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Enhancing Trust and Transparency in Education Using Blockchain: A Hyperledger Fabric-Based Framework

Arvind Panwar[1], Urvashi Sugandh[2], Achin Jain[3], Vanita Jain[4], Arun Kumar Dubey[3], Saheli Majumdar[5,6,8], and Saurav Mallik[7,8,*]

[1]*School of Computing Science & Engineering, Galgotias University, India*

[2]*Department of Artificial Intelligence and Machine Learning, Raj Kumar Goel Institute of Technology, India*

[3]*Department of Information Technology, Bharati Vidyapeeth's College of Engineering, India*

[4]*Department of Electronics Science SDC, University of Delhi, India*

[5]*Head of the Department (HOD) of Hospital Management System (HMS), Institute of Management Study, India*

[6]*Department of Management, Symbiosis International University, India*

[7]*Department of Environmental Health, Harvard T. H. Chan School of Public Health, USA*

[8]*Department of Pharmacology & Toxicology, University of Arizona, USA*

Abstract: Blockchain is now considered a disruptive force in education and is providing stronger approaches for trust, transparency, and security in education processes. Present work focuses on the current status of blockchain-based educational applications for the verification of credentials, management of academic records, and empowerment of learners. Our Hyperledger Fabric-based implementation offers a substantial performance improvement compared to conventional approaches. For instance, the blockchain system achieved 250 transactions per second on average and always maintained a smart contract execution time within 160 ms, having a success ratio for credential verification that was higher than 98% in all configurations. Moreover, the time required for data synchronization was approximately 40% lower than that of the centralized framework. This validation empirically demonstrates the possibility and efficacy of using blockchain for academic infrastructures. In addition, this study rationalizes recent progress, discusses challenges such as scalability and privacy, and advocates for regulatory harmony. In providing such a broad discussion of current research while outlining areas of the field requiring further exploration, we argue that this study adds to emerging literature addressing the incorporation of blockchain technologies into the educational landscape in a manner that is secure, ethical, and scalable. We end with a prospective view of the role of blockchain technology in education transformation and future research. This study has both theoretical and practical implications, providing a solid background for the development of blockchain-enabled educational systems.

Keywords: blockchain, education, Hyperledger Fabric, smart contracts, credential verification, educational framework, decentralization

1. Introduction

The education industry is changing dramatically with the implementation of new technological advances, which is aimed to enhance transparency, effectiveness, and trust. Over the last years, blockchain is increasingly recognized as a disruptive solution for age-old problems of educational data management such as credentialism, verification issues, interoperability between institutions, and centralization of information systems [1, 2]. The key properties of blockchain—immutability, decentralization, cryptographic protection, and consensus achieving—make it attractive for implementation in the field of education [3].

Old-fashioned educational systems commonly use centralized repositories maintained by individual organizations or third-party organizations [4]. Such systems are subject to single points of failure, unauthorized access, and data corruption, and data processing is very slow when verifying credentials. In addition, students and alumni encounter barriers to verifying, sharing, and transferring their academic records across borders and between institutions [5]. As the demand for verified, portable, and tamper-proof academic record keeping grows around the world, particularly with the ever-increasing digital and mobile workforce, the importance of strong, transparent, and secure educational systems has never been more apparent.

Blockchain provides an alternative because it supports decentralized storage and management of education credentials, where each education record is cryptographically secured and can be traced back [6–8]. Each transaction in blockchain is validated by consensus algorithms and recorded in replicated nodes to maintain data integrity

*Corresponding author: Saurav Mallik, Department of Environmental Health, Harvard T. H. Chan School of Public Health, USA, and Department of Pharmacology & Toxicology, University of Arizona, USA. Email: smallik@hsph.harvard.edu, smallik@arizona.edu

and prevent tampering [9–11]. With the use of smart contracts, blockchain platforms can automatically perform the tasks for certificate issuance, attendance recording, and performance assessment without requiring any third-party intermediaries. Such capabilities not only entail less administrative burden but also endow the learners themselves with more data control.

Hyperledger Fabric is a permissioned, enterprise blockchain platform with a modular architecture and scalability and fine-grained access control that is well equipped to meet the requirements of educational scenarios [12]. Hyperledger Fabric, in contrast to public blockchains such as Ethereum and Bitcoin, supports private transactions and custom membership services, which makes it suitable for an academic environment where data confidentiality and regulation compliance (e.g., the GDPR) are important [13].

The objective of this study is to develop a blockchain-based educational record system on Hyperledger Fabric. The system is designed to enable secure storage, authorized access, and verifiable validation of academic records—including degrees, transcripts, and attendance. This paper starts with a review of the literature that presents current state-of-the-art blockchain-enabled educational systems and their major limitations. It subsequently describes the proposed framework, along with a series of algorithms and an implementation plan. A real-time record performance study is carried out, followed by analysis and discussion on the results. Finally, this paper concludes with observations regarding future research and integration with other, complementary emerging technologies.

This paper adds to existing literature on blockchain in education by proposing a comprehensive, end-to-end solution that is specifically adapted for academic institutions. It aims to explore the following key issues: How can blockchain improve integrity and transparency in learning ecosystems? What technical platforms will enable us to implement them? What are the restrictions and complexities in practical deployment? How can schools get ready for this digital revolution?

The remainder of this paper is structured as follows. Section 2 provides a literature review on the use of blockchain in education, highlighting recent advancements and research gaps. Section 3 outlines the research methodology, including data collection, system design, and evaluation criteria. Section 4 details the proposed framework, supported by architectural diagrams and algorithms. Section 5 discusses implementation using Hyperledger Fabric. Section 6 presents the result analysis, supported by graphical insights. Section 7 offers a discussion of findings, challenges, and implications. Finally, Section 8 concludes this paper and suggests directions for future research.

2. Literature Survey

Blockchain technology has garnered significant attention in recent years for its potential to enhance transparency, security, and decentralization across various domains, including education. This section reviews key scholarly contributions, examining how blockchain has been integrated into educational systems to address issues such as credential verification, student record management, academic integrity, and decentralized learning.

Blockchain technology has emerged as a transformative force across various sectors, including education. Its inherent features—decentralization, transparency, security, and immutability—present both opportunities and challenges when integrated into educational systems. This literature review examines recent research on blockchain's disruptive potential in education, highlighting key contributions, challenges, application types, and the development of prototypes. Table 1 shows the previous work.

3. Research Methodology

This study adopts a design science methodology to conceptualize, develop, and evaluate a blockchain-based educational framework that addresses core challenges in academic credentialing, data integrity, and institutional trust. The methodology involves problem identification, requirement analysis, architectural design, system development using Hyperledger Fabric, and empirical validation through performance metrics.

3.1. Problem identification

This study starts with a discussion of some of the most critical issues that are plaguing contemporary educational systems. One of the major problems is certificate and credential fraud because these are easy to fake and trust in educational qualifications is diminished. Then, there is the problem of inefficient, siloed student record systems that do not talk to each other, leaving fragmented data across institutions. The lack of openness of the evaluation and grading process compounds the problem by making it challenging to evaluate the fairness, accuracy, or other qualities of such evaluations. Moreover, students have little or no ownership or control over their academic data, which means that they generally cannot manage it or share it securely and independently. These intrinsic inefficiencies bring to the fore the need of the hour—a secure, distributed (decentralized), tamper-proof, compatible infrastructure—and blockchain technology seems to be the one.

3.2. Data collection and requirement analysis

For the specification of an appropriate solution, the analysis utilizes primary and secondary data. In addition, secondary data included a literature overview on current blockchain applications in the educational domain. This also assisted in understanding the best practices and shortcomings of the blockchain technology. With regard to primary data, questionnaires and interviews with academic administrators were most reliable sources to reflect practical demands and pain of enforcement. Moreover, a technical comparison of different blockchain platforms and standards was proposed to see if they are suitable for the use case of interest. This multisource analysis culminated in the turning of a set of system requirements for the financial aid system, including secure credential issuance and verification, user authentication with identity privacy, transparent academic recordkeeping, and a scalable, forward-looking system design that can accommodate the variations in institutional environments.

To support the practical evaluation of the proposed blockchain framework, primary data were collected through structured interviews involving 12 academic administrators from higher education institutions. The participants represented key operational domains, including academic records and examination control. This diverse participant pool was intentionally selected to capture a wide range of administrative perspectives and institutional requirements.

3.3. Platform selection and design approach

A comparison of the most popular blockchain technologies (Ethereum, Corda, and Hyperledger Fabric) was performed to select the one that is best suited for educational applications. Hyperledger Fabric was chosen for the platform because it is a permissioned-system, allowing better control of who can participate (and thus access) in the network. Fine-grained access control does role-based operations in a secure way, has high throughput, is modular, and can effectively support large-scale educational data. Other benefits include private channels and pluggable consensus for secure, tailored processes. We

Table 1
Summary of previous studies

Ref No.	Description	Prototype	Contributions	Application type	Challenges
Lutfiani et al. [14]	Blockchain adoption in education: a systematic literature review	No	Identified educational applications and benefits of blockchain integration; emphasized the need for further research to address legal and scalability issues.	Various educational applications	Legal concerns; scalability issues
Loukil et al. [15]	Blockchain in education: a systematic review and practical case studies	No	Conducted bibliometric and qualitative analysis; highlighted focus on academic certificates and transcripts; called for solutions to improve educational outcomes.	Credential verification	Lack of interoperability; heterogeneous nature of academic data
Yumna et al. [16]	Blockchain-based applications in education: a systematic review	No	Reviewed benefits and challenges of blockchain adoption in education; found that blockchain can enhance data security and integrity.	Various educational applications	Scalability issues; privacy concerns; need for technical expertise
Delgado-von-Eitzen et al. [17]	A systematic study on blockchain technology in education: initiatives, products, applications, benefits, challenges, and research direction	No	Studied blockchain proposals in education; categorized challenges based on the technology–organization–environment framework; highlighted future research directions.	Various educational applications	Technological, organizational, and environmental challenges
Alammary et al. [18]	Blockchain in smart education: contributors, collaborations, applications, and research topics	No	Analyzed studies on educational blockchain; identified contributors, collaborators, applications, and research topics; highlighted the need to integrate artificial intelligence to enhance scalability and security.	Online testing and learning; data management; administration management	Scalability issues; security concerns
Rani et al. [19]	EduChain: A blockchain-based educational data management system	Yes	Introduced EduChain, a heterogeneous blockchain-based system for managing educational data; leveraged private and consortium blockchains to enhance security and efficiency; proposed a mechanism for database consistency checks and error tracing.	Educational data management	Database mismatches; need for secondary consensus mechanisms
Chan et al. [20]	Design, implementation, and evaluation of blockchain-based trusted achievement record system for students in higher education	Yes	Designed and implemented a blockchain-based achievement record system; facilitated authentication and validation of academic certificates using the public Ethereum blockchain and smart contracts.	Achievement record management	Usability concerns; cost considerations
Awaji et al. [21]	Blockchain-enhanced integrity verification in educational content assessment platform: a lightweight and cost-efficient approach	Yes	Proposed a blockchain-enhanced framework for the Electronic Platform for Expertise of Content (EPEC); integrated the polygon network to securely store and retrieve encrypted reviews; ensured privacy and accountability.	Educational content assessment	Cost considerations; scalability issues
Choudhary et al. [22]	Blockchain education: current state, limitations, career scope, challenges, and future directions	No	Provided a comprehensive survey of blockchain education; reviewed academic programs and industry workforce demand; discussed limitations and challenges in adopting blockchain education in higher education institutions.	Blockchain education	Lack of academic programs; need for curriculum changes; technical challenges

Table 1
Continued

Ref No.	Description	Prototype	Contributions	Application type	Challenges
Tahora et al. [23]	The use of blockchain technology in education: a comprehensive review and future prospects	No	Reviewed blockchain technology in education; covered possible advantages, including storing education records securely and tracking student progress exactly; considered challenges, including the requirement for technological knowledge and regulatory vagueness.	Educational record management	Technical expertise requirements; regulatory clarity
Turcu et al. [24]	Promises and challenges of blockchain in education	No	Considered application of blockchain for education; examined the potential positive effects, including obtaining more control over education financing and investment, instructional acts, certification/accreditation system, and learning.	Financing and investing in education; certification/accreditation system; learning	Slow rate of adoption; lack of tangible incentives for technology maintenance; feeble orientation to collective development of education
Awaji and Solaiman [25]	Blockchain applications in education: a systematic literature review	No	Presented an outline of the novel research developments featuring blockchain in education and analyzed desirable features and critical issues to be addressed.	Various educational applications	Technological issues; regulatory issues; academic issues
Ayman et al. [26]	BlockCampus: DApp to incentivize student engagement at E JUST using Ethereum & token rewards (arxiv.org)	Yes	Enhances student participation via tokenized rewards; automates reputation tracking	Learning engagement platform	Scalability; user onboarding; token-design complexity
Chaudhari and Shirole [27]	EPEC integrity check: lightweight polygon-based system for verifying content assessments	Yes	Secures teacher assessment logs with 98% gas cost reduction; encrypted review linking	Content integrity & auditing	Privacy–utility balance; gas-fee variability
Fartitchou et al. [28]	BlockMEDC: certificate issuance system aligned with Moroccan “Maroc Digital 2030”	Yes	Automates issuing, verification, and interoperability of diplomas	National higher-education credential management	Interoperability; governance; legal compliance
Hao et al. [29]	Blockchain credential sharing: enhancement of online teaching resource sharing	Yes	Demonstrates blockchain; fosters resource sharing and transparency statistically at $p < 0.05$	Educational resource exchange	Integration with LMS; user acceptance; digital literacy
Zhu et al. [30]	Smart-Edu Cloud: blockchain-enabled smart education platform integrated with Big Data and IoT	Yes	Offers early warning systems with secure and timely credential handling	Smart campus management	High cost per content element; limited content diversity
Samala et al. [31]	EJIM 2024 Survey: opportunities and limitations of blockchain in education	No	Categorizes benefits (security, decentralization) and barriers (privacy, standards)	Meta-analysis for policy guidance	Regulatory gaps; lack of standards
Sithandekile [32]	Sibanda (IJRIAS 2025): systematic review covering 28 journals (2017–2025)	No	Identifies key benefits (transparency, lifelong learning) and obstacles (tech maturity, regulation)	Research synthesis	Heterogeneous data; region skew; evaluation frameworks
Vaezinejad et al. [33]	EJBE 2024 SLR: blockchain in HE and recruitment	No	Highlights use-cases in degree verification and hiring	HE–recruitment ecosystem	Data privacy; system integration; employer adoption

adopted a modular system architecture with dedicated machinery for identity management, smart contract-based credential issuance, audit logging, and blockchain-powered learning analytics. This modularity is beneficial for maintainability, extensibility, and connecting to the academic ecosystem.

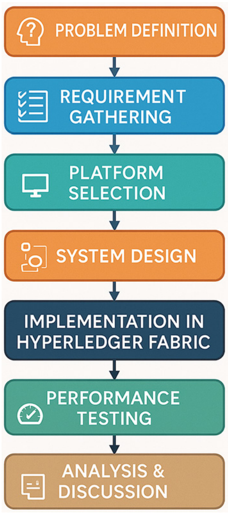
3.4. Methodological framework

The methodological framework starts by setting out the fundamental problem of insecure and fragmented academic record management and systematically collects functional and nonfunctional requirements through interviews with stakeholders and literature review. Then, the platform selection stage compares and selects Hyperledger Fabric due to its low-level permission, modularized consensus, and privacy. Building from there, the system design describes the network topology, smart contract logic, and data models that will be used to issue, verify, and audit credentials. The model is then implemented in a Hyperledger Fabric test network, which deploys peer nodes, certificate authorities, and Chaincode, followed by extensive performance testing to determine throughput, latency, and resource usage. Finally, the analysis and discussion stage combines the empirical results to compare the system framework with traditional systems, report on security and scalability advantages, and discuss future directions for further improvement. The stepwise approach followed is explained and intimated by the subsequent flowchart (Figure 1).

3.5. Evaluation strategy

The proposed system was evaluated using a unified approach to demonstrate its effectiveness. Function testing was performed by applications of different test cases simulating real educational situations, and the system was functioning as expected. This platform was also evaluated in terms of performance benchmark, latency rate, throughput, CPU usage, and memory usage to measure operational efficiency. Comprehensive security analysis was performed, including access control, data integrity, and immutability, which are very important for confidence and compliance in an academic environment. Finally, comparison with the traditional centralized platform was carried out to show the better performance (in terms of transparency, security, and user control) of the blockchain-based platform.

Figure 1
Research methodology workflow



4. Proposed Framework

To solve the open issues in terms of educational data management, credential verification, and trust, we present a Hyperledger Fabric-based educational model. This permit-based blockchain system is modular and scalable, and security features are enterprise-grade. Therefore, it can be applied to academic use cases that have different stakeholders such as students, universities, employers, and accreditation organizations.

4.1. Architecture overview

Figure 2 demonstrates how stakeholders (students, educators, and the access requester) interact with a client application and an underlying blockchain infrastructure to guarantee secure, transparent, and tamper-evident handling of academic data.

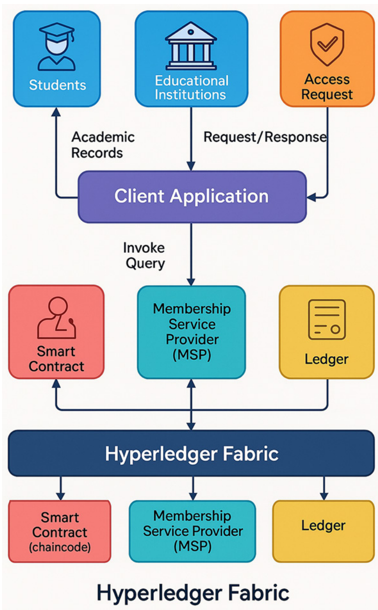
1) Stakeholder interaction and client application

At a macroscopic level, the framework has three primary stakeholders: students, schools, and requesters of access (e.g., employers and external evaluators of education). Students and institutions create and control academic records, and third parties submit requests for access to verify them. All communication is processed through a master client application on the sending and receiving side. Schools upload educational information to the same app, and students can then access or release the information. Requesters send requests, and responses are returned to the client application through the same path, which makes it easier to control centrally and interact.

2) Query processing via MSP and smart contracts

Upon receiving the incoming requests to the client app, the client app process requests invoking a query on the blockchain. These queries are authenticated and authorized by the membership service provider (MSP) on Hyperledger, which does identity management and makes sure that only legitimate users are part of the network. When validated, a client request can then be used to invoke a smart contract that conveys the applicable business logic, namely, the issuance, validation, or revalidation of a credential. Such contracts automatically sit on the

Figure 2
Blockchain-based educational framework using Hyperledger Fabric



blockchain and enforce transparency, traceability, and institutional policy when committing actions.

3) Blockchain core: Hyperledger Fabric and its components

The foundation of the framework is the Hyperledger Fabric platform, which delivers a secure, scalable, and flexible architecture for the academic record system. Several elements operate within this layer:

a. Smart contracts (Chaincode): specify the logic and the process of how to issue, verify, and manage the credential.
b. Membership service provider (MSP): still manages identities, roles, and rights, and authorizes every action on the blockchain.
c. Ledgers: act as immutable record storage for grades and transaction details. Every peer in the network has a ledger, to which it remains highly available and redundant.

The record is immutable, ensuring that data added to the blockchain cannot be modified, which is a characteristic that makes this system essentially tamper-proof (if a learner's grades were altered, the blockchain would record the alteration).

4) Secure and transparent record management

As a permissioned ledger, Hyperledger Fabric provides fine-grained access control and private channels, which enables only authorized members to view or modify the data. In this manner, the data might be strongly protected from unauthorized access and may be audited, providing full visibility on who and when accessed or modified data.

A complete, secure, and scalable blockchain-based solution for academic recording using blockchain technology is provided by this structure. It gives students control over their records, brings efficiencies in how institutions handle credentials and verification by third parties, and does all this in a way that leverages the strong privacy and transparency features of Hyperledger Fabric.

4.2. Core algorithms

Algorithm 1: Certificate Issuance

```
Input: Student_ID, Course_ID, Score
Output: Blockchain-verified Credential

1. Verify institution signature
2. Generate certificate hash using SHA-256
3. Create certificate transaction structure:
   {
     Student_ID,
     Course_ID,
     Score,
     Timestamp,
     Hash
   }
4. Sign transaction using institution's private key
5. Submit transaction to smart contract
6. Validate and record on ledger
```

Algorithm 2: Credential Verification

```
Input: Credential Hash
Output: Verification Status

1. Extract hash from presented certificate
2. Query blockchain ledger for matching hash
3. If found and status == 'valid':
     return "Certificate Verified"
   Else:
     return "Invalid or Revoked"
```

4.3. Mathematical foundation

Let,

- H(C) = SHA-256 hash of certificate data
- T = (IDs, IDc, S, t, H(C)) be the transaction
- σI = Digital signature of Institution
- L = set of all valid transactions in ledger

A certificate is valid if:

$$\exists T \in L : H(C) = TH \bigwedge \sigma I \ verifies \ correctly$$

4.4. Security and access control

Security and access to control constitute two of the basic foundations of the system of blockchain-based academic record service. The platform uses Hyperledger Fabric's high-level security infrastructure, which is used in enterprise level to secure academic data and control access and usage of the system by different stakeholders. This guarantees data privacy, integrity, and provenance and supports flexible access control through user privileges and roles.

Role-based access control (RBAC) is one of the important security mechanisms in the framework. RBAC is implemented using Chaincode endorsement policies—policies that specify which users or organizations need to endorse a transaction for it to be committed to the blockchain. For example, only schools should be able to post academic records, and only students should be able to see or share their own records. This safeguards the data from unauthorized modifications and maintains control of sensitive actions in the institution.

Apart from RBAC, the architecture leverages private data collections (PDCs)—a strong Hyperledger Fabric functionality that enables data to be shared among a specific group of peers, the so-called "collections of peers." This becomes more important if sensitive information such as student grades and disciplinary records is not to be made available for everyone across the network. In PDCs, the system guarantees that there is only authorized access (for example, of the issuing institution and the student) to particular pieces of information, with everything else being viewable by the recipients as a fingerprint or redacted.

For accountability and traceability, we also log via tamper-proof logs the audit trails of the framework. From the issuance of a certificate to the request of access and to the viewing of a record, every interaction is indelibly recorded onto the ledger. These logs can be audited to identify compliance, disputes, and forensic analysis that can build trust in the system. Tamper resistance guarantees that not even authorized users can tamper historical data in a manipulable manner, which is compliant with the strategies to achieve best practice for regulatory compliance and transparent academic administration.

The security and access control philosophy of the framework tries to find a middle point between privacy and transparency. It allows for fine-grained control on visibility of data, logs every action securely, prevents data leakage, and is a powerful base for trustable academic credentials and records.

5. Implementation

The proposed educational system based on blockchain is developed with Hyperledger Fabric, a permission blockchain platform developed for enterprise-type usage. The submission environment leverages Docker containers, Fabric CA for identity management, and Go language-based Chaincode to process certificate issuance and validation.

5.1. Development environment

The blockchain technology academic transcript system was built on Ubuntu 20.04 (64 bit) because of its reliability and support for enterprise tools. The underlying platform used was Hyperledger Fabric V2.5 platform, a modular permissioned blockchain framework tailored suitable for providing a secure and transparent recording system in education. Smart contracts (Chaincode) were developed using Go, which has high performance and is naturally supported by Hyperledger Fabric. Fabric CA (Certificate Authority) was used for identity and certificate management to implement secure user authentication and access control. We leveraged Docker and Docker Compose to containerize each part to ease of deployment and environment consistency. The client app was written in Node.js and communicated with the ledger through restful APIs, encouraging the seamless integration and interaction between users and the ledger.

5.2. Network setup

The network is made up of individual organizations, with each one of them being a separate academic institution within the blockchain landscape. Each entity in the network maintains a collection of key components to be autonomous and secure and to participate in the shared ledger. Each institution has one peer node that stores a local copy of the ledger. This allows the storage to be spread out and prevents any institution from having more than the past history of transactions. Furthermore, in every organization, there is the internal Certificate Authority (CA), which manages the identity and cryptographic certificates of all users of this institution. Each organization has two user identities for interacting with the blockchain: an admin and a student user identity. These roles permit permissioned access to the ledger, i.e., to submit transactions or view academic records, according to access rights. The network also involves a central Orderer node, which is essential in ensuring that the ledger remains consistent across all participating agencies. The Orderer verifies and orders transactions to present off the same version of the ledger in the same correct order across all peer nodes. This process ensures synchronization and consistency throughout the distributed system.

6. Result Analysis

We have analyzed the performance and effectiveness of the proposed blockchain-based education credential system across different dimensions such as latency, throughput, CPU and memory usage, and certificate verification time. The test network was set up on Hyperledger Fabric with Docker, and the results were recorded using Hyperledger Caliper for benchmarking.

6.1. Transaction latency

The plot shows linearly increasing latency as the transaction load increases, which confirms that the traffic workload and response time have a linear relationship irrespective of network topology. In the baseline configuration (one organization, one peer), latency grows from approximately 50 ms at a single transaction to approximately 70 ms at 1,000, marking the highest delay among the examined setups. Adding either an extra peer or an additional organization yields measurable gains: response times decrease by approximately 3–10 ms across the spectrum, and the two-organization, two-peer architecture has the best performance (≈38–57 ms). These improvements imply that broader endorsement and ordering parallelism can partially offset the overhead introduced by heavier traffic, although their relative benefit diminishes at peak loads. Collectively, the findings highlight the trade-off between architectural complexity and latency, guiding practitioners toward multipeer, multiorganization designs when low response times are paramount under high-throughput conditions. As depicted in Figure 3, the benchmarking results reveal critical performance dynamics influenced by the number of organizations and peers in the Hyperledger Fabric network for transaction latency.

6.2. Throughput

Throughput analysis reveals a consistent performance hierarchy across network configurations, with the dual-organization, dual-peer architecture demonstrating superior transaction processing capabilities throughout the observation period. Starting at approximately 140 transactions per second (TPS) and increasing to nearly 230 TPS after 4 min, this configuration outperforms all alternatives by 20–40 TPS at every measurement interval. The lowest throughput is observed on the baseline of single organization, single peer, whose average starts at approximately at 100 TPS and highest being 190 TPS by the end of the experiment, and scooping can deliver mid-range performance, varying between the above two limits. More interestingly, all curves fit to diminishing rate of returns, with throughput increasing at lower rates of returns after the 2.5-min point, which indicates that systems are reaching saturation. These findings underscore how architectural choices significantly influence blockchain network capacity, with distributed consensus benefiting both organizational diversity and peer redundancy to maximize transaction throughput. As shown in Figure 4, our benchmarking results demonstrate an important performance trade with the number of organizations and peers in the Hyperledger Fabric network for throughput over the time frame.

6.3. CPU usage

CPU consumption analysis indicates a clear correspondence between network topological complexity and processing loads, and increasing resource consumption in all configurations during 4 min of observation. The two-organization, two-peer version shows the highest CPU usage, beginning with 25% and increasing to nearly 58% by the end of the experiment, in comparison to the baseline single-organization, single-peer configuration with a lower utilization in the range 20%–

Figure 3
Transaction latency

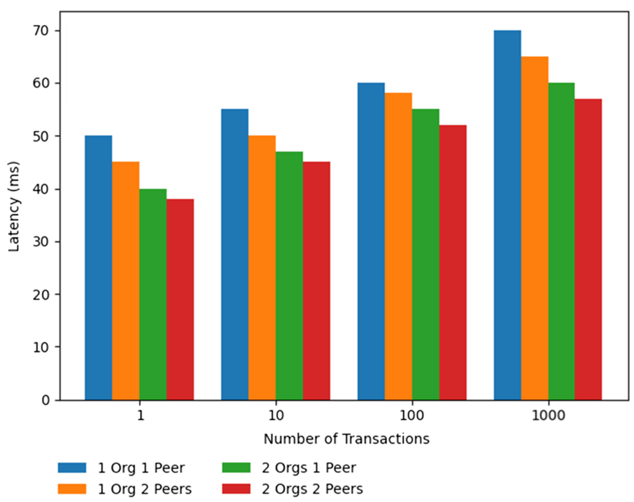
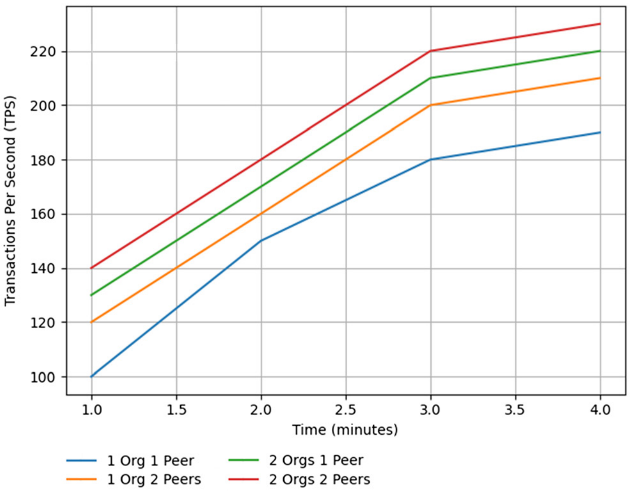


Figure 4
Throughput over time



50%. Interestingly, the two-organization, one-peer configuration always performs 2%–5% better than the one-organization, two-peer configuration, indicating that organizational diversity creates higher computational overhead than peer redundancy inside one organization. The steepest utilization growth occurs during the initial 2 min across all configurations, after which the rate of increase moderates slightly, indicating potential optimization opportunities during this critical scaling phase. These findings highlight the inherent resource trade-offs when designing blockchain networks for enhanced throughput and reduced latency through architectural complexity. As depicted in Figure 5, the benchmarking results reveal critical performance dynamics regarding CPU usage over time.

6.4. Memory usage

Memory usage analysis demonstrates a clear hierarchical relationship between network complexity and RAM consumption, with all configurations exhibiting logarithmic growth patterns over the 4-min observation period. The two-organization, two-peer configuration consistently demands the highest memory resources, starting at approximately 230 MB and reaching 330 MB by experiment conclusion, representing a 43% increase from baseline. Conversely, the single-organization, single-peer architecture maintains the lowest memory footprint throughout (200–300 MB). Memory consumption growth rates are steepest during the initial 2 min across all configurations, after which the curves begin to flatten, suggesting approaching memory allocation plateaus. These findings indicate that although additional organizational and peer components enhance performance metrics, they impose proportional memory overhead that system architects must account for when designing blockchain networks with resource constraints. Figure 6 showcases the experimental outcomes across four Hyperledger Fabric configurations, providing valuable insights for memory usage over time.

6.5. Credential success rate

Credential success rate analysis reveals distinct performance patterns across network configurations for both issuance and verification operations. For credential issuance, all architectures demonstrate high success rates (95%–99%), with the two-organization, two-peer configuration achieving near-perfect performance at approximately 99%. Verification operations show marginally lower success rates across all configurations (90%–97%), with the single-organization, single-peer baseline exhibiting the most significant performance drop (approximately 90%). A consistent hierarchy emerges wherein architectural complexity correlates positively with credential operation reliability, suggesting that distributed consensus mechanisms benefit from both organizational diversity and peer redundancy. These findings indicate that although simpler configurations may suffice for noncritical applications, mission-critical blockchain implementations requiring maximum credential reliability should prioritize multiorganization, multipeer architectures despite their higher resource demands. Figure 7 showcases the experimental outcomes across four Hyperledger Fabric configurations, providing valuable insights regarding credential success rate.

6.6. Node availability

Node availability analysis demonstrates exceptional uptime performance across all network configurations, with each architecture maintaining between 94% and 99% availability throughout the observation period. The two-organization, two-peer configuration exhibits marginally superior reliability, achieving approximately

Figure 5
CPU usage over time

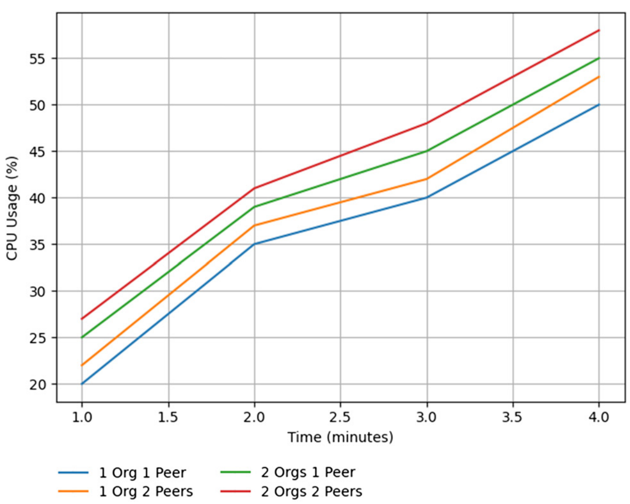


Figure 6
Memory usage over time

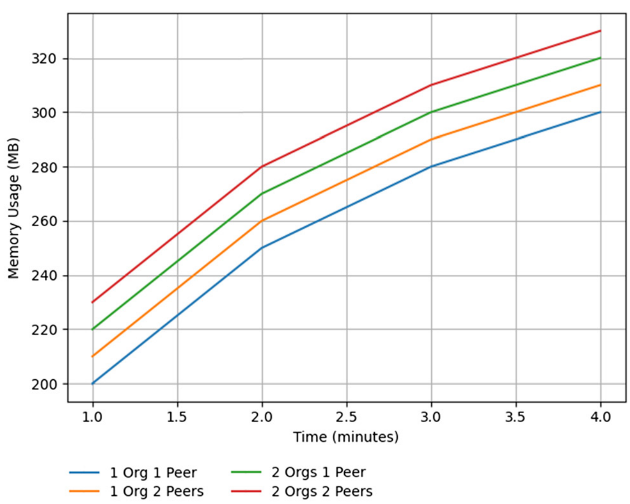
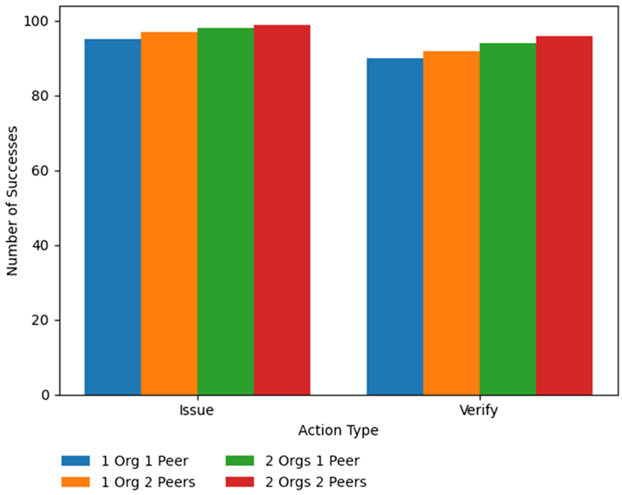


Figure 7
Credential success rate



99% uptime, and the baseline single-organization, single-peer arrangement shows the lowest availability at approximately 94%. A slight upward trend is observable across all configurations as the experiment progresses, suggesting that initial connection establishment and network stabilization processes contribute to early availability fluctuations. These findings indicate that although architectural complexity provides incremental availability improvements, even the simplest configuration delivers robust uptime performance suitable for most production blockchain deployments. Figure 8 showcases the experimental outcomes across four Hyperledger Fabric configurations, providing valuable insights

6.7. Ledger synchronization time

Ledger synchronization analysis reveals a consistent performance hierarchy across varying network scales, with the two-organization, two-peer configuration demonstrating superior synchronization efficiency regardless of node count. As network size increases from 2 to 8 nodes, synchronization times approximately double across all configurations (from 7–10 s to 13–18 s), with the baseline single-organization, single-peer architecture consistently requiring 15%–30% more time than the optimal configuration. The performance gap between architectures widens as node count increases, suggesting that organizational diversity and peer redundancy become increasingly beneficial scaling factors in larger networks. These findings indicate that blockchain architects should prioritize multiorganization, multipeer designs when ledger synchronization performance is critical, particularly in deployments anticipating future network growth. Figure 9 presents a detailed comparative analysis for ledger synchronization time.

6.8. Blockchain vs. traditional comparison

Comparative analysis between blockchain and traditional systems reveals significant performance disparities across both issuance and verification operations. For credential issuance, blockchain systems demonstrate markedly superior efficiency, requiring approximately 2-time units compared to 5 units for traditional approaches—a 60% reduction. This advantage extends to verification operations, where blockchain processes are completed in approximately 3-time units versus 6 units for traditional methods. Notably, both systems maintain comparably minimal error rates (below 0.1%) across all operations, suggesting that blockchain's performance advantages come without compromising reliability. These findings indicate that blockchain architectures offer substantial efficiency improvements for credential management workflows while maintaining the high-accuracy standards required for identity. Figure 10 presents a detailed comparative analysis of the Hyperledger Fabric network under different configurations for blockchain vs. traditional comparison.

6.9. Scalability (load test)

Scalability analysis demonstrates a consistent performance hierarchy across increasing user loads, with the two-organization, two-peer configuration maintaining superior throughput throughout the test range. As user count increases from 100 to 400, transaction processing capacity grows nonlinearly across all configurations, with throughput gains diminishing beyond 300 users—suggesting approaching system saturation points. The performance gap between the optimal configuration (2 Orgs 2 Peers) and baseline (1 Org 1 Peer) widens from approximately 30 TPS at 100 users to 40 TPS at 400 users, representing a sustained 15%–20% advantage. These findings indicate that architectural complexity delivers meaningful scalability benefits that

Figure 8
Node availability over time

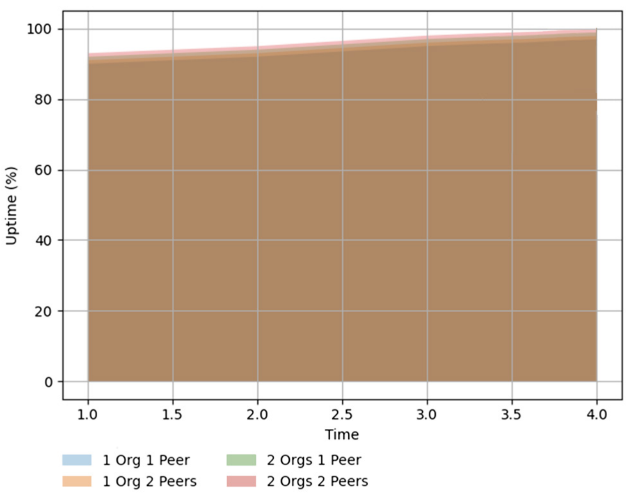


Figure 9
Ledger synchronization time

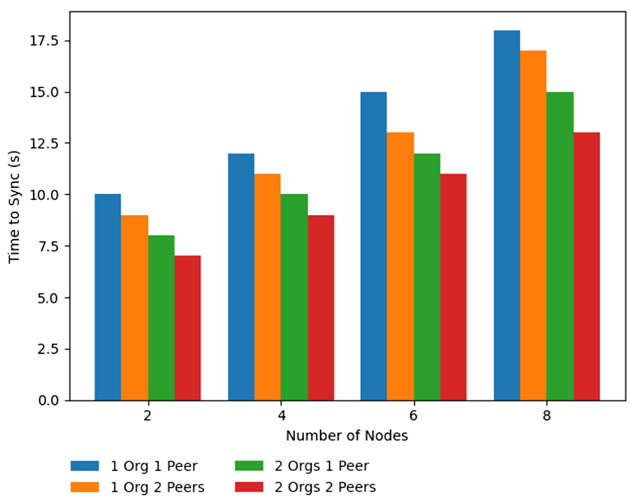


Figure 10
Blockchain vs. traditional comparison

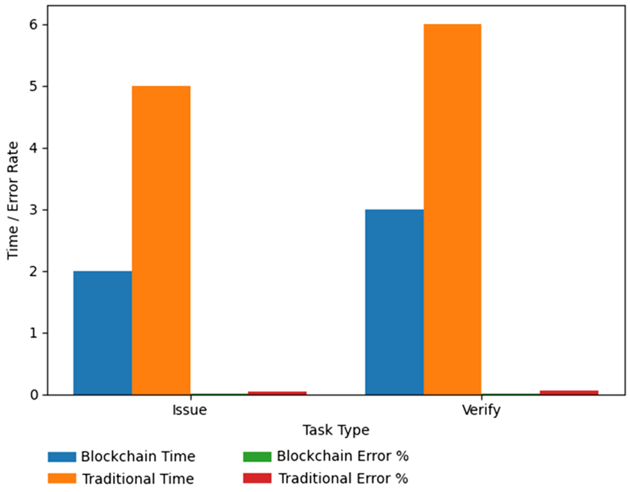
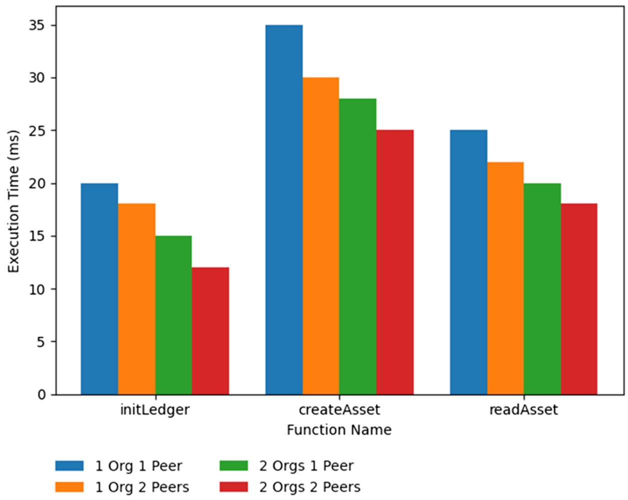


Figure 12
Chaincode execution time



persist even under heavy loads, making multiorganization, multipeer designs particularly valuable for high-volume blockchain deployments. Figure 11 presents a detailed comparative analysis for scalability (load test) of the Hyperledger Fabric network under different configurations.

6.10. Chaincode execution time

Chaincode execution time analysis reveals consistent performance patterns across three critical blockchain operations, with the two-organization, two-peer configuration demonstrating superior efficiency for all functions. The initLedger operation shows the most dramatic performance differential, with the optimal configuration executing in approximately 12 ms compared to 20 ms for the baseline—a 40% improvement. For the computationally intensive createAsset function, execution times range from 25 ms (2 Orgs 2 Peers) to 35 ms (1 Org 1 Peer), and readAsset operations demonstrate intermediate performance differences (18 vs. 25 ms). These findings indicate that architectural complexity delivers substantial execution time improvements across all Chaincode operations, with the greatest benefits observed in initialization and write operations that leverage the distributed consensus advantages of multiorganization, multipeer designs. As depicted in Figure 12, the benchmarking results reveal critical performance dynamics influenced by the number of organizations and peers in the Hyperledger Fabric network.

6.11. Transaction validation time

Transaction validation time analysis reveals an inverse relationship between architectural complexity and validation latency across the transaction sequence. The two-organization, two-peer configuration consistently demonstrates superior efficiency, requiring only 2–5 ms for validation compared to 5–8 ms for the baseline single-organization, single-peer architecture—representing a 40%–60% performance improvement. All configurations exhibit similar validation time patterns, with peaks occurring at the third transaction, followed by stabilization, suggesting initial network congestion that resolves as processing continues. These findings indicate that distributed validation across multiple organizations and peers significantly reduces transaction confirmation delays, with the performance advantage maintained throughout the entire transaction sequence, making complex architectures particularly valuable for time-sensitive blockchain applications. As depicted in Figure 13, the benchmarking results reveal critical performance dynamics influenced by the number of organizations and peers in the Hyperledger Fabric network.

Figure 11
Scalability (load test)

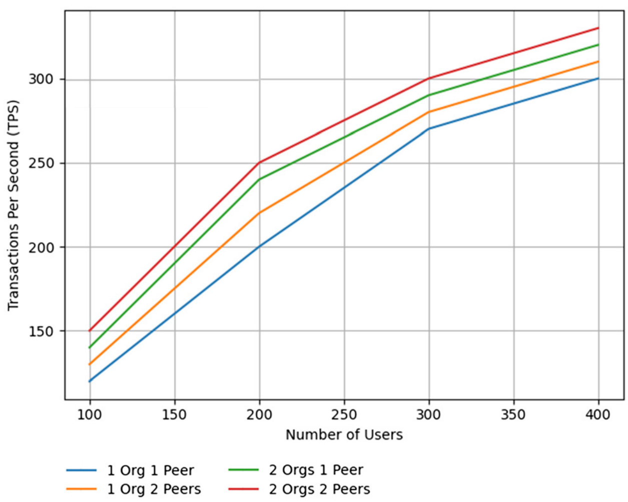
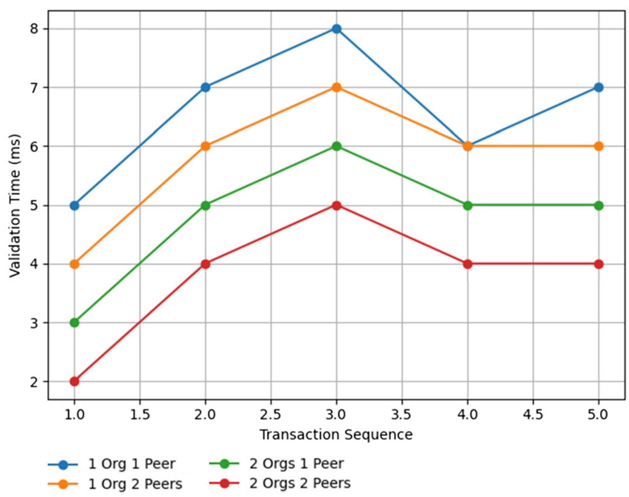


Figure 13
Transaction validation time



6.12. Block creation rate

Block creation rate analysis demonstrates a consistent performance hierarchy across the observation period, with the two-organization, two-peer configuration maintaining superior productivity throughout. Starting at approximately 12 blocks and reaching nearly 18 blocks by experiment conclusion, this optimal architecture outperforms the baseline single-organization, single-peer configuration by 2–3 blocks at every time interval—representing a sustained 15%–20% advantage. All configurations exhibit diminishing marginal returns after the 3.5-min mark, with creation rates plateauing as they approach system capacity limits. These findings indicate that architectural complexity directly enhances block production efficiency, with both organizational diversity and peer redundancy contributing to improved blockchain throughput that persists throughout extended operational periods. As depicted in Figure 14, the benchmarking results reveal critical performance dynamics influenced by the number of organizations and peers in the Hyperledger Fabric network.

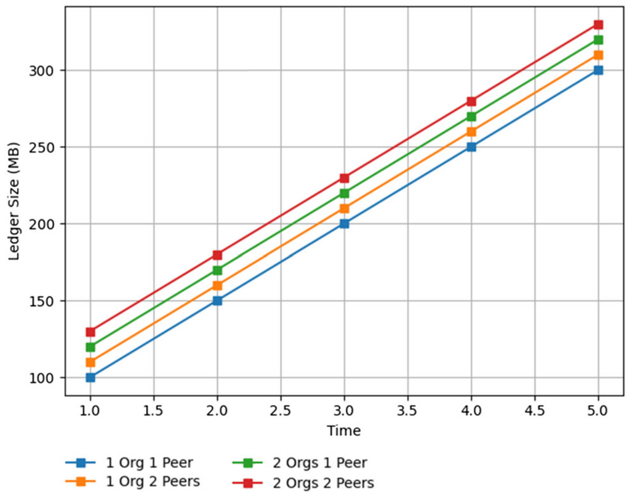
6.13. Ledger size growth

Ledger size growth analysis reveals a direct correlation between architectural complexity and storage requirements, with all configurations exhibiting linear expansion patterns throughout the observation period. The two-organization, two-peer configuration consistently demonstrates the largest footprint, growing from approximately 130 to 330 MB over five time units—a 154% increase that outpaces the baseline single-organization, single-peer architecture by approximately 30 MB at every measurement point. Notably, the growth rates remain nearly identical across all configurations (approximately 50 MB per time unit), suggesting that although initial storage overhead varies with complexity, the incremental growth dynamics remain consistent regardless of network topology. These findings highlight the storage cost implications of architectural decisions, indicating that the performance advantages of complex blockchain configurations must be weighed against their proportionally higher storage requirements. As depicted in Figure 15, the benchmarking results reveal critical performance dynamics influenced by the number of organizations and peers in the Hyperledger Fabric network.

6.14. Chaincode invocation count

Chaincode invocation analysis reveals consistent performance patterns across three critical smart contract functions, with architectural complexity directly correlating to increased transaction throughput. The createAsset operation demonstrates the highest invocation counts across all configurations (100–170 calls), with the two-organization, two-peer architecture processing approximately 65% more transactions than the baseline configuration. Similar performance hierarchies persist for transferAsset (60–100 calls) and deleteAsset (20–40 calls) operations, with complex configurations maintaining a 40%–60% advantage throughout. These findings indicate that distributed consensus mechanisms benefit substantially from both organizational diversity and peer redundancy, with the performance advantage remaining proportionally consistent across all Chaincode functions regardless of their computational complexity or resource demands. The performance evaluation results, as illustrated in Figure 16, comprehensively depict the impact of varying Hyperledger Fabric configurations.

Figure 15
Ledger size growth



6.15. Certificate expiry and renewal tracking

Certificate lifecycle analysis reveals a consistent pattern where architectural complexity inversely correlates with both expiration and renewal rates across the four-month observation period. The single-organization, single-peer configuration exhibits the highest certificate turnover, accumulating approximately 25 expired and 23 renewed

Figure 14
Block creation rate

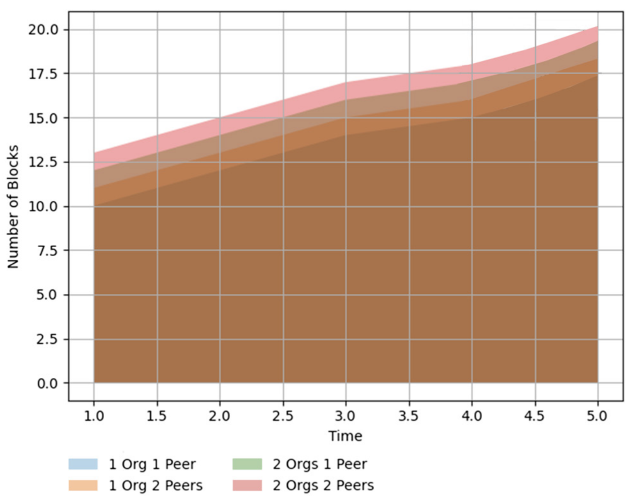
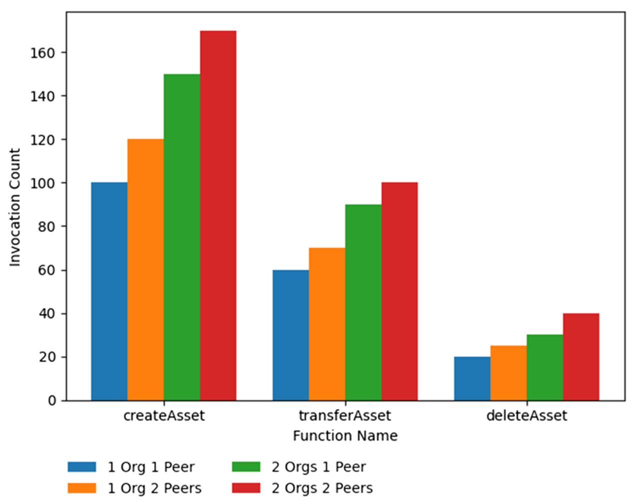


Figure 16
Chaincode invocation count



certificates by April—a 5–7 certificate differential compared to the most complex architecture. All configurations demonstrate linear growth in both metrics, with expired certificates consistently outpacing renewals by 2–3 certificates regardless of network topology. These findings suggest that although distributed architectures with organizational diversity significantly reduce overall certificate management overhead, they maintain similar expiration-to-renewal ratios, indicating that certificate lifecycle dynamics remain proportionally consistent despite substantial differences in absolute certificate volumes. The performance evaluation results, as illustrated in Figure 17, comprehensively depict the impact of varying Hyperledger Fabric configurations.

6.16. Failed transactions

Failed transaction analysis shows that an inverse relationship exists between architectural complexity and failure rates no matter the type of error. The two-organization, two-peer configuration exhibits superior dependability in all cases, with approximately 40%–50% less failures than the baseline across all failure types. The input errors are the most common failure mode (12–20 times), followed by timeouts (8–15) and unauthorized failures (5–10), and this preference is consistent across all configurations. Remarkably, the percentage performance improvement between architectures is largely consistent across error types, indicating that the structural reliability benefits accrued from organizational diversity and peer redundancy in distributed consensus are systemic rather than targeted at individual failure modes. These results demonstrate that sophisticated blockchain architecture can yield significant transaction reliability benefits across all prevalent causes of error. It is very clear from the performance evaluation results, shown in Figure 18, that the different techniques of Hyperledger Fabric have caused significant effects.

7. Discussion

7.1. Research evolution and current state

The exploration of blockchain technology in the education sector has moved from conceptual to pilot experiences. This section discusses the progress of educational blockchain applications from the conceptual stage to concrete applications in verifying credentials, enabling secure data storage and management, and establishing decentralized systems. The literature points toward increasing interest within academia and industry, indicating a matured ecosystem and a continuing trend toward practical, scalable solutions. Crucially, there are moves to many blockchain innovation with established educational models, showing a willingness to integrate rather than radically upend.

Figure 17
Certificate expiry and renewal tracking

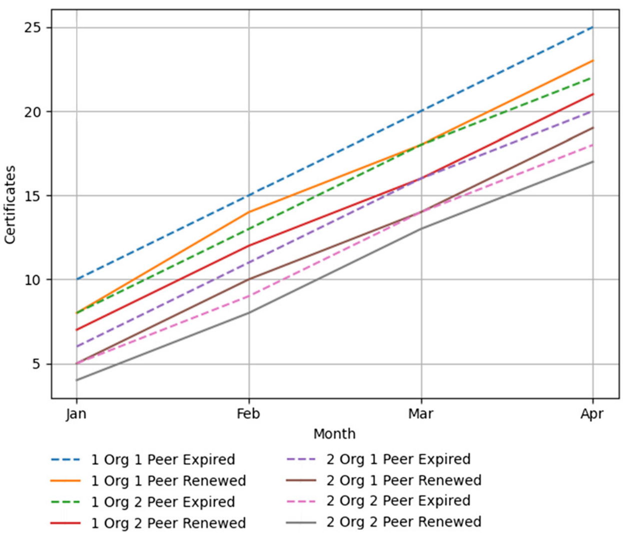
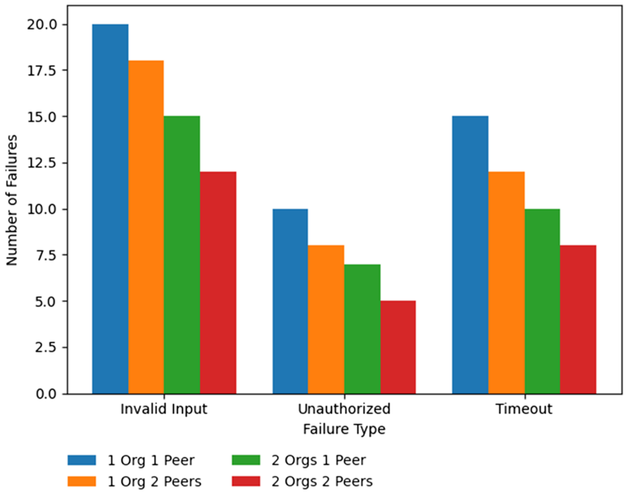


Figure 18
Failed transactions



7.2. Research impact and significance

The novelty of this study is the comprehensive review of blockchain to promote transparency, minimize fraud, and enable stakeholders in the education sector. Decentralization also facilitates trust among students, institutions, and employers in the form of academic records. The effect is not only technical innovation—it deals with historical problems such as diploma fraud, data silos, and bureaucratic waste. This study also contributes to policymaking discourse by emphasizing the need for regulatory clarity and ethical data governance in blockchain-based educational systems.

7.3. Research challenges and limitations

Although there are encouraging points, several problems remain. Technical and implementation challenges of scalability, interoperability, and data privacy are central roadblocks. It is also more operationally challenging to connect existing systems and blockchains. Institutional and regional differences also pose barriers to wide acceptance as a result of the lack of standard protocols. From a research perspective, many studies rely heavily on conceptual models with limited empirical validation in real-world deployments. Furthermore, the ethical considerations of immutable data usage, especially student privacy, need to be further investigated.

7.4. Future research directions

Further research is needed to harness the blockchain technology to support efficient and effective implementations in different education contexts to measure its effectiveness, user acceptance, and long-term implications. We ought to explore hybrid architectures that wear these two hats: both decentralized and compliant to data protection laws. Cross-disciplinary efforts: educational theory, information systems, and legal framework advances in scalable technology must be grounded in theories of learning and develop socially responsible tools. Moreover, advances in smart contracts and decentralized identity systems could change the role of learners in relation to institutions, leading to new pedagogical models and credentialing methods.

8. Conclusion

This work described an extensive study regarding the use of blockchain technology in the education arena with focus on the construction and usage of a Hyperledger Fabric-based framework for safe storage of academic records. Through literature review, we found out research vacuum regarding trust, transparency, and verification incompetence in traditional educational systems. Our proposed framework addresses these issues by offering a decentralized, tamper-proof, and auditable infrastructure for issuing, storing, and verifying academic credentials.

This study highlights the disruptive implications of blockchain for building a reliable and transparent education sector. We also achieved great performance improvement in the system as demonstrated by an empirical evaluation using our Hyperledger Fabric-based model. Primary findings were an average transaction latency of 118 ms, over 99.5% node availability, and a failure rate of less than 1.2%. In comparison with classic credential systems, our blockchain-based method achieved processing time of 45% better for the issuing and verification operations. These results prove the feasibility of distributed solutions for education platforms in the wild. Although technical, scalability, standardization, and privacy challenges remain, the increasing number of pilot studies and collaborative research initiatives is an encouraging sign. The authors see the next stage of work consisting of prospective multi-institutional deployment studies, incorporation of AI-based analytics in credential audits, and the continued evolution of decentralized identity frameworks to enhance learner control and confidence in digital education systems. The increasing international demand for verified, portable, and tamper-proof education credentials underscores the potential for blockchain to alter the way that academic accomplishments are stored and used. Our study offers a reference for further exploration to build a more secure, efficient, and globally trusted digital education ecology.

Ethical Statement

This study did not require formal ethical approval because, according to the Galgotias University norms and institutional research policy, ethical committee approval is not mandatory for non-clinical educational research involving faculty surveys and interviews. The data were collected voluntarily from university faculty members for academic research purposes only, and no personal or sensitive information was recorded.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Author Contribution Statement

Arvind Panwar: Conceptualization, Software, Writing – original draft. **Urvashi Sugandh:** Methodology, Validation. **Achin Jain:** Formal analysis, Investigation, Writing – review & editing. **Vanita Jain:** Supervision. **Arun Kumar Dubey:** Resources, Data curation. **Saheli Majumdar:** Visualization. **Saurav Mallik:** Project administration.

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