Article

Research on the Construction of a Dynamic Evaluation Model for Vocational Education Quality Based on Multimodal Learning Analytics

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Abstract: Driven by globalization and educational informatization, new models of vocational education have emerged, posing significant challenges to traditional mechanisms of vocational education quality assessment and certification. Existing evaluation frameworks are constrained by two critical limitations: data silos and timeliness lag, which are reflected in issues such as single-source data dependence, static and retrospective assessment processes, difficulties in establishing cross-border data trust, and restricted circulation of certification outcomes. From an international perspective, this study constructs a dynamic evaluation model for vocational education quality by integrating blockchain technology with multimodal learning analytics theory. Leveraging the inherent characteristics of blockchain, the model establishes a cross-border and cross-institutional trusted network for the authentication and circulation of learning achievements, enabling continuous tracking of learners' cross-border learning trajectories. By incorporating multimodal learning analytics techniques, the model conducts in-depth mining of multi-source learning data and integrates sentiment recognition to achieve comprehensive, fine-grained, and real-time analysis of learning processes. Ultimately, through smart contract-enabled data aggregation, the model generates traceable, quantifiable, and dynamically updated learner competency profiles and evaluation reports, providing effective support and practical pathways for quality assessment and certification in internationalized vocational education.

Keywords: Vocational Education; Quality Assessment; Multimodal Learning Analytics; Dynamic Model; Data Silos

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1. Introduction

As a pivotal hub for cultivating technical and skilled talents, the internationalization of vocational education has become an indispensable strategic imperative for advancing national development goals. In recent years, driven by globalization and educational informatization, new models of vocational education have continuously emerged, placing unprecedented demands on existing quality assessment and certification mechanisms.

However, in practical implementation, current evaluation systems for vocational education are still constrained by a series of persistent and structural problems. First, the issue of data silos remains prominent. Disparate data standards and incompatible information systems across institutions and regions have resulted in isolated information islands, making effective data sharing and integration difficult. Second, there is a significant timeliness lag in evaluation practices. Most assessments are conducted in a static and retrospective manner, meaning that by the time problems are identified, opportunities for timely intervention and improvement have often been missed. Third, cross-border trust in certification remains difficult to establish, as verifying the authenticity of academic credentials and skill certificates frequently requires substantial time and administrative resources. Finally, existing evaluation frameworks tend to focus on limited assessment dimensions and struggle to comprehensively reflect students' dynamic learning processes and holistic competency development [1].

These systemic deficiencies seriously constrain the high-quality development and credibility building of internationalized vocational education. If left unaddressed, they may further weaken the effectiveness of quality assurance and the international recognition of vocational qualifications. Therefore, it is imperative to introduce advanced information technologies and innovative evaluation approaches to reconstruct existing evaluation mechanisms. Against this backdrop, this study integrates blockchain technology with multimodal learning analytics theory to construct a dynamic evaluation model for vocational education quality. The proposed model aims to break data barriers, enable process-oriented and real-time evaluation, and provide credible support for cross-border quality assessment and certification in internationalized vocational education.

2. Core Theoretical Foundations and Key Technologies for Model Construction

2.1. Theoretical Underpinnings

1) Educational Quality Assurance Theory

Educational Quality Assurance Theory emphasizes the holistic management of educational inputs, processes, and outputs, covering all stakeholders and all stages of the educational lifecycle. It advocates a systematic approach to quality monitoring and continuous improvement. Building on this theoretical foundation, the proposed model further incorporates advanced digital technologies to enable refined, data-driven monitoring of the learning process. In addition, the scope of quality assurance is extended from individual institutions to a broader cross-border vocational education ecosystem, addressing the demands of internationalized vocational education.

2) Multimodal Learning Analytics Theory

Multimodal Learning Analytics Theory focuses on collecting and analyzing learning data from multiple modalities, such as text, speech, video, and physiological signals, to obtain a more comprehensive and authentic understanding of learning processes and contexts. This theory provides the conceptual basis for shifting vocational education quality assessment from single-dimensional evaluation to integrated analysis, and from outcome-oriented assessment to process-oriented evaluation. It supports the comprehensive examination of learners' cognitive and non-cognitive development throughout the learning process [2].

3) Blockchain Distributed Trust Theory

Blockchain Distributed Trust Theory establishes a decentralized trust mechanism through cryptographic techniques, consensus algorithms, and distributed data storage, eliminating reliance on centralized authorities. This theory offers a fundamental solution to key challenges in cross-border vocational education, including data authenticity verification, privacy protection, and trusted data circulation. It provides a reliable theoretical foundation for constructing a credible and transparent quality assessment and certification framework in internationalized vocational education contexts [3].

2.2. Core Technologies

1) Blockchain and Smart Contracts (AI-Enabled Tools)

Blockchain and smart contract technologies serve as the trust backbone and automated execution mechanism of the proposed model. By leveraging the immutability, traceability, and decentralization characteristics of blockchain, the model ensures the authenticity and credibility of learning achievement data. Specifically, hash values of key learning outcomes-such as course grades, skill badges, internship reports, and project portfolios-are recorded on the blockchain to enable immutable authentication and traceable verification [4].

In addition, the model establishes a distributed international credit bank, in which smart contracts automatically enforce rules for credit accumulation, conversion, and redemption, thereby supporting cross-border credit recognition and circulation. Decentralized Identifiers (DID) are adopted for identity management and authorization, allowing learners to retain ownership of their learning data and to share it securely with educational institutions and employers under permissioned conditions. Furthermore, core assessment logics, including attendance calculation and basic skill proficiency verification, are encoded into smart contracts, enabling automated, transparent, and standardized assessment processes.

2) Multimodal Learning Behavior Data Mining

Multimodal learning behavior data mining functions as the data sensing interface and process analysis engine of the model. The system integrates with Learning Management Systems (LMS), such as Moodle and Blackboard, to collect and analyze learners' online behavioral data, including login frequency, resource access paths, video completion rates, and forum interactions. These data are used to examine students' learning engagement, persistence, and collaborative behaviors in online learning environments.

Textual data generated during learning activities-such as online discussions, assignments, and learning reports-are further analyzed using natural language processing techniques. This enables the evaluation of learners' knowledge acquisition depth, critical thinking ability, and learning-related emotional states, such as confusion, enthusiasm, and anxiety. In addition, computer vision technologies are applied to classroom video data to automatically identify attendance, eye contact rates, facial expressions (e.g., focus, perplexity, and disengagement), and interaction frequencies, thereby quantifying the quality of classroom participation.

3) Multimodal Sentiment Recognition

Multimodal sentiment recognition serves as an important complement to multimodal learning analytics by providing insights into learners' non-cognitive factors. By integrating speech-based sentiment analysis-such as intonation and speech rate-with facial expression recognition, the model comprehensively evaluates students' emotional states and engagement levels across multiple learning scenarios, including classroom discussions, online defenses, and practical training activities. These analyses provide data support for assessing soft skills such as learning motivation, professional identity, and emotional engagement, which are essential components of vocational competency development.

3. Core Architecture of the Dynamic Evaluation Model 3.1 Data Layer

3.1. Data Layer

The Data Layer serves as the foundational layer of the dynamic evaluation model and is responsible for the large-scale collection of heterogeneous data from multiple sources. These sources include cross-border partner institutions, online learning platforms, and vocational training bases. The Data Layer provides comprehensive and reliable data support for subsequent analysis, evaluation, and certification processes.

According to data characteristics and usage purposes, the Data Layer consists of two main categories. The first is blockchain-authenticated data, which includes hash values of verifiable learning outcomes such as academic credits, certificates, project achievements, and skill credentials. These data represent authoritative learning evidence and ensure authenticity, integrity, and traceability through blockchain-based authentication.

The second category is multimodal process data, which captures learners' dynamic learning behaviors throughout the educational process. This category includes learning management system (LMS) logs, classroom video and audio recordings, assignment texts, online discussion records, and practical operation videos. These data reflect learners' engagement, interaction patterns, and performance across different learning scenarios and provide rich input for multimodal learning analytics and dynamic quality evaluation [5].

3.2. Network Layer

The Network Layer constitutes the blockchain infrastructure of the proposed model and provides a trusted operational environment for data storage, sharing, and circulation. It is implemented as a consortium blockchain jointly maintained by multiple stakeholders, including host institutions, cross-border partner institutions, enterprises, and certification bodies. Through collaborative governance, this layer establishes a shared trust foundation for internationalized vocational education quality assessment.

By leveraging blockchain's characteristics of immutability, traceability, and decentralized consensus, the Network Layer ensures the security, authenticity, and integrity of all on-chain data. Learning achievements and evaluation results recorded on the blockchain cannot be tampered with and can be reliably traced throughout their lifecycle. At the same time, permissioned access mechanisms enable secure data sharing among authorized participants, supporting cross-institutional and cross-border cooperation while protecting data privacy.

Overall, the Network Layer functions as the trust backbone of the dynamic evaluation model, enabling credible data exchange and laying a solid foundation for subsequent analytics, automated assessment, and certification processes.

3.3. Analytics Layer

The Analytics Layer serves as the core intelligence component of the dynamic evaluation model and is responsible for cleaning, integrating, and deeply analyzing multimodal data collected at the Data Layer. This layer transforms heterogeneous raw data into structured, analyzable information that supports dynamic quality evaluation and decision-making.

Key functions of the Analytics Layer include feature extraction, model computation, and dynamic profile generation. Feature extraction focuses on identifying critical indicators from multimodal data, such as learning behavior sequences, emotional fluctuation patterns, knowledge structure representations, and skill tags. Based on these features, machine learning and deep learning techniques are applied to construct prediction, classification, and clustering models, enabling intelligent diagnosis of learning effectiveness, dropout risks, and competency gaps.

By integrating both process data and outcome data, the Analytics Layer generates dynamically updated digital competency profiles for individual learners. These profiles provide a comprehensive representation of students' knowledge acquisition, skill development, and competency progression, offering essential analytical support for automated assessment, quality monitoring, and personalized feedback [6].

3.4. Contract Layer

The Contract Layer consists of a suite of smart assessment contracts deployed on the blockchain, which encode evaluation rules and assessment logic into executable programs. This layer serves as the automated rule enforcement and result generation mechanism of the dynamic evaluation model, ensuring transparency, consistency, and credibility in the evaluation process.

One core function of the Contract Layer is automatic triggering. Smart contracts are executed autonomously when predefined conditions are met, such as reaching specific assessment time nodes or data volume thresholds. This mechanism enables continuous and timely evaluation without reliance on manual intervention.

Another key function is rule enforcement. Smart contracts automatically verify the validity of academic credits, determine the achievement level of specific practical competencies based on outputs from multimodal learning analytics, and dynamically calculate comprehensive quality indices. By embedding assessment logic into smart contracts, the evaluation process becomes standardized, traceable, and resistant to manipulation.

In addition, the Contract Layer supports trustworthy report generation. Evaluation outcomes, including competency evaluation reports and certification results, are automatically generated upon contract execution and recorded on the blockchain. These outputs inherit the blockchain's trust attributes, ensuring that evaluation results and certification documents are authentic, traceable, and widely verifiable [7].

3.5. Application Layer

The Application Layer provides user-oriented service interfaces based on the outputs of the dynamic evaluation model and supports practical application scenarios for different stakeholders. It translates evaluation results into actionable information and services, facilitating the use of assessment outcomes in learning, teaching, management, and certification contexts.

For students, this layer enables access to personal dynamic competency profiles and trusted learning portfolios. Learners can review their competency development trajectories and independently apply for credit conversion, accumulation, and certification based on verified learning achievements.

For teachers and administrators, the Application Layer offers real-time dashboards for monitoring teaching quality and learning progress. It supports early warning mechanisms for targeted teaching interventions and facilitates the generation of evaluation and compliance reports, thereby improving teaching management efficiency and decision-making quality.

For employers, the Application Layer allows the verification of academic qualifications and skill certificates with student authorization. Employers can access desensitized competency profiles to support recruitment decisions and talent matching, reducing information asymmetry and verification costs.

For certification bodies, this layer enables efficient and low-cost remote auditing and certification based on comprehensive and trustworthy on-chain data. By relying on blockchain-authenticated evaluation results, certification processes can be streamlined while maintaining credibility and rigor.

4. Implementation and Application of the Dynamic Evaluation Model

4.1. Model Implementation Process

The implementation of the dynamic evaluation model follows a structured and incremental process that integrates data acquisition, analytical processing, rule execution, and application services within a unified framework. Heterogeneous learning data are continuously collected from multiple learning scenarios and uploaded to the data layer through standardized interfaces. After data validation and preprocessing, qualified data are securely stored and prepared for subsequent analysis, ensuring the reliability and continuity of evaluation inputs.

Based on the processed data, the analytics layer dynamically analyzes learning behaviors and performance indicators to generate intermediate evaluation results that reflect learners' competency development and learning progress. When predefined evaluation conditions are met, smart contracts are automatically triggered to execute assessment rules, calculate comprehensive evaluation outcomes, and generate traceable records. The finalized evaluation results are then delivered to the application layer and presented to different stakeholders in appropriate forms, supporting the stable operation of the model and the effective use of evaluation outcomes in teaching, learning, and management practices.

4.2. Dynamic Evaluation Mechanism and Operational Workflow

The dynamic evaluation mechanism of the model is centered on continuous data flow and iterative assessment. Unlike traditional static evaluation approaches, the model enables real-time monitoring of learners' behaviors and competency development by continuously updating multimodal data inputs. Evaluation indicators are dynamically adjusted according to learning progress, ensuring that assessment outcomes reflect both short-term learning performance and long-term competency accumulation.

The operational workflow emphasizes closed-loop feedback. Evaluation results generated through analytics and smart contracts are not only used for certification purposes but also fed back into teaching and learning processes. This mechanism supports timely instructional adjustments, targeted learning interventions, and ongoing optimization of evaluation criteria, thereby enhancing the responsiveness and adaptability of vocational education quality assessment.

4.3. Application Scenarios in Vocational Education

The dynamic evaluation model can be applied across multiple vocational education scenarios, including classroom teaching, online learning, practical training, and cross-border cooperative programs. By integrating data from diverse learning contexts, the model provides a comprehensive view of students' learning processes and competency development, supporting consistent evaluation standards across different instructional environments.

In international and cross-institutional vocational education settings, the model facilitates the authentication and circulation of learning achievements through trusted digital records. Authorized stakeholders-such as educational institutions, enterprises, and certification bodies-can access verified evaluation results, enabling efficient credit recognition, competency verification, and talent selection. This broad applicability enhances the practical value of the model and supports the sustainable development of internationalized vocational education.

4.4. Practical Outcomes and Effectiveness Analysis

The application of the dynamic evaluation model contributes to the optimization of vocational education quality assessment by improving the continuity, transparency, and credibility of evaluation outcomes. Through the integration of multimodal learning analytics and blockchain-based trust mechanisms, the model enables a more accurate reflection of learners' competency development and learning processes, reducing the limitations of single-point and outcome-oriented assessments. This supports a more comprehensive understanding of educational quality at both the individual and institutional levels.

From an operational perspective, the model enhances the efficiency of evaluation and certification processes by reducing manual intervention and information asymmetry. Trusted digital evaluation records facilitate timely feedback, informed decision-making, and cross-institutional recognition of learning achievements. Although large-scale empirical validation remains a task for future research, the model demonstrates clear practical potential in improving the effectiveness and reliability of vocational education quality assessment within internationalized contexts [8].

5. Discussion

5.1. Theoretical Contributions of the Model

This study contributes to vocational education quality assessment theory by proposing a dynamic evaluation framework that integrates blockchain technology with multimodal learning analytics. By embedding distributed trust mechanisms into the evaluation process, the model extends traditional educational quality assurance theory from institution-centered assessment toward a cross-border, ecosystem-oriented perspective. At the same time, it enriches multimodal learning analytics theory by positioning multimodal data not only as analytical evidence for learning processes but also as a foundational input for formal evaluation and certification. Through this integration, the model advances existing theoretical approaches by shifting quality assessment from static, outcome-based judgments to continuous, process-oriented, and trustworthy evaluation, thereby offering a new theoretical pathway for internationalized vocational education quality assurance.

5.2. Practical Implications for Vocational Education Quality Assessment

The proposed dynamic evaluation model offers practical implications for improving vocational education quality assessment in internationalized contexts. By enabling continuous monitoring and trusted sharing of evaluation data, the model supports more timely instructional adjustments, targeted learner support, and transparent certification processes. It provides educational institutions and administrators with a systematic tool for integrating process data into quality management, while offering students and employers access to credible and interpretable competency information. As a result, the model contributes to enhancing the effectiveness, consistency, and credibility of vocational education quality assessment practices.

5.3. Limitations and Future Research Directions

Despite its theoretical and practical potential, this study has several limitations. The proposed model remains primarily conceptual and requires empirical validation through pilot implementations and longitudinal data analysis. In addition, challenges related to data standardization, privacy protection, and cross-border coordination may affect large-scale deployment. Future research should focus on conducting empirical studies to test the model's effectiveness, refining technical and governance mechanisms, and exploring alignment with national and international qualification frameworks to further support the sustainable development of internationalized vocational education.

6. Conclusion

Against the backdrop of the convergence of vocational education internationalization and the digital technology revolution, the innovation of quality assessment and certification mechanisms has become a strategic priority of paramount importance. The dynamic evaluation model for vocational education quality constructed in this study integrates blockchain's trust-building capabilities with the deep analytical insights of multimodal learning analytics, forming a systematic and forward-looking evaluation framework. This model provides a feasible technical pathway for addressing the two core challenges of data silos and timeliness lag that persist in current internationalized vocational education quality assessment practices. By enhancing the scientific rigor, real-time responsiveness, and credibility of evaluation processes, the model demonstrates strong potential to reshape the trust ecosystem of internationalized vocational education, promote the global circulation of learning achievements, and ultimately offer institutional support for cultivating high-quality technical and skilled talents capable of responding to future global challenges.

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