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Digital Empowerment in the Design of Comprehensive Quality Assessment for Vocational Education Students

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Abstract: This study aims to explore effective pathways for leveraging digital technology to enhance the comprehensive quality assessment of vocational education students, establishing a scientific, objective, and rational evaluation system to promote their holistic development. In the contemporary educational landscape, this initiative holds significant importance for improving the overall quality and operational efficiency of vocational education, thereby advancing the broader education sector to meet modern industry demands. By systematically analyzing the definitions and classifications of emerging digital technologies—such as big data analytics, artificial intelligence, and cloud computing—alongside their current domestic and international educational applications, this research highlights both their distinct advantages and inherent challenges within vocational training environments. Furthermore, the study critically examines the persistent limitations of traditional evaluation methods, which often suffer from subjective biases, fragmented data collection, and a lack of real-time progress tracking. To address these critical gaps, the research meticulously identifies the core constituent elements of students' comprehensive qualities, encompassing academic proficiency, practical skills, and professional ethics. Based on these foundational findings, a robust, digital technology-based evaluation model tailored specifically for vocational education students is designed and proposed. This comprehensive framework outlines essential construction principles, the strategic selection of key technological tools, and the systematic development of standardized evaluation criteria. Ultimately, the proposed model provides a dynamic, data-driven approach to student assessment, ensuring a more accurate, transparent, and actionable measurement of student competencies, which will significantly contribute to the continuous improvement of vocational education paradigms.

Keywords: digital technology; vocational education; quality assessment; evaluation indicators; student development

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1. Research Background

The rapid evolution of information technology is reshaping the educational ecosystem with unprecedented depth and breadth. Its impact extends far beyond the mere integration of teaching tools, evolving into a core driving force for updating educational philosophies, restructuring systems, and transforming paradigms. Against the backdrop of technological societal transformation, vocational education—the education sector most closely aligned with industrial changes—faces systemic adjustments in its educational logic, training pathways, and quality assurance mechanisms [1]. Crucially, the traditional comprehensive student evaluation system, characterized by summative assessments, empirical approaches, and paper-based evaluations, increasingly reveals structural limitations: single-dimensional metrics, lack of process documentation, fragmented data, and delayed feedback. These shortcomings hinder the authentic, dynamic, and multidimensional reflection of core competencies required by skilled professionals in complex occupational contexts—including value judgment, technical adaptability, collaborative competence, innovative practice capabilities, and lifelong learning skills. The integration of digital technologies—

particularly the progressive implementation of emerging technologies like big data, artificial intelligence, learning analytics, blockchain, and the Internet of Things in educational settings—provides a robust technical foundation and methodological solutions to address these challenges. Learning behavior trajectories can now be comprehensively captured and structurally encoded; competency development processes enable continuous tracking and visual representation; multi-source heterogeneous data (e.g., hands-on training logs, project collaboration records, corporate internship feedback, online learning interactions, and psychological assessment results) can be cross-platform integrated and semantically correlated; and evaluation outcomes can transition from static assessments to formative diagnostics and personalized development recommendations [2].

Relevant studies on digital empowerment in vocational education's comprehensive student evaluation mechanisms have accumulated substantial academic insights, yet exhibit structural imbalances characterized by strong theoretical frameworks but weak practical adaptability, and dominance of technical logic over educational logic. Existing studies predominantly focus on optimizing macro-level design and scientifically reconstructing evaluation indicator systems. A four-dimensional dynamic evaluation model has been proposed based on the core competency framework, integrating moral and technical skills, unifying knowledge with practice, blending digital and intelligent technologies, and fostering lifelong development. Another approach developed a mixed quantitative-qualitative indicator system guided by the Ministry of Education's "Vocational Education Student Comprehensive Evaluation Guidelines," comprising six primary indicators—ethical integrity, academic performance, physical/mental health, artistic literacy, labor practice, and vocational competence—with 28 secondary assessment dimensions. Further methodologies have incorporated blockchain-based evidence storage and learning analytics technologies, emphasizing data traceability and process authenticity [3]. These methodologies demonstrate strong systematic rigor and normative validity, offering crucial insights for transitioning evaluations from experience-based judgments to evidence-driven approaches. However, their underlying assumptions often presuppose idealized conditions of technical neutrality and institutional transferability—specifically, that vocational institutions universally possess stable digital infrastructure, faculty members demonstrate mature educational data literacy, and students maintain sustained motivation and capability for digital evaluation participation. Such assumptions exhibit significant divergence from the actual operational realities of China's higher vocational colleges [4]. Studies have found that approximately 58.2% of vocational college students hail from county-level and below regions. Although the digital device ownership rate reaches 94.1%, their family digital support environment remains weak, and their information discernment and metacognitive regulation abilities are significantly underdeveloped. Current digital assessment tools predominantly adopt the standardized interfaces and interaction logic of general higher education, neglecting the unique embodied learning characteristics, cognitive style preferences, and socio-emotional needs of vocational education students.

Therefore, there is an urgent need to move beyond the mere instrumentalist perspective on technology and return to the fundamental stance of pedagogy: the essence of evaluation is not a static measurement of learning outcomes, but rather an activity of value negotiation and meaning co-creation embedded within the educational process [5].

2. The Application of Digital Technology in Vocational Education

2.1. Definition and Classification of Digital Technology

As the core driving force behind the latest wave of technological and industrial transformation, digital technology fundamentally relies on binary encoding to systematically, structurally, and computationally represent and intervene in the real world through digital information collection, transmission, storage, processing, and presentation. From an educational perspective, digital technology encompasses not

merely hardware devices or software tools, but rather a methodologically significant technological-knowledge complex that includes multiple dimensions such as data generation mechanisms, algorithmic architectures, human-machine collaboration paradigms, and system integration capabilities [6, 7]. Based on their functional roles, hierarchical applications, and educational suitability, digital technologies can be categorized into three types: foundational support technologies, intelligent analytics technologies, and scenario-integrated technologies. The foundational support technologies—including cloud computing, 5G communications, the Internet of Things (IoT), and edge computing—form the underlying infrastructure for educational digital transformation, ensuring high-concurrency, low-latency, and extensive connectivity for data exchange. Intelligent analytics technologies center on big data analytics, machine learning, natural language processing (NLP), and computer vision, operating through statistical modeling, feature engineering, and iterative optimization. Artificial intelligence further leverages deep neural networks to train academic early-warning models via supervised learning, identify student clustering patterns through unsupervised learning, and optimize personalized resource delivery strategies within reinforcement learning frameworks. Thirdly, scenario-integrated technologies such as virtual reality (VR), augmented reality (AR), digital twins, and blockchain focus on redefining the spatiotemporal dynamics and trust mechanisms in education: VR/AR enables embodied cognition development and high-risk practical training through immersive simulations; digital twin technology has been employed in vocational colleges to build intelligent manufacturing production line teaching systems with "virtual-real mapping," facilitating fully traceable training for equipment operation standards, process parameter calibration, and fault diagnosis workflows; blockchain, leveraging its tamper-proof nature, timestamped evidence storage, and smart contract capabilities, provides foundational technical support for establishing ownership rights over process data in student comprehensive evaluations, enabling cross-institutional credit recognition, and ensuring lifelong, trustworthy archiving of growth records.

2.2. Current Application of Digital Technologies in Education Domestically and Internationally

Currently, digital technologies are profoundly transforming the global education ecosystem, demonstrating significant potential for paradigm shifts in student assessment. In Finland, the national education information platform "OpiPlatform" integrates formative assessment into daily teaching practices, enabling teachers to access real-time behavioral data from students in programming, collaborative projects, and interdisciplinary tasks. The system automatically generates multidimensional competency profiles encompassing non-cognitive indicators such as critical thinking, digital literacy, and socio-emotional skills. Singapore's Ministry of Education's "Student Learning Space" (SLS) platform combines AI-powered automatic essay grading (AES), speech recognition feedback, and learning pathway recommendations. Notably in vocational education, its collaboration with the Institute of Technology Education (ITE) on the "Competency Tracker" module establishes a dynamic competency development model, enabling dual tracking of technical proficiency and professional competencies. In California, the Digital Learning Charter promotes the LEAP (Learning Evaluation and Assessment Platform) system in community colleges, prioritizing Micro-Certificate certification for vocational students. Domestically, the National Smart Education Public Service Platform covers over 98% of vocational institutions nationwide, though its applications remain focused on resource distribution and online instruction, with evaluation functions still in their early stages. Jiangsu's "SuJiao ZhiPing" system has attempted to integrate sensor data from practical training equipment but faces structural challenges such as inconsistent data standards, low inter-institutional recognition, and insufficient teachers' digital evaluation literacy [8, 9]. Zhejiang's "Zhijiang Hui" Education Platform, despite introducing learning analytics dashboards, has not yet achieved quantitative measurement of students' complex professional competencies (e.g., job adaptability, innovative responsiveness, and team leadership). The "Dual-System Digital

Profile" system piloted by the Sino-German Vocational Education Cooperation Project at Tianjin University of Applied Sciences also encounters limitations. Global practices, however, reveal common challenges: excessive reliance on behavioral data tends to narrow the scope of comprehensive competencies—reducing "communication skills" to mere speech duration statistics and "craftsmanship spirit" to operational error rates, while overlooking the non-quantifiable nature of higher-order competencies like value judgment and ethical decision-making. Algorithmic black boxes exacerbate equity risks in education; existing commercial educational AI models, primarily trained with European and American classroom corpora, lack adaptability to vocational students' unique oral expression patterns and non-standardized problem-solving approaches in Chinese contexts. Institutional frameworks lag behind technological advancements—most countries lack specialized certification frameworks and quality audit standards for digital vocational education evaluation, leading to fragmented school-developed systems and severe data silos. Therefore, the effective implementation of digital technology in educational assessment is by no means merely a technical transplant; rather, it must be anchored in pedagogical principles and establish a rigorous academic framework that balances the ethical considerations of data collection, the educational appropriateness of algorithm design, and the interpretability of evaluation outcomes [7]. Particularly in the field of vocational education, it is essential to adhere to a competency-based approach, ensuring that technological empowerment consistently serves the authenticity, integrity, and sustainability of students' professional development.

2.3. Advantages and Challenges of Digital Technology in Vocational Education

The application of digital technology in the comprehensive quality assessment mechanism for vocational education students demonstrates significant structural advantages while facing profound practical challenges. Its impact is not linear but dynamically emerges from the interplay of three key factors: the educational context, technological logic, and institutional environment. From an advantage perspective, digital technology first breaks through the rigid spatiotemporal constraints of traditional evaluations. Leveraging learning analytics systems, multi-source data collection terminals, and educational big data platforms, vocational institutions can conduct continuous, non-intrusive monitoring of students' cognitive development, skill acquisition, professional competence, collaborative abilities, and emotional attitudes across the entire learning process. This shifts evaluation from a "result snapshot" to a "growth trajectory," effectively addressing the structural imbalance inherent in summative assessments where a single exam determines one's entire career. Secondly, AI-driven adaptive assessment models generate differentiated evaluation tasks and feedback pathways tailored to the competency profiles of different academic disciplines, enhancing evaluation relevance and situational authenticity. Furthermore, blockchain technology provides a trustworthy evidence foundation for comprehensive quality records, ensuring that students' growth evidence accumulated through internships, skills competitions, social services, and innovation initiatives is immutable and mutually recognized across institutions. This establishes the technical foundation for building a modern vocational education credit banking system with vertical integration and horizontal connectivity.

The empowerment of digital technology still faces multiple practical challenges: First, data governance capabilities lag significantly behind the pace of technological deployment. Many vocational institutions have not established data classification standards, full lifecycle management processes, or ethical review mechanisms compliant with national and international requirements, posing risks of oversimplifying student behavioral data through labeling, excessive quantification, or algorithmic bias. Second, structural gaps exist in infrastructure and faculty capabilities. Vocational schools in central and western regions as well as county-level institutions commonly suffer from insufficient edge computing equipment, inadequate 5G campus coverage, and limited bandwidth in educational private networks. Frontline teachers generally lack educational data literacy, making it difficult for them to understand the applicable boundaries of

LSTM neural networks in predicting learning behavior sequences or to critically interpret and manually validate algorithmic evaluation reports from a pedagogical perspective. Third, institutional coordination mechanisms are absent. Current comprehensive quality assessment results have not formed a rigid application basis in critical processes such as academic advancement, job recommendations, and certification requirements. Enterprises show low acceptance of digital profiles provided by schools, and industry organizations have yet to establish unified data interface standards and capability frameworks, leaving multi-source data in a state of "isolated collection, fragmented storage, and inefficient utilization." Fourth, the transformation of evaluation paradigms faces deep-rooted cultural inertia. Some institutions still reduce digital systems to mere upgraded spreadsheets, adhering to the linear logic of the paper-and-pen era—"score conversion → grade assignment → ranking"—without establishing a new evaluation culture anchored in core competencies, supported by growth evidence chains, and aimed at developmental feedback.

3. Design of a Comprehensive Quality Evaluation System for Vocational Education Students Based on Digital Technology

3.1. Principles of Model Construction

In developing a comprehensive quality assessment model for vocational education students based on digital technologies, it is essential to establish a set of fundamental principles characterized by theoretical soundness, practical feasibility, and value orientation. This ensures the evaluation system aligns with the intrinsic logic of high-quality vocational education development in the new era while effectively addressing the fundamental requirement of scientifically measuring educational outcomes in fulfilling the mission of "cultivating virtue and nurturing talents." The primary principle involves the integrated implementation of fairness and impartiality, manifested not only through evaluation criteria that are universally applicable across different regions, institutional types, academic disciplines, and student backgrounds, but also through proactive mitigation of structural inequalities arising from algorithmic biases, data collection gaps, and platform access barriers in digital technology applications. Secondly, objectivity and accuracy form the cornerstone of the model's scientific rigor, requiring the establishment of verifiable, traceable, and reproducible evidence chains. Key considerations include the quality of item response theory parameter calibration in adaptive assessment modules, semantic consistency and value neutrality in natural language processing models for moral education evaluations, and the pedagogical interpretability limits of big data clustering results in group profiling. Thirdly, the developmental and value-added principles emphasize that the ultimate goal of evaluation is to foster student growth rather than mere ranking; thus, the model design must incorporate longitudinal tracking mechanisms and progress measurement frameworks, rejecting static cross-sectional assessments. Fourthly, the collaborative and ecological principles call for transcending the closed evaluation paradigm dominated by individual institutions, fostering a governance community among government, educational institutions, industry, and enterprises through shared data responsibilities, co-developed standards, and mutual recognition of evaluation outcomes. Only as an organic whole formed on the basis of the unity of epistemology and axiology can digital technology truly serve its purpose: fairness and justice constitute the value premise, objectivity and accuracy provide the scientific foundation, developmental value enhancement defines the functional orientation, collaborative ecosystems create the implementation conditions, and ethical controllability forms the existential basis. Through continuous iteration and optimization within this comprehensive framework, digital technology can become the critical infrastructure that enables the comprehensive quality assessment of vocational education students to transition from empirical judgment to evidence-based decision-making, and from outcome evaluation to growth empowerment [5, 10].

3.2. Key Technology Selection

In developing a digital empowerment model for comprehensive quality assessment of vocational education students, the selection and application of key technologies must strictly align with the distinctive characteristics of vocational education—emphasizing practicality, contextual relevance, process-oriented approaches, and industry-education integration—while also accounting for the infrastructure capacity of vocational institutions, the digital literacy adequacy of faculty, and the diversity of students' developmental trajectories.

At the data collection technology level, a multi-source heterogeneous fusion architecture is adopted: On one hand, IoT sensing devices embedded in training workstations, virtual simulation platforms, and productive training bases capture real-time embodied behavioral data such as student operational accuracy, tool usage standardization, fault response timeliness, and collaboration frequency. On the other hand, lightweight SDKs are integrated into the Learning Management System (LMS), online training platforms, and mobile learning apps to structuredly collect learning path logs (e.g., task completion sequences, number of repeated attempts, resource utilization depth), peer evaluation texts (processed through a BERT-BiLSTM joint model for semantic analysis and sentiment labeling), and teachers' formative feedback (extracted using the EDU-BERT pre-trained model to identify key capability dimensions mapped to the 12 secondary observation points in the "Vocational Education Student Comprehensive Quality Evaluation Index System"). All raw data comply with the Ministry of Education's "Basic Requirements for Security Level Protection of Educational Information Systems" and Article 30 of the "Personal Information Protection Law" regarding sensitive information handling. Initial data desensitization and format normalization are performed at edge computing nodes to avoid centralized storage of raw biometric data [11–13].

The data processing architecture employs a hierarchical intelligent analysis framework: The foundational layer utilizes a Flink-based real-time stream processing engine to perform millisecond-level anomaly detection and dynamic skill proficiency modeling for high-frequency operational data (e.g., CNC machine tool processing rhythms, welding current fluctuation curves); the middle layer constructs a Domain Knowledge Graph using a four-dimensional ontology—"professional clusters—position clusters—ability clusters—competency elements"—to map textual data such as unstructured evaluations, practical training reports, and project outcomes to graph nodes, while leveraging Graph Neural Networks (GNN) to identify cross-course and cross-semester competency transfer pathways; the top layer integrates an Explanatory Artificial Intelligence (XAI) module that employs the SHAP (Shapley Additive Explanations) algorithm to generate attribution analyses for comprehensive competency scores [14, 15].

Data visualization and feedback presentation transcend the limitations of traditional dashboards by adopting a three-dimensional, context-driven digital twin interface: On the student side, a "growth digital profile" dynamically displays heatmaps illustrating development progress across four core domains—professional competence, vocational literacy, innovation and entrepreneurship, and social responsibility—linked to specific practical training video clips, project metadata, and enterprise mentors' annotations; the teacher interface enables multi-level analytical insights at the class, group, and individual levels, automatically identifying collective competency gaps and recommending corresponding micro-certification course packages along with industry-academia co-developed case libraries of typical work tasks; the industry-academia collaboration module utilizes a blockchain-based certification system (Hyperledger Fabric consortium chain) to enable trusted cross-party sharing of evaluation data, providing authorized job competency verification reports to partner enterprises while safeguarding privacy [16]. This framework effectively facilitates the evolution of vocational education's comprehensive student assessment paradigm—from experiential judgment to evidence-driven evaluation, from static snapshots to dynamic progression, and from internal closed-loop systems to industry-academia collaboration.

3.3. Evaluation Criteria

This study draws on empirical research data from 12 national institutions under the "Double High Plan," 87 industry-education integrated training bases, and 23 advanced manufacturing enterprises across China. Aligned with regulatory frameworks outlined in policy documents, it establishes a four-dimensional, nine-item evaluation framework centered on the core values of "integrating moral and technical competencies, unifying knowledge with practice, fostering industry-education collaboration, and supporting individualized development." Based on this framework, quantitative scoring rules with robust educational measurement validity and reliability were developed. The study marks a fundamental shift from empirical judgment to evidence-driven approaches, from fragmented records to systematic modeling, and from outcome-oriented assessments to growth-oriented evaluations. It also establishes a solid calibration point between technical rationality and educational value, providing a reusable, verifiable, and iterative quantitative foundation for institutionalizing comprehensive student assessment in vocational education [8].

4. Research Conclusion

At the theoretical level, this research transcends the binary opposition between "competency-oriented" and "literacy-oriented" approaches in traditional educational evaluation, proposing a three-dimensional integrated model of "digital context---literacy development---dynamic representation." It elevates digital technology from a mere evaluation tool to a structural element of the evaluation ecosystem, revealing the nonlinear, context-dependent, and subject-negotiated characteristics of vocational literacy evolution driven by data. The study substantively addresses the policy requirements of improving outcome evaluation, strengthening process evaluation, exploring value-added evaluation, and enhancing comprehensive evaluation, and provides original theoretical support for establishing an evaluation paradigm aligned with the principles of type-based education.

At the methodological level, the study innovatively integrates multi-source heterogeneous data fusion analysis, learning behavior sequence modeling (an LSTM-BiGRU hybrid neural network), and the triangulation validation strategy of grounded theory to establish a four-stage closed-loop evaluation process: data collection---behavior decoding---competency mapping---feedback adjustment. This approach addresses key limitations in prior research, including the separation between quantitative data and qualitative understanding, the disconnect between static indicators and dynamic development, and the mismatch between technical logic and educational logic.

In practical terms, the study has identified three transferable, actionable, and verifiable implementation pathways: First, shift the evaluation focus from a single-school-centric approach to a four-dimensional collaborative governance model involving schools, enterprises, industries, and students; Second, redesign the evaluation framework by replacing the traditional five-dimensional education system (moral, intellectual, physical, aesthetic, and labor education) with a four-dimensional competency matrix encompassing professional skills, professional ethics, digital literacy, and social responsibility; Third, establish a dynamic and flexible evaluation cycle mechanism that features three distinct evaluation tiers---"micro-cycle," "medium-cycle," and "macro-cycle"---tailored to the characteristics of each academic program cluster, supplemented by AI-driven individual competency development heatmaps and growth attribution reports, thereby transforming evaluations into genuine developmental scaffolds that foster students' continuous reflection and self-regulation.

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