Research on the Model Construction and Practical Pathways of Human-AI Collaborative Teaching in the Digital-Intelligent Era: From the Perspective of Teacher Adaptive Development

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Abstract: Amidst the profound reconstruction of the educational ecosystem by digital-intelligent technologies, teachers face dual challenges of role transition pains and technological adaptation crises. This study focuses on the core issue of "teachers' role adaptation and pedagogical innovation in human-AI collaborative teaching," integrating Social-Technical Systems (STS) theory with an ecological model of teacher professional development to reveal teachers' irreplaceable value as instructional designers, emotional connectors, and ethical guardians. Key findings include: Three predominant scenarios of human-AI collaborative teaching have emerged-intelligent diagnosis, virtual-physical inquiry, and generative collaboration, yet three critical adaptation gaps persist among teachers: weak technological integration capabilities, role identity anxiety, and deficient algorithmic ethics judgment; Fundamental conflicts stem from the tension between technological efficiency orientation and educational process values, manifested through AI's compression of student trial-and-error space and tool fragmentation undermining holistic education; Accordingly, a "Three-Phase Five-Dimension" collaborative model is proposed, adopting dynamic equilibrium principles to allocate responsibilities (AI handles standardized tasks while teachers lead value-rational domains) with embedded ethical review mechanisms; Teacher adaptation pathways are suggested: developing technological integration and interdisciplinary design capabilities at individual level; innovating virtual teaching communities and competition-incubation mechanisms at organizational level; and creating teacher-friendly interfaces at technological level. The study concludes that human-AI collaboration must center on teacher agency, advocating future trustworthy AI educational infrastructure and teacher ethical certification to build a "Humanities as Essence, Technology as Utility" educational ecosystem.

Keywords: Human-AI Collaborative Teaching; Teacher Role Transformation; Digital-intelligent Education; Educational Ethics; Adaptive Development

1. Research Background

Currently, artificial intelligence is profoundly reconstructing the educational ecosystem, driving the transformation of teaching from "standardized indoctrination" to "personalized cultivation." At the policy level, China's Ministry of Education Digital Empowerment Action Plan for Teacher Development (2025) explicitly proposes to "explore effective pathways for human-computer collaborative teaching" and identifies digital literacy as a core competency for teachers. Technologically, innovative applications such as large language models and multi-modal interaction have been implemented in both higher education and K-12 education.[1] However, current technology implementation still faces triple contradictions: capability gaps, role conflicts, and ethical risks.[2]

Within this context, this study focuses on "teachers' role transformation and pedagogical innovation for adapting to human-computer collaborative environments in the digital-intelligent era." This research aims to transcend the limitations of the "technological instrumentalism" perspective, construct a "technology-teacher-student" triadic interaction model, and reveal teachers' irreplaceable roles in emotional connection and ethical guardianship within human-computer collaboration. This will enrich the theoretical framework of digital-intelligent education while providing an actionable framework for teachers' adaptive development. Ultimately, it seeks to alleviate the pains of teacher transformation and advance education from "machine replacement" to "human-computer symbiosis."

2. Industry Status and Research Framework

2.1 Core Characteristics of Digital-Intelligent Teaching Environments

Current digital-intelligent teaching environments exhibit dual characteristics of deepened technological empowerment and increasingly visible ethical risks. From the technological dimension, AI has evolved from an auxiliary tool to a core component of teaching systems. Domestic practices include Shenzhen Luohu District schools' "New-Quality Classroom" digital interactive system, which constructs a virtual-physical integrated space through smart interactive walls, VR/AR devices, and sensors. Meanwhile, Heze Information Engineering School leverages the DeepSeek-R1 large model to achieve full-process intelligent "lesson preparation-diagnosis-evaluation," serving over 5,000 teachers and students daily.(https://heze.dzwww.com/news/202507/t20250716_16220679.htm) Further international studies demonstrate that generative AI can dynamically create personalized learning pathways, shifting pedagogy from "standardized instruction" to "cognitive difference adaptation."[3] However, from an ethical perspective, technological applications raise concerns about algorithmic black boxes[4] and data privacy. The year 2025 witnessed a surge in global education data breaches, while algorithmic biases may lead to inequitable outcomes. This disjunction between technological intentionality and educational intentionality underscores the fundamental contradiction of lacking humanistic care in intelligent tools.

2.2 Theoretical Framework Construction

Guided by the perspective of teacher adaptability, this study synergistically integrates contextualized cultivation with ethical governance to construct the Social-technical Systems (STS) Theory [5] and the Teacher Professional Development Ecosystem Model. Within the framework of STS, it reveals the triadic interaction mechanism of "technology-teacher-student," wherein the technological subsystem (e.g., AI teaching assistants) must serve the objectives of the educational subsystem (e.g., creativity cultivation), while teachers, as the core of the organizational subsystem, must reconcile the contradictions between technological empowerment and educational essence. Regarding the Teacher Professional Development Ecosystem Model, it establishes a three-tiered interconnected system comprising the policy-driven layer (e.g., teacher digital literacy standards), the technology-supported layer (e.g., "AI + Psychological Education" platforms), and the school-based practice layer (e.g., modular classrooms).

3. Current Practices and Challenges in Human-Computer Collaborative Teaching

3.1 Penetration of Representative Application Scenarios

Current human-computer collaborative teaching has developed three representative scenarios, each characterized by distinct technological logic and teacher role transformations, as outlined below (Table 1)

Specifically, the intelligent diagnosis scenario relies on dynamic knowledge graphs to achieve precise learning intervention. For example, Tianjin University of Finance and Economics has established a "teacher-student-machine" collaborative model, training an intelligent agent matrix with real-world industry data to address the pain points in new liberal arts practical teaching of "difficult case implementation and challenging outcome evaluation," transforming teachers' roles from experience-driven to data-based personalized solution designers.

The virtual-real integration scenario bridges the theory-practice gap through digital twin technology. Chengdu's pilot project integrates AI into engineering education by creating scenarios such as virtual tax offices and logistics sand tables, requiring teachers to reconstruct the "problem chain-resource chain-evaluation chain" to guide students through the competency transition from "cognitive execution to risk decision-making."

The generative collaboration scenario highlights human-machine complementary innovation. For instance, teachers in Shanghai's Hongkou District independently developed educational intelligent agents, using AI to adapt the "Ballad of Mulan" into classroom plays in Chinese literature classes, transforming teachers' roles from knowledge lecturers to "creative curators" who filter AI-generated content and guide students in critical reconstruction.

Table 1. Typical Scenarios and Role Transformations in Human-Computer Collaborative Teaching

Scenario Type	Representative Case	Teacher Role Transformation	Core Technological Empowerment
Intelligent Diagnosis and Tiered Instruction	Tianjin University of Finance and Economics "Agent Matrix"	Data-Driven Decision Maker	Industry Data-Driven Personalized Learning Pathways
Virtual-Real Integrated Inquiry Learning	Chengdu Basic Education AI Pilot "AI + Engineering Education"	Scenario Designer	VR/AR-Constructed Interdisciplinary Practice Field
Generative Task Collaboration	Shanghai Hongkou District HEADS System Customized Agents	Collaborative Facilitator	Natural Language Interaction-Enabled Creative Generation

3.2 Three-Dimensional Characterization of Teacher Adaptability Gaps and Underlying Contradictions

Despite significant scenario innovations, structural discontinuities persist in teacher competencies and role transformation, primarily manifested as weak technology integration capacity,[6] role identity anxiety, and deficient ethical judgment (Table 2).

Table 2. Core Issues in Teacher Adaptive Development

Issue Dimension	Key Data
Weak Technology Integration Capacity	Difficulty in Independent Development; Limited Systematic AI Training in Vocational Education
Role Identity Anxiety	Concerns About Algorithmic Impact on Creativity; Teachers Experience Occupational Burnout Due to Relinquished Instructional Autonomy
Deficient Ethical Judgment	Educational data breach incidents show increasing trends; Lack of Algorithmic Transparency Training

The root causes of these gaps lie in three structural contradictions. First is the conflict between efficiency orientation and process value: AI pursues standardized output and immediate feedback, while education inherently requires fault-tolerant exploration. For example, generative AI can rapidly produce teaching plans, yet it compresses students' reflection and innovation space. Second is the disconnection between technological silos and holistic education: the core manifestation is that fragmented functionalities of intelligent tools hinder comprehensive student development. In specialized teaching, while AI assistants excel at process optimization, they struggle to integrate "quality chains and competency chains," resulting in misalignment between technological systems and educational objectives. Third is the mismatch between developer mindset and user capabilities: policies promote teacher participation in agent development, yet frontline teachers generally lack skills in prompt engineering and ethical review. Therefore, human-computer collaboration is not merely a tool upgrade, but rather an ecological reconstruction of educational paradigms.

4. Construction of Human-Computer Collaborative Teaching Models

4.1 Design Principles: Dynamic Equilibrium and Ethical Embedding

The human-computer collaborative model must resolve the fundamental contradiction between "technological efficiency" and "educational value" by establishing two core principles. The first is the dynamic equilibrium principle: delineating human-computer responsibilities based on task attributes. AI assumes standardized, highly repetitive tasks, thereby freeing teachers to focus on value-rational domains—emotional connection, creative thinking stimulation, and interdisciplinary integration. The second is the ethical embedding principle: incorporating ethical rules into the technical architecture. In accordance with the Ministry of Education's "Digital Empowerment Action for Teacher Development" requirements, an algorithmic transparency review mechanism must be established (including traceable data sources, visible decision logic, and bias correction pathways) to prevent data misuse and algorithmic bias at their source.[7]

4.2 "Three-Stage Five-Dimension" Model Framework

Building upon STS Theory and centering on teacher role transformation, a "Three-Stage Teacher Capability Evolution × Two-Dimension AI Function Empowerment" collaborative framework (Figure 1) is constructed.

The five dimensions are instructional design, emotional connection, ethical governance, process automation, and cognitive expansion.

The instructional design dimension refers to teachers integrating AI-generated content to design interdisciplinary tasks; the emotional connection dimension means teachers identifying non-verbal signals that AI cannot capture (such as anxious emotions) and dynamically adjusting teaching pace; the ethical governance dimension involves teachers reviewing algorithmic biases (such as gender discrimination); the process automation dimension denotes AI completing repetitive work (such as automatically grading programming assignments); the cognitive expansion dimension indicates AI generating virtual experimental environments to expand students' thinking boundaries.

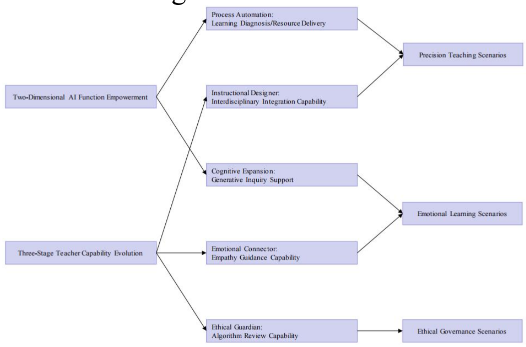

Figure 1. The Three-Stage Five-Dimension Collaborative Framework

4.3 Discipline-Specific Application Pathways

The Three-Stage Five-Dimension collaborative framework can undergo differentiated adaptations according to disciplinary knowledge characteristics across various subject scenarios (Table 3).

Table 3. Differentiated Adjustments of Collaborative Practices in Disciplinary Scenarios

Discipline Type	Instructional Design Dimension	Emotional/Ethical Dimension	AI Functional Dimension
Science & Engineering	AI Simulation + Physical Experiments	Monitoring virtual experiment safety ethics Intervening in student frustration	Process automation: Real-time experiment data feedback Cognitive expansion: Generating dynamic molecular structure models
Humanities	AI Text Generation	Reviewing cultural biases Facilitating empathetic discussions	Process automation: Classical Chinese knowledge point delivery Cognitive expansion: VR reconstruction of Han Dynasty market scenes

This model provides teachers with a systematic framework of "role transformation-capacity rebuilding-ethical practice," which subsequently requires school-based adaptation to enhance its universality. Teachers' adaptive development in human-computer collaborative environments must transcend the singular dimension of "technical operation training" to construct a synergistic framework of "capacity rebuilding—ecological support—technological empowerment."

5. Teacher Adaptive Development Pathways

Teachers' adaptive development in human-computer collaborative environments must transcend the singular dimension of "technical operation training" to construct a synergistic framework of "capacity rebuilding—system support—technological empowerment." This framework aligns closely with the trinity requirements of "standards guidance, mechanism empowerment, and practical innovation" proposed in the "Digital Empowerment Action for Teacher Development." Against the backdrop of current educational digital transformation, teacher professional development faces unprecedented opportunities and challenges. Traditional technical training models can no longer meet the demands of human-computer collaborative teaching, necessitating the establishment of a more systematic and multidimensional support system. This synergistic framework focuses not only on enhancing individual teacher capabilities but also emphasizes the coordinated advancement of organizational institutional safeguards and technological environment optimization, forming a virtuous ecosystem that promotes teacher professional development.

5.1 Individual Level: Dual-Core Driven Capacity Rebuilding

At the individual capability development dimension, teachers' roles must transform from traditional tool users to modern educational intelligence architects. This transformation requires focused cultivation of two core competencies:

First is technological integration capability. Teachers need to master key skills for "AI-pedagogical" adaptation, including but not limited to: intelligent teaching tool selection and evaluation capabilities, discipline-specific adaptation skills for general AI technologies, and technological implementation abilities for teaching scenarios. Specifically, mathematics teachers may need to master the combined application of geometric sketchpads and AI algorithms, while Chinese language teachers must become proficient in using natural language processing technologies for automated essay grading. This professionalized technological integration capability forms the core guarantee for transforming general technologies into effective teaching tools.

Second is interdisciplinary design capability. Under the human-computer collaborative education philosophy, teachers must break through single-discipline thinking and develop curriculum design abilities that integrate multidisciplinary knowledge and technological elements.[8] For example, developing an "AI + Classical Poetry Creation" course requires synthesizing knowledge from literature, information technology, and artistic design fields; designing a "Robot Ethics" course necessitates integrating perspectives from engineering, philosophy, and sociology.[9] This interdisciplinary capability demands not only expanded knowledge breadth but also fundamental shifts in pedagogical thinking modes.

To support teacher capacity rebuilding, national-level supporting mechanisms must be established: reforming teacher education curricula to incorporate digital education as compulsory modules; improving teacher training systems by adding specialized programs in AI educational applications and interdisciplinary teaching design; implementing teacher digital competency certification systems to promote capability standard adoption. Simultaneously, local governments and schools must provide ongoing professional development opportunities through capacity-building activities such as workshops and advanced study programs.

5.2 Organizational Level: Three-Dimensional Innovation in System Support

School organizations need to provide comprehensive support systems for teachers to overcome the developmental dilemma of "isolated combat," with focused advancement in three innovative dimensions:

The first dimension involves constructing virtual collaboration platforms. Establishing cross-school "virtual teaching research offices" to build shared resource libraries containing instructional design cases, technology application exemplars, and assessment tools. For instance, a provincial education department's "AI Teaching Innovation Platform" has aggregated over 2,000 high-quality cases, supporting teachers' online collaborative course development. The platform also features expert guidance modules providing real-time professional support.

The second dimension cultivates competition incubation mechanisms. Through organizing events like AI Teaching Innovation Competitions and Digital Teaching Case Evaluations, these activities promote learning through competition and research through competition. Competition designs should emphasize practical orientation, featuring themes such as "Intelligent Diagnostic Teaching Plan Design"[10] and "Interdisciplinary Project-Based Learning Implementation" to guide teachers in translating theory into practice. Award-winning projects will receive incubation support to facilitate the application and promotion of their outcomes.

The third dimension refines evaluation mechanisms. Incorporating teachers' digital literacy into qualification certification and professional title evaluation systems, with established operational assessment indicators. For example, adding dimensions like "Technology-Integrated Teaching Capability" and "Digital Resource Development Capability" to teacher evaluations, accompanied by detailed scoring criteria. Simultaneously establishing developmental evaluation mechanisms that focus on the dynamic process of teachers' professional growth.

These three dimensions of support systems interconnect and interact synergistically, collectively constructing an organizational environment that promotes teacher professional development. School management needs to formulate supporting policies to provide institutional guarantees and resource support for system implementation.

5.3 Technological Level: Dual-Directional Adaptation of Human-Centered Design

The design of technological systems must center on teachers' needs to achieve "empowerment rather than burden-increasing" dual-directional adaptation:

On one hand, optimize the usability of technological tools. Develop low-code or even no-code educational specialized tools, such as visual programming courseware creation systems and voice-interactive intelligent lesson preparation assistants, significantly reducing technological usage barriers. Simultaneously, promote natural language programming tools that allow teachers to customize subject-specific intelligent agents using everyday language instructions, for example: "Create a math teaching assistant capable of automatically grading geometry proofs."

On the other hand, improve developmental resource provision. Based on the National Education Big Data Center, construct a teacher digital profile system to accurately analyze teachers' developmental needs. According to profile results, intelligently push modular learning resources such as "intelligent diagnostic teaching" and "interdisciplinary curriculum design." The system should also establish teacher growth portfolios to track professional development trajectories and provide personalized recommendations.

The key to this dual-directional adaptation lies in: technological design must deeply understand teachers' working scenarios and cognitive characteristics, avoiding "technology-centric" design approaches. Development teams should comprise diverse combinations of educational experts, frontline teachers, and technical personnel to ensure educational suitability of products. Concurrently, establish continuous feedback and optimization mechanisms to iteratively upgrade technological tools based on teachers' usage experiences.

In summary, this developmental pathway promotes teachers' role transition from "passive adapters" to "human-computer collaborative leaders" through the synergistic effects of "capability enhancement—institutional support—technological burden reduction." These three levels mutually reinforce and organically unify: individual capability forms the foundation, system support provides the safeguard, and technological empowerment serves as the means. Only through coordinated advancement of all three can we truly establish a solid human resource foundation for implementing educational digitalization strategies and facilitate the realization of educational modernization objectives. Moving forward, continuous improvement of relevant policies, optimization of implementation pathways, and establishment of more scientific teacher digital capability development systems remain necessary.

6. Conclusions

The essence of human-computer collaborative teaching lies in "teacher-led technological empowerment," with its core value manifested in two aspects. First is role irreplaceability: Teachers' functions as instructional designers (e.g., developing interdisciplinary task chains), emotional connectors (e.g., intervening in technology anxiety), and ethical guardians (e.g., reviewing algorithmic biases) cannot be substituted by AI. Second is the dynamic equilibrium pathway: The "Three-Stage Five-Dimension" model clarifies responsibility boundaries (AI handles standardized tasks while teachers lead value-rational domains), resolving the conflict between technological efficiency and educational essence.

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