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Digital Intelligence Drives the Generation of New Quality Literacy: Constructing a Value-Added Evaluation System for University Teachers' Deep Learning from a Complex Systems Perspective

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Abstract: In response to the national strategy of integrated development of education, science, and technology, and talent, this study addresses the critical need to transform university teacher development from traditional "instrumental training" toward cultivating "new-quality competencies" aligned with new-quality productive forces. Grounded in complex systems theory, this research proposes a novel Deep Learning Value-Added Evaluation (D-VAE) framework to bridge theoretical and methodological gaps in defining and measuring teachers' deep learning and competency growth. The study defines university teachers' new-quality competencies as a five-dimensional structure comprising High-Consciousness Learning, AI Symbiosis, Transdisciplinary Integration, Pedagogical Innovation, and Ethical Responsibility. Methodologically, the study constructed a multi-layered D-VAE model integrating input, process, output, value-added, and contextual dimensions, supported by a 5×3×45 indicator cube with explicit data sources, calculation rules, and ethical review mechanisms. Utilizing longitudinal equating and hierarchical linear modeling, the framework enables full-chain estimation of teacher competency growth and teacher–student synergistic value-added. This research contributes theoretically by translating policy discourse into a measurable educational construct and offers a replicable system-level solution for teacher evaluation, promoting the transition from performance accountability to public good governance in higher education.

Keywords: Digital intelligence; New quality literacy; Deep learning; Value-added evaluation; Complex systems

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1. Introduction: Paradigm shifts in the professional development of university teachers in the digital intelligence era

1.1. Problem statement: From "instrumental training "to the "cultivation of new-quality competencies"

The report to the 20th National Congress of the Communist Party of China firstly proposed the integrated

planning of "education, science and technology, and talent", emphasizing that higher education should align with the development of new-quality productive forces and take the lead in digital transformation. New-quality productive forces are characterized by "human–machine integration, digital–physical symbiosis, intelligent interaction, and foundational breakthroughs", among which teachers with interdisciplinary innovation capabilities and ethical governance awareness represent the most dynamic variable [1]. However, traditional university teacher development programs remain at the level of "instrumental training", primarily manifested in the following ways: a focus on the accumulation of isolated skills while neglecting systemic competency development; an emphasis on horizontal performance comparisons rather than longitudinal value-added evidence; and a prioritization of external accountability over the stimulation of intrinsic motivation. Consequently, issues such as the "digital divide", "ethical risks", and "evaluation distortions" have become critical bottlenecks hindering the high-quality development of higher education [2].

International research indicates that teacher professional learning is undergoing a paradigm reconstruction centered on "deep learning–practical wisdom–collaborative value creation" [3]. Deep learning emphasizes teachers' knowledge creation and value generation through the integration of cognitive, metacognitive, affective, and interactive dimensions in authentic contexts [4]. However, three major research gaps persist: First, at the conceptual level, few studies define the structural boundaries and philosophical foundations of "new-quality competencies" for university teachers within the discourse of new-quality productive forces. Second, at the methodological level, there is a lack of causal models that capture the complete evidence chain of "teacher learning input–deep learning process–new-quality competency output–teacher–student collaborative value creation. Third, at the evaluation level, longitudinal value-added frameworks have primarily been applied in basic education, while the complexity, disciplinary heterogeneity, and digital–intelligent contextual factors of higher education remain significantly underestimated [5]. Therefore, there is an urgent need to develop an indicator system and theoretical model for "Deep Learning Value-Added Evaluation (D-VAE)" for university teachers, addressing the strategic demands of the "Education Power" initiative for a new paradigm in teacher development.

1.2. Theoretical gaps: Disconnections among new-quality competencies, deep learning, and value-added evaluation

1.2.1. Research on new-quality competencies: Conceptual borrowing and contextual absence

The term "new-quality competencies" originates from the policy discourse on "new-quality productive forces" but lacks a rigorous definition from an educational perspective. Existing digital competency frameworks (e.g., DigCompEdu, HL-DigiEdu, and industry standards for teachers' digital literacy) predominantly focus on "technical operation-resource integration-instructional optimization" dimensions, paying insufficient attention to "human-machine collaborative creation", "ethical governance responsibilities", and "cross-cultural-cross-disciplinary integration." Moreover, they lack a unified philosophical–scientific framework grounded in the context of China's higher education system.

1.2.2. Research on deep learning: Student orientation and teacher absence

While the learning sciences have extensively explored deep learning, most studies focus on K–12 students, offering limited insights into the unique aspects of university teachers' "professional deep learning"—such as advanced disciplinary knowledge, complex teaching contexts, and multiple roles in research, teaching, and

service. Furthermore, the causal mechanisms through which teachers' deep learning contributes to multi-level collaborative value creation for the "self–student–institution" remain a black box.

1.2.3. Research on value-added evaluation: Misalignment between basic and higher education

Value-added evaluation has been incorporated into teacher performance accountability systems in countries like the United States and the United Kingdom. However, these models largely rely on standardized tests, suffering from simplistic indicators, disciplinary limitations, and significant ethical controversies. Domestic research also concentrates on academic achievement in basic education, lacking tailored indicators for higher education's "complex outcomes" (e.g., interdisciplinary innovation capability, research-to-teaching translation, and ethical collaborative governance) and failing to integrate multimodal data from digital–intelligent scenarios [6].

2. Theoretical framework: A complexity model of university teacher deep learning oriented by new-quality competencies

2.1. Philosophical foundation: Metaphors of teacher learning from a complex systems perspective

2.1.1. Ontological turn: From "entity—attribute" to "relation—emergence"

Traditional teacher development research treats competencies as static attribute sets, neglecting their "generative" and "context-dependent" nature [7]. Complex systems theory emphasizes that teacher learning is an emergent process coupled across "multi-agent–multi-level–multi-timescale" dimensions: at the micro-level, interactions among cognition, emotion, and technology produce nonlinear fluctuations; at the meso-level, tasks related to teaching, research, and social service form attractors; at the macro-level, institutional systems, disciplinary cultures, and policy orientations constitute external control parameters. Therefore, new-quality competencies are not merely "additive modules" but new qualitative states emerging from the system's cycle of "digital–intelligent input–deep learning–feedback iteration."

2.1.2. Epistemological reconstruction: From "representational acquisition" to "participatory generation"

Representationalist epistemology views learning as knowledge "transfer", reducing teachers to "information transmitters" [8]. The sociocultural–material turn argues that teachers and digital–intelligent technologies form "heterogeneous networks", where competencies are generated through continuous negotiation among "human–technology–context." University teachers' disciplinary knowledge, teaching contexts, and AI tools form a "cognitive ecology", where their deep learning is "participatory generation" rather than "isolated acquisition."

2.1.3. Axiological dimension elevation: From "performance accountability "to "public good"

Within the discourse of new-quality productive forces, the ultimate value of university teacher learning is not merely performance enhancement but cultivating new-quality talent with global competitiveness and ethical responsibility, thereby realizing sustainable "individual–disciplinary–societal" public good [9]. Public good refers to goods or services that are non-excludable and non-rivalrous, meaning no one can be excluded from using them, and one person's use does not diminish another's. In education, public goods can be manifested through high-quality educational services that enhance societal human capital and promote sustainable development [10]. Consequently, value-added evaluation must transcend unidimensional indicators like "scores–publications" and

incorporate long-term effects such as "teacher–student collaborative value-added" and "contributions to ethical governance" to achieve the goal of education as a public good.

2.2. Conceptual generation: The five-dimensional structure of university teachers' "new-quality competencies"

Based on triangulation among policy discourse, international frameworks, and the local context, this study defines university teachers' new-quality competencies as "a composite capability system for teachers in the digital–intelligence era to utilize high-consciousness learning, transdisciplinary integration, and ethical governance to promote synergistic innovation among individuals, students, and disciplines", detailed into the following five dimensions:

High-Consciousness Learning (HCL): Refers to teachers maintaining metacognitive awareness of the "unknown–known" continuum, possessing sixfold consciousness (vision, problem, creation, collaboration, critique, and value), and autonomously setting learning goals and iterating strategies amidst rapid technological change.

AI Symbiosis (AIS): Emphasizes teachers forming "complementary–mutually reinforcing–co-evolutionary" relationships with generative AI: capable of leveraging large models for higher-order cognitive tasks while critically correcting algorithmic biases and data ethics, achieving integrated innovation of "human intelligence + machine intelligence."

Transdisciplinary Integration (TDI): Facing complex real-world problems, teachers can transcend disciplinary boundaries, integrate knowledge, methods, and cultural perspectives to develop innovative curricula like STEAM and sustainability education, cultivating students' systems thinking and ability to tackle wicked problems.

Pedagogical Innovation (PI): Designing integrated "learning–research–service" teaching models in digital–intelligent environments, utilizing technologies like learning analytics, XR, and digital twins to reinvent personalized, inquiry-based, and service-learning processes.

Ethical Responsibility (ER): Encompasses data ethics, algorithmic justice, privacy protection, and sustainable digital governance. Teachers embed ethical considerations throughout the entire process of instructional design, research activities, and social service, guiding students to form values oriented towards "technology for good."

2.3. Process mechanism: The "four-dimensional coupling" spiral of deep learning

Cognitive Dimension: Teachers engage in conceptual reorganization and model construction based on disciplinary frontiers and teaching problems, using knowledge graphs and generative AI, forming a "deep understanding–knowledge creation" loop.

Metacognitive Dimension: Utilizing learning dashboards to monitor teaching effectiveness in real-time, employing "prediction–monitoring–evaluation" cycles to adjust strategies, and achieving self-directed learning.

Affective Dimension: Activating teachers' professional well-being and sense of mission through digital badges, peer assessment, and narrative reflection, reducing technological anxiety and burnout risks.

Interactive Dimension: Within the "human–technology–context" network, teachers engage in multimodal interactions with AI, students, and colleagues: co-planning lessons with AI, co-creating knowledge with students, and sharing data with peers, promoting the emergence of distributed cognition.

These four dimensions are mutually coupled, forming a "Digital–Intelligent Deep Learning Spiral": each cycle re-embeds new-quality competencies at a higher level, creating a "stepped–leaping" growth trajectory.

2.4. Value-added logic: The "dual-level emergence" of teacher–student synergy

Traditional value-added evaluation focuses on the unidirectional causality of "teacher → student", neglecting the reverse effect of" "student → teacher" and the contextual effects of "institution–discipline." This study proposes a "dual-level emergence" logic: Level 1 (Micro): Teacher deep learning → Enhancement of new-quality competencies → Improvement of teaching practice → Value-added in student academic achievement and core competencies. Level 2 (Macro): Student value-added feedback → Enhancement of teacher emotion and efficacy → Further stimulation of deep learning engagement → Emergence of institutional innovation ecosystems. The two levels are coupled through a "data–evidence–improvement" closed loop, achieving "individual–organizational" synergistic value-added. This synergistic value-added not only enhances individual and organizational effectiveness but also provides a public good for society by promoting overall social progress and sustainable development through the high-quality development of education.

3. D-VAE indicator system and model construction: An evidence-based framework for digital–intelligent enabled deep learning value-added evaluation of university teachers

3.1. Theoretical model: The D-VAE complexity framework

Integrating the above dimensions, the "Digital–Intelligent Enabled Deep Learning Value-Added Evaluation (D-VAE)" theoretical model is constructed, comprising: (1) Input Layer: Innate competencies, digital–intelligent foundation, ethical baseline. (2) Process Layer: Four-dimensional deep learning (cognitive, metacognitive, affective, interactive). (3) Output Layer: Five-dimensional structure of new-quality competencies. (4) Value-Added Layer: Value-added in teacher new-quality competencies, value-added in student core competencies. (5) Context Layer: Institutional digital governance, disciplinary culture, policy control. The model, characterized by the complex system features of "non-linearity, feedback, emergence", provides a conceptual blueprint for the subsequent indicator system and multilevel linear modeling.

3.2. Indicator system architecture

Table 1 presents the D-VAE indicator cube: 5 first-level dimensions, 15 second-level sub-dimensions, 45 third-level observation points. Each observation point is equipped with three elements: "data source–calculation rule–ethics review", achieving the integration of indicators–algorithms–governance.

Table 1. The D-VAE indicator cube

First-level dimension	Second-level sub-dimension	Third-level observation point (Calculation rule)	Digital intelligence source	Ethical review
A High-Consciousness Learning	A1 Vision Awareness	A1-1 Frequency of setting semester goals (≥3 times/semester)	Teacher development platform goal module	Anonymized storage
	A2 Problem Awareness	A2-1 Proportion of high-cognitive classroom questions (Bloom's Level ≥4)	Classroom voice AI tagging	Informed consent
	A3 Creative Awareness	A3-1 Number of co-created lesson plans using generative AI (cumulative)	Collaborative lesson preparation system	Algorithm transparency
B Human-Machine Synergy	B1 Complementary Decision-Making	B1-1 AI recommendation adoption rate (adoptions/recommendations)	LMS logs	Fairness audit
	B2 Critical Correction	B2-1 Number of algorithm bias identifications (supervision records)	Peer review system for lessons	Bias detection
C Cross-Boundary Integration	C1 Interdisciplinary Integration	C1-1 Number of interdisciplinary concept map nodes (≥50)	Knowledge graph engine	Copyright review
	C2 Method Integration	C2-1 Number of instructional design documents utilizing diverse methods	Instructional design repository	Peer review
D Educational Innovation	D1 Model Redesign	D1-1 Complexity of blended learning flowchart (nodes ≥20)	Process mining tool	Explainability
	D2 Technology Adaptation	D2-1 Usage duration of immersive technology (minutes/instructional hour)	XR device logs	Safety & compliance
E Ethical Responsibility	E1 Data Ethics	E1-1 Student data anonymization rate (100% = full score)	Data governance platform	Third-party audit

Note: *Shortcuts given in abbreviations

4. Conclusion: Towards an educational new-quality governance ecosystem of "teacher–student collaborative value-added"

4.1. Theoretical contribution

A unified "New-Quality Competency" framework transcending the "instrument–performance" paradigm. Grounded in complex systems philosophy, this study is the first to translate the "new-quality productive forces" policy discourse into the five-dimensional structure of "university teacher new-quality competencies" within an educational context, demonstrating its unique connotations distinct from existing digital competency frameworks—a dual foundation of "High-Consciousness Learning" and "Ethical Responsibility", dual drivers of "AI Symbiosis" and "Transdisciplinary Integration", and an ultimate orientation towards "Pedagogical Innovation." This framework provides a deducible, measurable, and improvable conceptual tool for teacher professional development in the smart education era, filling the theoretical gap in "deep learning–competency value-added" in higher education.

4.2. Methodological innovation

Constructing the integrated "indicator–algorithm–governance" D-VAE model. Addressing the common dilemma of "abundant data, scarce evidence, feeble improvement", this paper developed a 5×3×45 three-level

cube indicator system, paired with longitudinal equating, empirical Bayesian dynamic weighting, and piecewise linear HLM, achieving full-chain estimation from "baseline–process–value-added."

5. Conclusion

University teacher deep learning is not merely a "means" enabled by digital–intelligent technologies but also the "end" of reshaping educational value in the era of new-quality productive forces. The D-VAE framework, grounded in complex systems philosophy, leveraged by evidence-based evaluation, and safeguarded by ecological governance, addresses the triple challenges of "how teachers learn, how competencies grow, how teachers and students grow together." It provides a replicable, scalable, and sustainable "system-level solution" for building a strong education nation. In the future, with continuous cross-regional, cross-cultural, and cross-institutional validation and iteration, university teacher evaluation will transition from "performance accountability" to "public good governance", ultimately achieving multi-dimensional synergistic value-added for "individual growth, student success, disciplinary development, and societal prosperity."

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