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DESIGN AND IMPLEMENTATION OF A BLOCKCHAIN-BASED SELF-DIRECTED LEARNING PROCESS EVALUATION TRACEABILITY PLATFORM*

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Abstract

This study proposes a blockchain-based self-directed learning process evaluation traceability platform to address issues in current self-directed learning evaluation systems, including insufficient transparency, single evaluation subjects, low student participation, and non-standardized evaluation criteria. The platform, designed based on a self-directed learning ability influence factor model, utilizes blockchain's immutability to achieve secure storage, transparent recording, and trusted sharing of learning data. Comprising blockchain and application layers, the platform enables users to monitor the entire learning process and trace data through its interface. Multi-dimensional test results demonstrate the platform's usability and reliability in high-concurrency scenarios. This study enriches self-directed learning evaluation and learning analytics theories. It provides new possibilities for integrating blockchain technology with digital education, significantly promoting educational evaluation reform and high-quality education development.

Keywords: *Blockchain; Digital Education; Self-Directed Learning; Process Evaluation; Traceability Platform.*

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1. INTRODUCTION

In the rapidly developing global information and intelligent educational environment, self-directed learning has become critical for learners to acquire knowledge and enhance abilities [1, 2]. Self-directed learning emphasizes learners' consciousness and initiative, allowing them to choose learning time, place, and methods according to personal schedules, interests, or other needs, thus promoting educational model reform [3]. With the widespread application of self-

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directed learning models, objective and scientific evaluation of students' self-directed learning processes has become an important research topic. Assessing students' self-directed learning abilities helps them better cultivate these skills in the new technological era, aligning with the inherent requirements of self-directed learning and serving as an essential means to achieve teaching effectiveness [4].

However, traditional classroom learning evaluation systems overly rely on centralized examinations, focusing excessively on scores and neglecting process evaluation. It makes it difficult to comprehensively and objectively reflect on learners' performance and progress in self-directed learning processes [5]. Traditional teaching evaluation methods, primarily based on students' test scores, emphasize results over process. While they can reflect learners' learning outcomes to some extent, they often overlook more valuable aspects, such as efforts in self-directed learning processes and cognitive growth [6, 7]. Although existing evaluation systems have a set of standards or rules, they need a comprehensive and credible management mechanism for evaluating students' overall quality and abilities, which quickly leads to discrepancies in evaluation results and information ambiguity [8]. Additionally, educational evaluation information is highly enclosed within centralized systems, needing more transparency, with concentrated evaluation subjects, making it difficult for various social sectors to monitor and actively participate [9] effectively. Furthermore, the construction of learning process evaluation traceability systems still needs to be completed [10], with the reliability, integrity, and traceability of learning process data facing numerous challenges. On the one hand, traditional centralized management has limitations such as non-transparent process data storage vulnerability to attacks and lack of reliable and complete protection for data privacy and security [11, 12]. On the other hand, data traceability in self-directed learning process evaluation is an urgent issue that needs to be resolved. How to ensure that learners' digital learning process trails are traceable, thereby effectively and accurately assessing students' self-directed learning abilities, has become an important research direction [13].

As a decentralized, immutable distributed ledger, blockchain technology has shown good application potential in multiple fields [14]. Its advantages in the educational field lie in providing data security and the ability to protect data even if specific nodes are compromised [15]. With the popularization of digital education and continuous innovation and upgrading of teaching concepts, methods, and forms, blockchain's distributed ledger can effectively address the shortcomings of traditional teaching models. It positively impacts learner-instructor collaboration, learning record management, transparency, and accountability, facilitating the deep integration of blockchain with digital education [16].

This study introduces blockchain technology to design and implement a self-directed learning process evaluation traceability platform for recording and tracing various types of learner information to ensure the evaluation process's authenticity, transparency, and traceability. Multi-subject decentralized participation avoids subjective cheating by individuals or organizations, enabling more effective evaluation of students' self-directed learning processes from multiple perspectives. This study aims to provide practical cases for enhancing educational assessment's objectivity, transparency, and traceability by utilizing blockchain technology and promoting new developments in future educational technology directions.

2. SELF-DIRECTED LEARNING AND BLOCKCHAIN TECHNOLOGY

Blockchain is a decentralized distributed ledger technology that ensures data security, transparency, and immutability through cryptography [17, 18]. This technology records data in a series

of blocks connected to the previous one through encryption algorithms, forming an immutable chain. Currently, traditional self-directed learning process assessment primarily relies on centralized Learning Management Systems (LMS) [20], such as Moodle and Blackboard platforms, which assess learners through their online behavioral data [20]. However, these systems face potential trust risks in data management. In recent years, some AI-based adaptive assessment systems have emerged [21], but their assessment processes lack transparency due to their closed algorithmic models. Blockchain technology has been widely applied in fields such as finance [22], supply chain management [23], and agricultural Internet of Things [24], providing reliable decentralized data management solutions. Its basic structure is shown in Figure 1, where the block structure includes a block header and block body. The block header contains information such as the previous block's hash value, timestamp, and nonce, while the block body records the actual transaction data. The blockchain network maintains the ledger through distributed nodes, where nodes validate and record new transactions through consensus mechanisms (such as Proof of Work or Proof of Stake) to ensure ledger consistency across all nodes and data immutability.

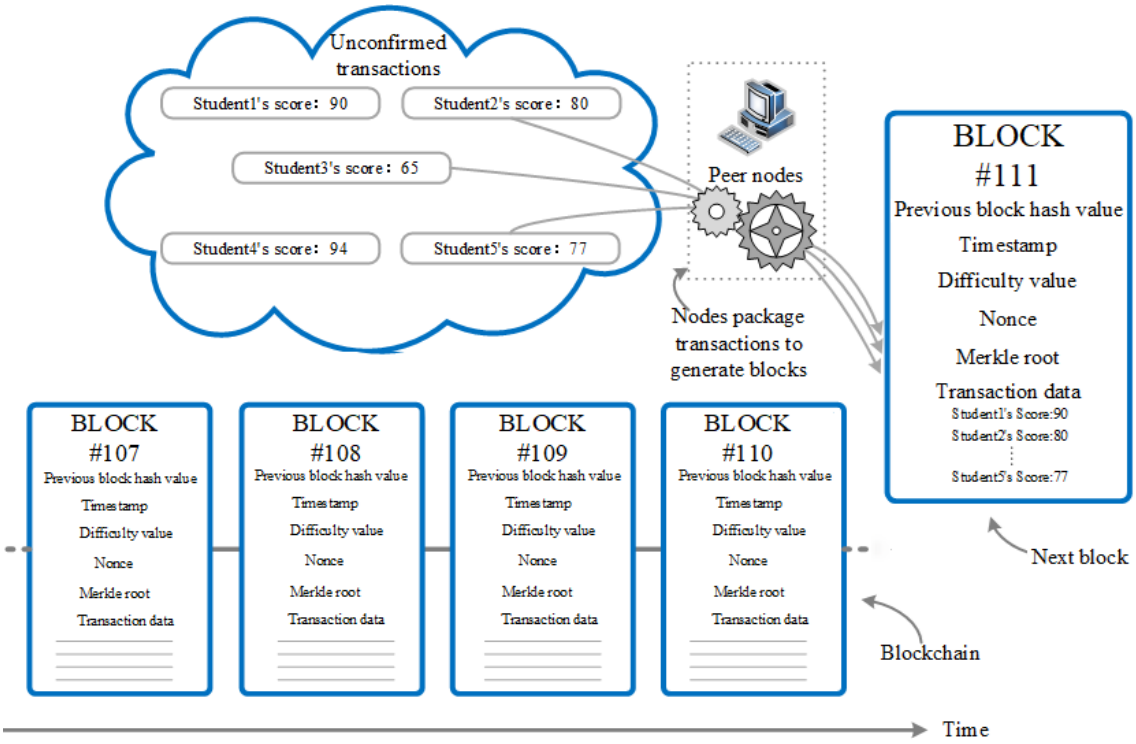


Figure 1. Blockchain structure

This study utilizes blockchain technology to collect information on students' research-based learning, self-directed learning duration, utilization of learning resources, communication and collaboration, completion of learning tasks, and self-evaluation and reflection through data recorded in the system database. It forms a comprehensive portfolio of the entire self-directed learning process, providing conditions for continuous formative assessment; by constructing a blockchain-based self-directed learning process traceability platform, a reliable and immutable data traceability system is provided for real-time recording and secure storage of learning data. Simultaneously, related smart contracts are responsible for verifying the legitimacy of requests, ensuring data security and transparency [25].

3. PLATFORM DESIGN

The self-directed learning process traceability platform adopts a two-layer architecture design, establishing a decentralized learning process evaluation system. As shown in Figure 2, the platform's overall architecture can be divided into a blockchain foundation layer and an application service layer, with functional modules at each layer working closely together to support the platform's efficient operation.

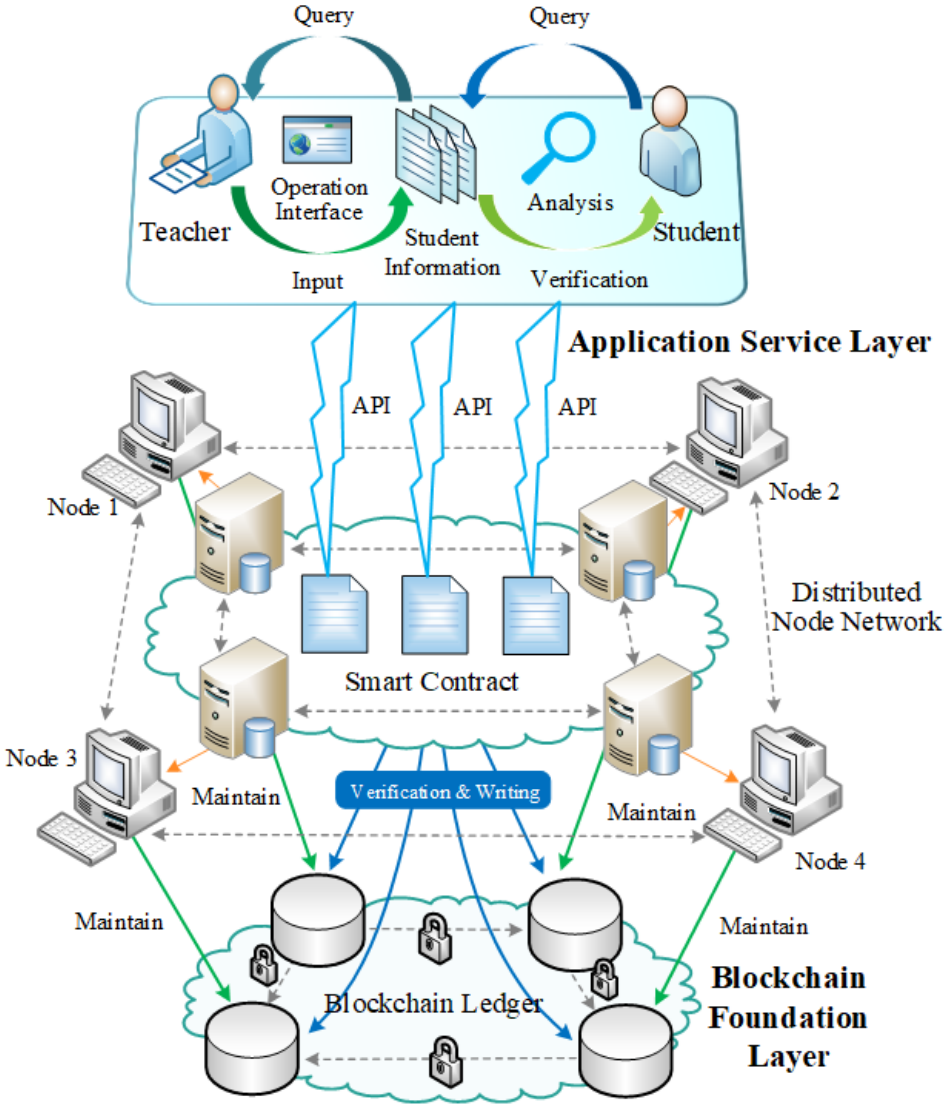


Figure 2. Platform framework

3.1. Blockchain Foundation Layer

The blockchain foundation layer is the core technical support of the platform, mainly consisting of three core components: distributed node network, smart contract system, and blockchain ledger:

(1) The distributed node network is built using P2P technology, ensuring the decentralized nature of data storage through multi-node collaboration. The nodes form a peer-to-peer network, jointly maintaining data integrity and consistency, effectively enhancing the system's fault tolerance and operational stability.

(2) as a programmatic carrier of business rules, the smart contract achieves automation and standardization of the educational evaluation process. Its built-in verification mechanism ensures the legitimacy of data entry while automatically executing relevant business logic through preset trigger conditions, improving system operational efficiency.

(3) The blockchain ledger adopts a distributed storage structure, ensuring data immutability through cryptographic mechanisms and consensus algorithms. All educational evaluation data, after verification, is permanently recorded on the blockchain, forming a complete information traceability chain.

3.2. Application Service Layer

The application service layer interfaces with end users, interacting with the blockchain foundation layer through API interfaces, primarily including teacher-end and student-end functional modules:

(1) The teacher-end implements educational evaluation data input and management functions. Teachers can input student information, course grades, and evaluation indicators through a standardized operation interface, with the system automatically calling smart contracts for data validation and on-chain storage.

(2) The student-end provides comprehensive data query and analysis functions. Students can view personal learning trajectories, grade assessments, and evaluation details in real-time, supporting traceability verification of each evaluation data entry and thoroughly ensuring the transparency of the evaluation process.

3.3. Classes and Interfaces

The platform's architecture adopts an object-oriented design pattern, including three main classes: User, Teacher, and Student. These classes are implemented through inheritance and interface relationships, forming an object-oriented structure. This design enables the system's unified use of common user concepts and introduces specific behaviors and properties for teacher and student classes. The system's class diagram structure is shown in Figure 3. The User class is the foundation for other classes, defining basic user information and login functionality. EduAction is an interface defining a series of education-related behaviors. Teacher and Student classes are subclasses of the User class, inheriting User class properties and methods while adding specific functionalities. Traceability is an interface defining support for traceability functions.

The platform has the following notable characteristics:

(1) Data Security: Based on blockchain technology's cryptographic mechanisms [17], ensuring the authenticity and immutability of all educational evaluation data.

(2) Process Traceability: Building a complete information traceability mechanism, supporting tracking and verifying each step in the evaluation process.

(3) Intelligent Automation: Implementing automatic execution of business rules through smart contracts, significantly improving evaluation work efficiency.

(4) Fine-grained Permissions: Establishing role-based access control mechanisms, achieving secure sharing and precise authorization of educational data.

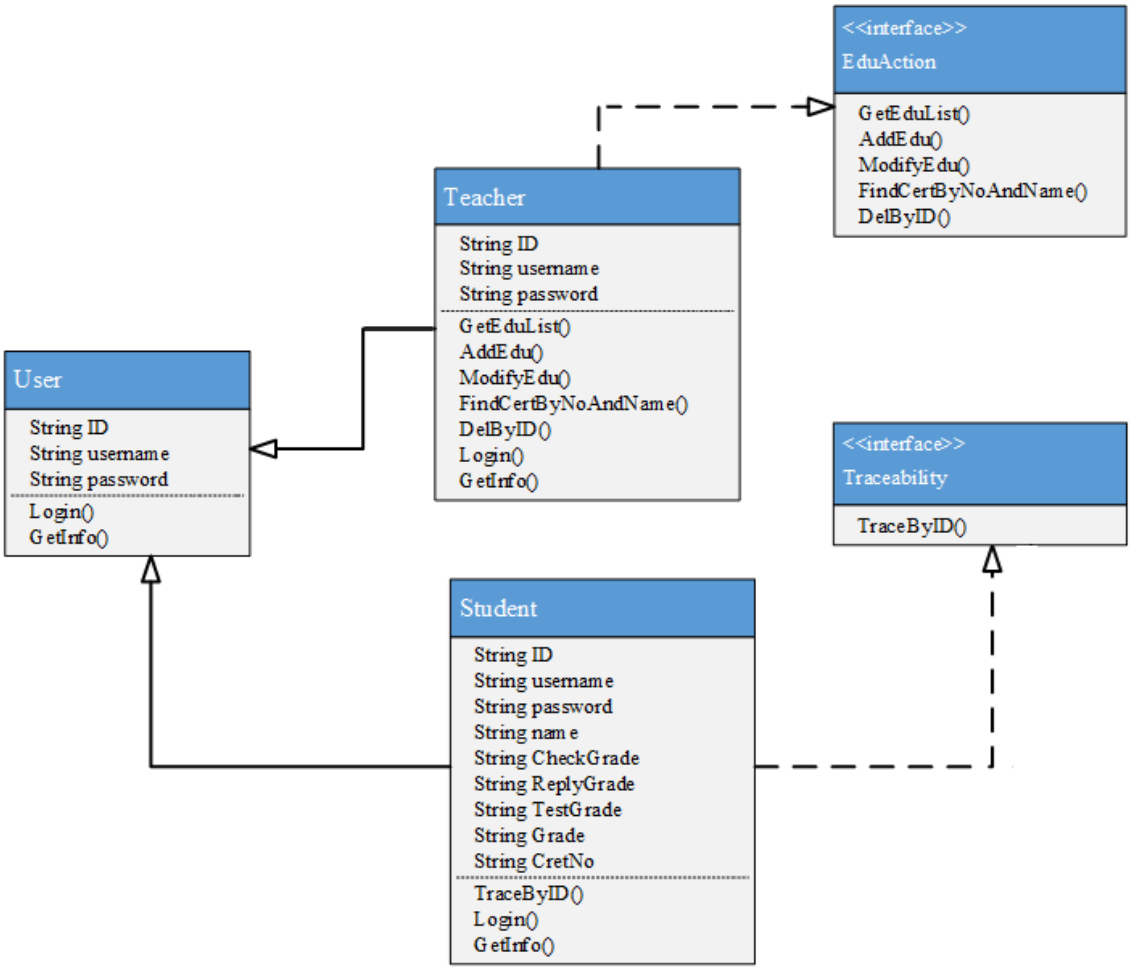


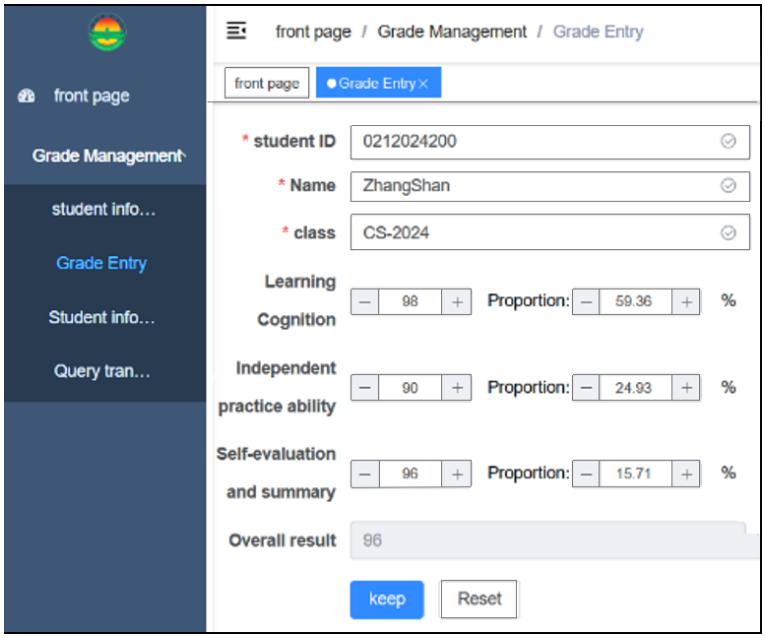
Figure 3. Platform Classes and Interface Design

Through the innovative application of blockchain technology, the platform effectively addresses issues such as low data credibility and difficult process traceability in traditional educational evaluation systems, providing reliable technical support and practical reference for building a new-era self-directed learning capability evaluation system. The platform's layered architecture design ensures system scalability and maintainability while delivering a solid architectural foundation for continued functional optimization in the future.

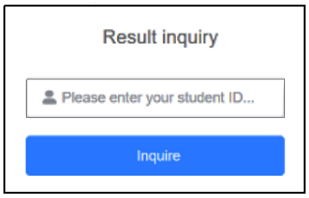
4. RESULTS AND DISCUSSION

4.1. Platform Implementation

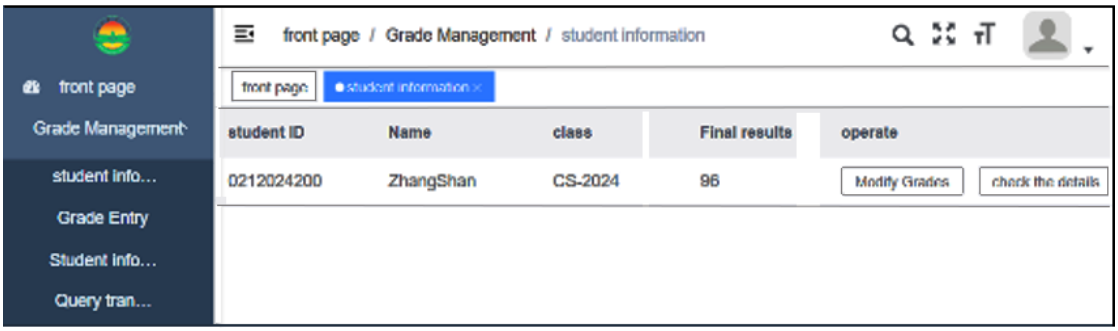
The implementation of this platform is based on the indicators affecting self-directed learning ability previously explored by Yi et al. [4], combined with the definition of evaluation dimensions and the application of blockchain technology. It quantifies learners' results in completing the self-directed learning process, better leveraging the effectiveness and function of the evaluation system. Based on this, the current study developed a prototype system to assess students' self-directed learning processes. The interface of the platform for data entry, result query, student information, and student information traceability is shown in Figure 4.



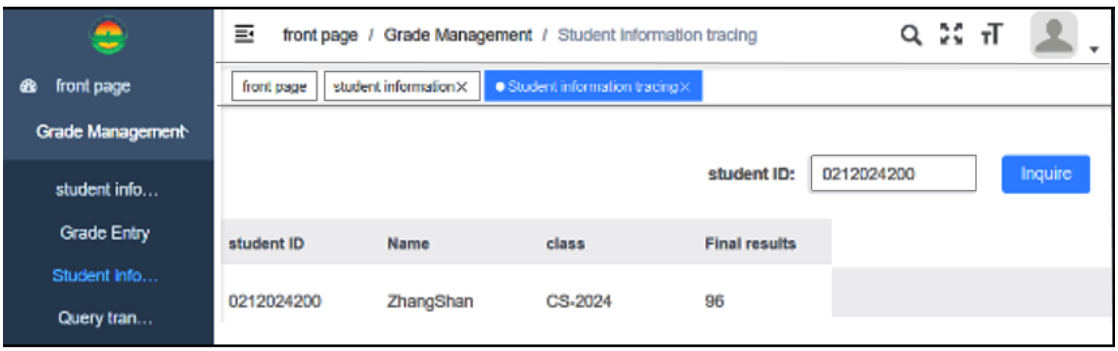
(a) Data entry



(b) Result query



(c) Student information



(d) Student information traceability

Figure 4. Platform interface

4.2. Performance Discussion

This study conducted a comprehensive system performance assessment to verify its application feasibility in actual educational scenarios. As the platform needs to support multiple ed-

ucational entities, including teachers and students, simultaneously participating in the evaluation process and data interaction, the system's concurrent processing capability directly affects whether the platform can effectively support multi-party participation in evaluation activities. We developed a distributed ledger system based on the Hyperledger Fabric framework, ensuring the consistency and credibility of evaluation data through an improved Raft consensus mechanism [26]. To simulate real educational evaluation scenarios, we set up different scales of concurrent users (100, 200, 300, and 400), with test users continuously submitting evaluation data and query requests. As shown in Figure 5, the test results indicate that even under high-concurrency evaluation data submission conditions, the platform's response time increase was minimal, with the average time, minimum time, and maximum time fluctuation range remaining stable, verifying that this platform can effectively support the self-directed learning evaluation process with multi-entity participation.

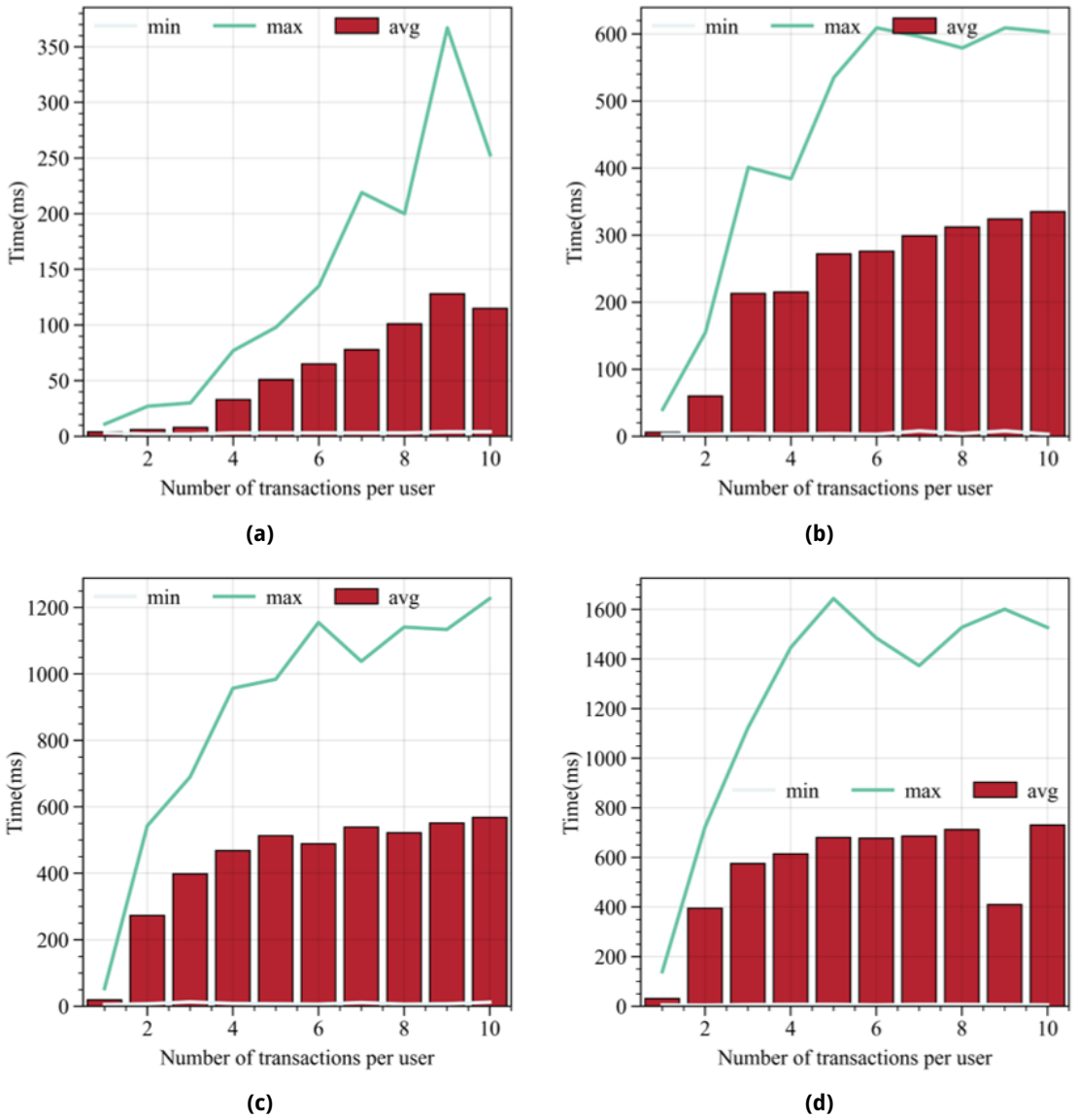


Figure 5. Processing delay of traceability interface under different concurrency levels: (a) 100 concurrent users, (b) 200 concurrent users, (c) 300 concurrent users, (d) 400 concurrent users

Through comparative analysis of the experimental data, it was found that the increase in concurrent users significantly impacted the platform's average throughput (TPS) and latency, exhibiting varying degrees of change. The specific manifestations are as follows:

Relationship between average TPS and traceability time (Figure 6a): As the number of concurrent users increased from 100 to 500, the average TPS showed an upward trend. Simultaneously, the traceability time exhibited a non-linear characteristic of decreasing and increasing. This phenomenon may reflect the platform's performance adjustment mechanism under different load conditions.

TPS variation patterns under different numbers of concurrent users (Figure 6b): A common trend was observed under four different concurrent user conditions: as the number of transactions per user increased, the platform's TPS showed corresponding growth. This phenomenon indicates that the platform is scalable and can handle continuously increasing transaction volumes.

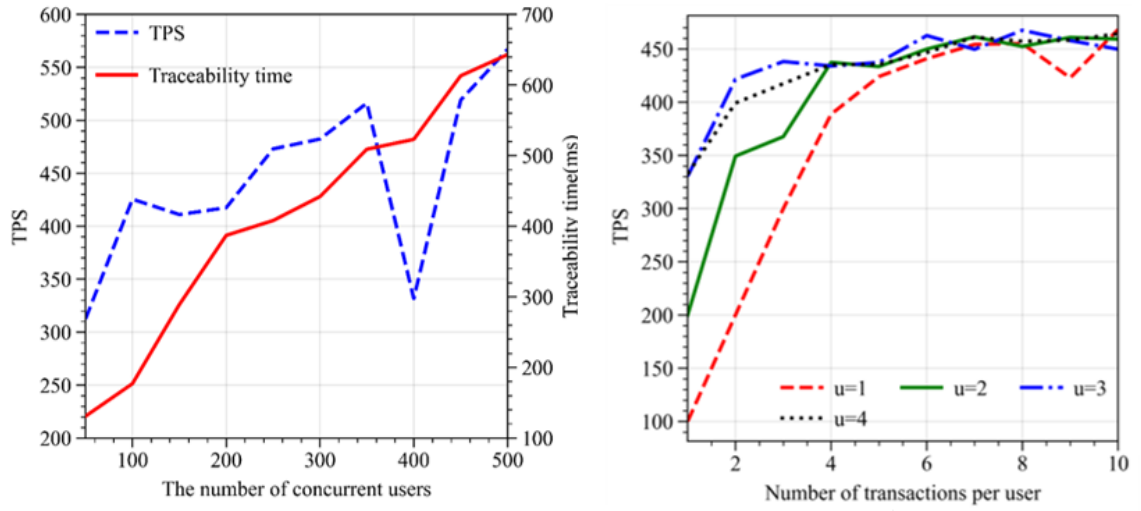


Figure 6. Comprehensive performance test of traceability interface under different concurrency levels: (a) Average TPS and latency of traceability interface under different concurrency levels, (b) TPS of traceability interface under different concurrency levels

The above experimental results reveal the performance characteristics of the system under different numbers of concurrent users and transaction volumes. The platform demonstrated good performance adaptability and stability when facing varying load pressure.

5. CONCLUSIONS

This study explored the practical application of blockchain technology in educational evaluation, focusing mainly on designing and implementing a traceability platform for learners' self-directed learning process evaluation. The research results indicate that the immutability and traceability of blockchain provide authenticity and transparency assurance for the evaluation process. At the same time, the multi-subject decentralized participation mechanism effectively reduces the influence of subjective judgments, enhancing the credibility of evaluation results. This application not only expands new directions for blockchain technology in the educational field but also provides novel theoretical foundations and technical pathways for educational

evaluation systems, promoting the development of educational informatization. The immutable learning records permanently preserved on the blockchain provide reliable data support for student selection and employment recommendations as an essential supplement to existing educational evaluation systems. Simultaneously, this study offers theoretical foundations and practical examples for integrating blockchain technology with digital education. However, it is worth noting that the current platform design is still preliminary and requires further improvement and optimization. Future research directions should include continuous optimization of platform functions, expansion of application scope, and in-depth exploration of the long-term impacts of blockchain technology in educational evaluation. Joint efforts are required from educators, technical experts, and policymakers to promote continuous innovation and improvement of the educational evaluation system.

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Разработка и внедрение платформы отслеживания оценки процесса самостоятельного обучения на основе блокчейна

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Аннотация

В этом исследовании изучалось практическое применение технологии блокчейн для оценки результатов обучения. Основное внимание уделялось разработке и внедрению платформы для прослеживаемости процесса самостоятельного обучения учащихся. Результаты исследования показывают, что неизменяемость и прослеживаемость блокчейна обеспечивают подлинность и прозрачность процесса оценки. В то же время многосубъектный децентрализованный механизм участия эффективно снижает влияние субъективных суждений, повышая достоверность результатов оценки. Это приложение не только открывает возможности для использования технологии блокчейн в образовательной сфере, но и предоставляет новые теоретические модели и технические пути для оценки образовательных результатов, способствуя информатизации образования.

Ключевые слова: *блокчейн, цифровое образование, самостоятельное обучение, оценка процесса, платформа отслеживания.*

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