsible subjects. Especially in the processes of automated marking, student situation diagnosis, and course recommendation, once errors or deviations occur, it is difficult to clearly define the responsibility. For instance, an AI composition correction system may misjudge students' expressions due to insufficient training data, which could affect their academic evaluations. If an intelligent tutoring system provides guidance for incorrect problem-solving, it is still not clearly defined whether the teaching responsibility should be borne by the developer, the teacher or the system.

In response to this issue, some studies have attempted to establish a rights and responsibilities framework based on task types and risk levels, classifying teaching tasks into "mechanical execution type", "auxiliary decision-making type" and "fully autonomous type", and clearly defining the human-computer leading roles and responsibility boundaries respectively. Some research suggests implementing a "dual-subject accountability system" to clarify the responsible subjects. On the one hand, the responsibility of technical subjects should be limited; on the other hand, the responsibility of educators should be strengthened [35]. In addition, it is recommended to embed responsibility traceability and auditing functions in the system design, record the human-computer interaction logs of key decision-making nodes, and provide a basis for post-event assessment and responsibility determination. Teachers also need to, on the basis of receiving training, possess the ability to review and intervene in intelligent outputs, forming a collaborative mechanism of "human-computer-assisted, human-reviewed, machine-executed".

(3) Challenges to educational equity

The advancement of human-computer collaborative education relies on multiple conditions such as hardware facilities, network environment, and digital literacy, which may exacerbate the digital divide among different regions,

schools, and groups. Underdeveloped regions or schools with weak resources often encounter difficulties such as equipment shortages and insufficient teacher training, making it difficult to carry out in-depth human-computer collaborative teaching. Furthermore, if algorithms do not fully take into account the diverse backgrounds of students, they may invisibly marginalize certain cultural, linguistic or learning style groups, resulting in "technical exclusion". For instance, intelligent speech systems trained on mainstream language data have insufficient support for dialects or minority languages, which affects their teaching usability.

To promote educational equity, current research emphasizes the balanced allocation of infrastructure and systematic improvement of digital literacy, with a particular focus on investment in rural and remote areas. At the technical level, it is advocated to carry out "algorithmic fairness audits", reducing algorithmic discrimination through the training of diverse datasets, bias detection and correction mechanisms. At the same time, it is encouraged to develop lightweight intelligent educational tools with low thresholds and high adaptability, supporting multi-modal and multi-language interaction, to ensure that students from different backgrounds can all benefit from human-computer collaboration.

(4) Lack of humanistic care and emotional interaction

Education is not only a process of knowledge transmission, but also an interactive practice of emotional communication, value shaping and personality cultivation. Although current human-computer collaborative systems perform outstandingly in cognitive support, they still have obvious limitations in aspects such as emotion recognition, empathetic response, and value guidance. Excessive reliance on technology may lead to a reduction in interpersonal interaction between teachers and students as well as among students themselves, a weakening of emotional bonds, and even turn education into an isolated process of "human-computer dialogue". For instance, in fields such as moral education and mental health education that are highly dependent on emotional communication, AI is difficult to replace the emotional companionship and value guidance role of teachers.

To make up for this deficiency, the academic community has proposed strategies from two directions: Firstly, strengthen the core role of teachers in emotional education and personality cultivation, and clarify their positioning as emotional coordinators and value guides in the human-computer collaborative environment; Secondly, promote the application of affective computing and multimodal interaction technologies in education, and develop intelligent study companion systems with emotional recognition and adaptive response capabilities, enabling them to provide initial support in aspects such as learning motivation and emotional guidance. However, researchers also stress that technology can only serve as an aid, and the warmth and depth of education should still be based on genuine interpersonal connections and humanistic care.

5. Discussions

Human-computer collaborative teaching, as an important application of artificial intelligence in the field of education, is continuously expanding its research scope and depth. This article systematically reviews and comments on the research of human-computer collaborative teaching from multiple dimensions such as connotation evolution, theoretical basis,

teaching application, and challenges and strategies. At the connotative and theoretical levels, human-computer collaboration has evolved from the early concept of "tool assistance" to a "collaborative integration" paradigm that emphasizes the complementary advantages and mutual enhancement of human intelligence and machine intelligence. Its theoretical basis is rooted in multiple disciplines such as collaborative theory, distributed cognition, information processing theory and embodied cognition, which together form a framework for understanding how humans and machines achieve distributed processing and self-organizing development of knowledge through systematic interaction, providing a solid theoretical support for teaching practice. At the level of teaching application, research shows a trend of deepening from macro model construction to micro scenarios. Scholars have not only explored teaching models suitable for the characteristics of different school stages, but also innovatively combined them with existing models such as dual-teacher classrooms, flipped classrooms, and blended teaching. They have also meticulously discussed the functional positioning and integration paths of agents as assistants, teachers, or study companions in different roles. These practices indicate that human-computer collaboration is transforming from peripheral technological assistance to a core element in reshaping the structure of classroom teaching, the roles of teachers and students, and the learning ecosystem. However, behind the booming applications, a series of challenges and ethical risks are also increasingly prominent. Data privacy and algorithmic black boxes, blurred boundaries of human-computer rights and responsibilities, the potential intensification of educational equity due to uneven application of technology, as well as the lack of humanistic care that may result from excessive reliance on technology, have become the focus of academic attention and debate. The current research not only explores the existing risks and challenges, but also investigates technical and institutional response strategies for these risks. However, building a secure, trustworthy, fair and warm human-computer collaborative teaching ecosystem remains a subject that needs to be continuously tackled in the future.

Future research on human-computer collaborative education should expand new directions on the basis of deepening the existing paths. For instance, promote the in-depth integration of disciplines such as education and computer science, and build an integrated framework that can explain human-computer interaction, design reliable systems and avoid risks. Conduct long-term tracking empirical research, focusing on the continuous impact on students' cognitive development, social and emotional aspects, and teachers' professional growth; And establish an operational scenario-based ethical governance system, integrating data norms, algorithm auditing and responsibility mechanisms into the entire process of the education system and products to ensure that technological development is always people-oriented. In conclusion, human-computer collaboration is not merely the integration of technologies, but also a systematic reconstruction of educational concepts, structures and relationships. Future research needs to promote technological empowerment while always adhering to the humanistic essence of education. Through continuous theoretical reflection, practical innovation and ethical exploration, it aims to ultimately build a new smart education ecosystem that is people-oriented, human-computer symbiosis and collaborative progress.

References

- [1] Central Committee of the Communist Party of China, State Council. The Central Committee of the Communist Party of China and the State Council issued the "Education Power Construction Plan Outline (2024–2035)" [EB/OL]. (2025-01-19).http://www.moe.gov.cn/jyb_xxgk/moe_1777/moe_1778/202501/t20250119_1176193.html.
- [2] Li Weiming. Understanding Great Value, Eliminating Potential Threats—Teaching Strategies for the Development and Application of Artificial Intelligence Technology [J]. China Information Technology Education, 2022, (08):12-14.
- [3] Fang Haiguang, Kong Xinmei, Li Haiyun, Zheng Zhihong. Theoretical Research on Human-computer Collaborative Education in the Era of Artificial Intelligence [J]. Modern Educational Technology, 2022,32 (7) :5-13.
- [4] Qian Xuesen, Yu Jingyuan, Dai Ruwei. A New scientific Field: Open Complex Giant Systems and Their Methodology [J]. Nature, 1990 (1): 3-10+64.
- [5] Lu Yongxiang, Chen Ying. Human-computer Integrated Systems and Technologies - An Important Development Direction of Mechanical Science in the 21st Century [J]. Journal of Mechanical Engineering, 1994 (5): 1-7.
- [6] Lenat D B, Feigenbaum E A. On the Thresholds of Knowledge [J]. Artificial Intelligence, 1991, 47(1): 185-230.
- [7] Gao Tingting, Guo Jiong. A Review of Research on the Application of Artificial Intelligence in Education [J]. Modern Educational Technology, 2019, 29(01):11-17.
- [8] Watters A. Teaching machines: The history of personalized learning[M]. Cambridge; The MIT Press,2023.
- [9] Guo Jiong, Rong Gan, Hao Jianjiang. A Review of Research on the Application of Artificial Intelligence in Teaching Abroad [J]. Educational Technology Research, 2020,41 (02) : 91-98+107.
- [10] Liu Wei. Intelligence and Human-computer Fusion Intelligence [J]. Command Information System and Technology, 2018 (4) :1-7.
- [11] Liu Buqing. Philosophical Research on Human-computer Collaborative Systems [M]. Beijing: Guangming Daily Press, 2018.
- [12] Yang Canjun, Chen Ying. Research on Human-computer Integrated Collaborative Decision-making [J]. Systems Engineering Theory & Practice,2000,(5):24-29.
- [13] Yu Shengquan, Wang Qi. Analysis on the Development of the Collaborative Path of "AI+ Teachers" [J]. Educational Technology Research,2019,40(4):14-22+29.
- [14] Xu Jian. Application of Computer-Aided Design in Clothing Design Teaching in Higher Vocational Colleges [J]. Chemical Fiber and Textile Technology, 24,53(11):228-230.
- [15] Jiang Lei. A Comparative Study of the Terms "Human-Computer Interaction" and "Human-Intelligence Interaction" [J]. Chinese Terminology of Science and Technology, 26,28(01): 177-179.
- [16] Ma Youran. Research on the Design of Human-computer Collaborative Teaching Mode from the Perspective of Collaborative Theory [D]. Tianjin University,2021.
- [17] Huang Jiang, Li Rongqiang. Exploration of the Framework and Path of Artificial Intelligence Empowering Smart Campus Construction from the Perspective of Synergistic Theory [J]. Architecture and Culture,2025,(07):284-286.
- [18] Wang Yi. Five-dimensional Optimization: Exploration of Human-computer Collaborative Education Path under Distributed Cognitive Theory [J]. Information Technology

- Education in Primary and Secondary Schools, 2026, (01):19-22.
- [19] Wang Shichong, Fang Haiguang, Zhang Ge, Ma Tao. Research on the New "Dual-Teacher Classroom" Supported by Artificial Intelligence Educational Robots: Also, on the "Human-computer Collaboration" Teaching Design and Future Prospects [J] Journal of Distance Education, 2019, 37,(2): 25-32.
- [20] Duan Yaqing Research on Human-Computer Collaboration Facilitated by Flipped Classroom [J]. Computer Knowledge and Technology, 2020, 16(31): 211-212, 218.
- [21] Liu Yang The Dilemma and Optimization of Blended Teaching [J]. Teaching and Management, 2020(18): 104-106
- [22] Liang Yunzhen, Liu Ruixing, Ren Liling. Research on the Human-Computer Collaborative Precision Teaching Model for Cultivating Computational Thinking: A Case Study of the "Silk Road Challenge" in the Sixth Grade Information Technology Class of Primary School [J] Modern Educational Technology, 2022, 32 (3) :51-60.
- [23] Lu Jijian, Zhou Meimei, Zhang Xia, He Wanqing, Zhang Mingmin. Exploration of "Multimodal and Human-computer Collaboration" Teaching and Application Based on MR Experiment [J]. Journal of Distance Education, 2021, 39(6): 58-66.
- [24] Cui Jing Research on Personalized Teaching Mode of College English under Human-computer Collaboration [J]. Overseas English, 2025, (21): 118-120.
- [25] Hu Xin, Zhang Sulan, Duan Jiangli. Research on Human-computer Collaborative Teaching Mode for Cultivating Innovative Practical Ability in the Digital Intelligence Era: Taking Data Structure and Algorithm as an Example [J] Science, Education and Culture, 2025, (22): 124-128.
- [26] Zhu Lin, Liu Qin Qin, Chen Hongyun, et al. Reconstruction and Practice of Teaching Mode for Digital Media Technology Major from the Perspective of Human-Computer Collaboration [J]. Computer Knowledge and Technology, 2020, 21(36): 103-106.
- [27] Li Fengmei Research and Practice on the "Human-computer Collaboration" Teaching Mode of Secondary Vocational Logistics Major Based on "AI and" [J] China Logistics and Purchasing, 2025, (05): 106-107.
- [28] Sheng Zhiquan. Research on Human-computer Collaborative Teaching Mode for Automobile Specialty in Higher Vocational Education [J]. Automobile Maintenance and Repair, 2025, (23): 57-58.
- [29] CAI Dapeng, Ma Qingsong, Liu Wei. Exploration of Human-computer Collaborative Teaching Mode in Vocational Education from the Perspective of Artificial Intelligence [J]. Education and Occupation, 2026, (02): 80-87.
- [30] Ren Xujing, Zheng Yuwei. Research on the Human-computer Collaborative Teaching Model of Primary School Science Oriented to the Cultivation of Scientific Thinking [J]. Fujian Education, 2024, (53): 5-6+64.
- [31] Hou Yucheng The Human-computer Collaborative Teaching Model Driven by Generative AI: A Case Study of Primary School Art "Science and Fantasy" [C]// Interdisciplinary Science Education Specialized Committee of Beijing Interdisciplinary Science Society. A collection of Papers on Educational Reform and Future Prospects Driven by Interdisciplinary Sciences. Dongsi Seventh Primary School , 2025: 247-251.
- [32] Yue Xiaoyang, Zhao Chenyu. From "Experiential" to "Digital Intelligence": The Role Transformation and Capability Reconstruction of Teachers in Human-computer Collaborative Teaching [J]. Journal of Yibin University, 2026, 26(01): 99-109.
- [33] Ma Ning, Fan Benchao, Tang Qianhui. Teacher Role Transformation and Ability Enhancement from the Perspective of Human-computer Collaboration [J]. Research on Teacher Development, 2025, 9(02): 28-35.
- [34] Fang Haiguang, Zhao Enyu. Synergy and Empowerment: Application of Human-Computer Collaborative Classrooms and Reconstruction of Teachers' Human-Computer Collaborative Capabilities from the Perspective of University-Primary and Secondary School Cooperation [J] Beijing Education (General Education Edition), 2025, (12): 5-7.
- [35] Lin Xiaoguo. Innovative Opportunities, Practical Challenges and Countermeasures of Generative Artificial Intelligence Empowering Moral Education in Colleges and Universities [J] Journal of Multimedia and Network Teaching in China (Upper Edition), 2025, (11): 13-16.