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Article

Integration of Blockchain Technology for Security and Transparency of Educational Data Archiving Systems in the Digital Age

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ABSTRACT

The manual and centralized education data archiving system is prone to data loss, manipulation, and verification difficulties. This condition poses a serious challenge to achieving secure, efficient education information management in the digital era. This study aims to examine the potential application of blockchain technology as a secure, transparent, and decentralized archiving solution. The method used is a qualitative literature review of relevant scientific literature from 2019 to 2024. The analysis shows that blockchain enables encrypted, immutable, and real-time verifiable data recording, thereby improving the integrity and efficiency of academic document management. Case studies such as EduChain and Blockcerts demonstrate the effectiveness of this system in accelerating credential validation and strengthening students' control over their data. However, the implementation of blockchain in Indonesia still faces challenges, including limited infrastructure, low digital literacy, and inadequate regulations. Thus, a phased implementation strategy that includes public policy support and stakeholder collaboration is needed.

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INTRODUCTION

The rapid advancement of digital technology has brought fundamental transformations in the management of educational data worldwide. Information such as student grades, certificates, and identities is a valuable asset that must be maintained with high standards of security, transparency, and accountability. In Indonesia, however, many educational institutions continue to rely on centralized and manual systems that are prone to data loss, manipulation, and unauthorized access (Hana & Tanaem, 2024). Such vulnerabilities underscore the urgent need for innovative solutions that ensure more secure, efficient, and reliable data management in educational environments.

These challenges are particularly evident in secondary schools located in regions with limited technological infrastructure. For instance, in several senior high and vocational schools in East Nusa Tenggara and Central Kalimantan, data management is still conducted manually through record books, paper-based archives, and Excel files without encryption or cloud-based backups. Reports from the East Nusa Tenggara Provincial Education Office (2023) and the

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Central Kalimantan Statistics Bureau (2023) indicate that most schools in these areas have not yet implemented integrated digital data archiving systems. This situation exposes them to a high risk of data loss due to natural disasters, administrative transitions, or hardware damage, and complicates data retrieval when certificates or transcripts need to be reissued.

In addition, the Indonesian Ministry of Education, Culture, Research, and Technology (2023) notes that reprinting diplomas and verifying academic data across institutions can take several weeks because there is no unified digital verification system. This illustrates the systemic weaknesses of traditional, paper-based data management that still dominates Indonesian education. The lack of automation and integration not only slows down administrative processes but also reduces the transparency and reliability of data validation. Consequently, the education sector remains vulnerable to inefficiencies that hinder both institutional governance and learner mobility.

These local challenges mirror global conditions, where educational institutions worldwide also struggle with slow, costly verification processes. The verification of diplomas and certificates across institutions and national borders remains a time-consuming and expensive process that limits the efficiency of educational systems (Liu et al., 2021). Moreover, the centralized, closed nature of traditional systems makes it difficult for external parties, such as employers or recruitment agencies, to accurately authenticate academic credentials (Steiu, 2020). Privacy concerns, risks of information leakage, and the absence of mature digital protection frameworks further exacerbate these global challenges (Bhaskar et al., 2020).

To address these pressing issues, blockchain technology has emerged as a promising alternative in data management. Blockchain is a decentralized digital ledger system that records transactions permanently and immutably, without a centralized authority. With key features such as decentralization, cryptographic security, smart contracts, and public verification, blockchain technology provides an infrastructure that enhances transparency, reliability, and security in educational data management (Azahra, 2024). Through these mechanisms, blockchain enables educational institutions to store and share verified data securely while reducing the risk of manipulation and unauthorized access.

Recent research has demonstrated the growing potential of blockchain integration in education. The EduChain system, for example, combines private and consortium blockchain structures to facilitate secure data exchange between institutions. This hybrid approach allows encrypted record-keeping, automatic error detection, and third-party verification without exposing personal or sensitive data (Liu et al., 2021). Similarly, Hana and Tanaem (2024) found that blockchain-based models in basic education environments support distributed and secure student data management while providing role-based access control for administrators and teachers. These findings demonstrate how blockchain can create a safer and more trustworthy digital ecosystem for educational data.

Beyond institutional advantages, blockchain technology empowers individuals to take greater control over their academic credentials. Students and graduates can securely store and share verified credentials directly with universities, employers, or professional organizations without undergoing lengthy manual verification processes. Features such as tokenization and data portability increase flexibility and ensure authenticity in academic record-sharing (Bhaskar et al., 2020). This paradigm shift not only simplifies data verification but also fosters trust, autonomy, and efficiency within the broader digital education ecosystem.

Nevertheless, the implementation of blockchain in education still faces significant barriers that must be carefully addressed. Issues related to network scalability, infrastructure costs, and compliance with international frameworks such as the General Data Protection Regulation (GDPR) present major technical and legal challenges (Steiu, 2020). In the Indonesian context, these issues are compounded by low digital literacy, uneven technological access across regions, and the lack of comprehensive scholarly studies exploring blockchain-

based educational data archiving. Furthermore, the current regulatory landscape on data privacy remains fragmented, requiring the establishment of clear policies to ensure ethical, lawful, and effective adoption of blockchain technologies in education.

Based on these considerations, this study aims to analyze the challenges in maintaining the security and transparency of educational data while evaluating how blockchain technology can be integrated into existing archiving systems. By applying a systematic literature review and qualitative analytical approach, this research seeks to develop a robust conceptual framework and practical recommendations for the adoption of blockchain-based systems in Indonesian educational institutions. The expected outcome is to strengthen the integrity, efficiency, and transparency of data management practices in order to build a more secure and trustworthy educational ecosystem.

METHOD

This study uses a qualitative literature review approach to examine the integration and impact of blockchain technology in educational data archiving systems. The analysis was conducted on scientific journal articles, case studies, and academic reports published between 2019 and 2024. Literature sources were obtained from reputable academic databases, such as Google Scholar, Scopus, and IEEE Xplore, with consideration given to methodological quality, thematic relevance, and contribution to the study's focus (Snyder, 2019).

This review focuses on key terms such as "blockchain in education," "academic data security," "digital credential verification," and "blockchain-based digital archives." These terms focus on applying blockchain technology to improve the effectiveness, security, and transparency of educational information management systems. The use of appropriate keywords helps researchers narrow the scope to relevant, in-depth literature on the issues under review.

Inclusion criteria were applied to filter the literature that explicitly discussed the conceptual and implementation aspects of blockchain technology applications in the context of education. The selected articles must demonstrate a direct link to data archiving practices or academic information systems, whether at the primary, secondary, or higher education levels. Literature that meets the criteria is then analyzed using a thematic approach, namely by grouping content based on key issues such as data security, archive management efficiency, and technical and policy challenges (Xiao & Watson, 2019).

By synthesizing findings from various sources, this study aims to present a comprehensive overview of the benefits, challenges, and development directions of blockchain technology in educational data archiving systems. This study is expected to strengthen the theoretical and practical foundations for the strategic use of blockchain technology in education information systems. In addition, this approach also provides space for further in-depth research on the technical, social, and institutional aspects of integrating this technology.

RESULT AND DISCUSSION

1. Challenges of Education Data Archiving in the Digital Age

Digital transformation in the education sector opens significant opportunities to improve data efficiency and accessibility, including in archiving. However, to date, many educational institutions are not yet fully prepared to adopt digital-based archiving systems. In some elementary schools, such as SDN Laihobu, student data archiving is still done manually using a master book. Conventional methods such as this are highly susceptible to physical damage and loss of archives, and they slow down the process of searching for and verifying the necessary information (Hana & Tanaem, 2024). When not supported by

a structured digital system, archiving becomes a slow, inefficient, and error-prone administrative activity (Azahra, 2024).

In addition to the limitations of manual methods, challenges arise from the implementation of digital archiving systems that are not optimally distributed. Many educational institutions still rely on centralized local storage, leaving them vulnerable to data loss from technical disruptions, cyberattacks, or natural disasters, without adequate backup mechanisms (Sharma et al., 2024). The absence of interoperability standards between educational archiving platforms is also an obstacle, as each institution tends to develop its own system. This causes difficulties in cross-institutional data integration and increases the risk of information fragmentation (Bhaskar et al., 2020).

Another equally crucial challenge is protecting personal data in digital archiving systems. The information currently stored is not limited to academic records; it also includes sensitive data such as students' health conditions and family backgrounds. Unfortunately, many archiving systems lack clear access rights settings, allowing information to be disclosed to unauthorized parties (Park, 2021). This condition reflects that digital education archiving systems still face various fundamental problems, ranging from technical and interoperability issues to security and data protection governance.

2. The Potential of Blockchain as a Secure and Transparent Archiving Solution

Education data management systems that still rely on centralized systems often face problems such as data manipulation, document duplication, and slow validation processes. In this context, blockchain technology offers an alternative approach through a distributed ledger system that is chronological, encrypted, and immutable, making it a potential solution for archiving that requires high integrity and transparency (Steiu, 2020). This system allows all authorized parties to verify data validity without the risk of unilateral changes, as each transaction is permanently recorded in a distributed network.

One real-world implementation of this technology is the EduChain system, which integrates a private and a consortium blockchain. Sensitive data, such as academic grades and personal information, is stored privately within the consortium's network, while the hash of this data can be publicly verified by participating institutions. This approach maintains data confidentiality while increasing reliability in the verification process between educational institutions (Liu et al., 2021). The application of such a system has proven effective in reducing the time and cost of verifying academic documents, which previously took weeks, to only seconds through encrypted hash matching (Steiu, 2020). Transparency in the blockchain system does not mean making all data public, but rather ensuring an audit trail that cannot be manipulated without the collective consensus of the network (Park, 2021).

Several leading global educational institutions have adopted this approach, including the Massachusetts Institute of Technology (MIT) through the Blockcerts project, the University of Malta, and BCDiploma, which uses the Ethereum blockchain to store and verify academic certificates (Steiu, 2020). In addition to enhancing document validity, this approach shifts the paradigm of data ownership, giving students direct control over their academic data through digital wallets that enable independent management of access rights without institutional bureaucratic intervention (Park, 2021). Thus, blockchain technology not only enhances security and efficiency but also supports student data sovereignty in an integrated, digital-based education information system.

3. Data Security in Blockchain-Based Archiving Systems

Data security is a fundamental element in archiving systems, especially in the education sector, which manages sensitive information such as academic grades, student

identities, and official documents. In manual or centralized systems, security generally depends on centralized authentication, firewalls, and basic encryption. However, this approach still leaves the organization vulnerable to cyberattacks and administrative errors. As an alternative, blockchain technology offers a security approach embedded in its system architecture through a decentralized, encrypted, and immutable design (Bhaskar et al., 2020).

Each piece of data recorded in the blockchain is secured with cryptographic algorithms and arranged in a chronologically connected series of blocks. Each block stores the hash of the previous block, so that any unauthorized modification to one block will be immediately detected and rejected by the entire network. This principle ensures data integrity automatically without reliance on a single authority. In practice, systems such as EduChain use tools like pt-table-checksum to detect data inconsistencies across network nodes, and WebSocket for real-time monitoring of changes. EduChain also implements a multi-party consensus mechanism, under which data changes can be made only after approval from all network members (Liu et al., 2021). The combination of technology and collective governance results in a distributed, adaptive, and transparent security system.

Another crucial aspect is the regulation of data access rights. Blockchain enables the use of smart contracts, automated digital protocols that execute commands based on predefined conditions. In the context of educational archiving, smart contracts can be used to determine access rights based on user roles. For example, only students and supervisors can access thesis drafts, while administrative staff can only view metadata. A study by Azahra (2024) shows that implementing smart contracts can improve security and accountability in educational data management.

In addition to protecting data from manipulation, blockchain technology also excels in data backup and recovery. Because this system is distributed, each network node stores an identical copy of the data. If one node is damaged, the data remains available from other nodes without losing integrity. This resilience far exceeds that of centralized cloud-based storage systems, which still carry the risk of failure if the entire system is managed by a single entity (Irawan et al., 2020).

However, security challenges remain, especially at the user endpoint. Blockchain network security can be compromised if user private keys are not managed properly. Even though the network infrastructure is very robust, weaknesses on the user side can create vulnerabilities that attackers can exploit (Judijanto et al., 2025). Therefore, the application of blockchain technology in educational archiving systems should be accompanied by digital security education, the adoption of strong encryption standards, and the use of two-factor authentication to ensure comprehensive protection.

4. Transparency and Accountability in Educational Document Archiving

Transparency and accountability are two fundamental principles in a credible and trustworthy education information system. In the context of archiving, transparency refers to openness in the process of recording, maintaining, and providing access to education data, while accountability relates to responsibility for the validity, integrity, and utilization of such data. Manual archiving systems, which are still adopted by many educational institutions, are often closed, lack historical documentation, and do not provide independent verification mechanisms for students, external institutions, or other interested parties.

Blockchain technology offers an innovative approach to overcoming these problems. Using a chronologically structured, immutable blockchain-based data structure,

every transaction or modification is permanently recorded in the network. Although it does not publicly disclose the contents of the data, this technology provides full visibility into the recording history and authentication process for each document. For example, the Blockcerts platform developed by the MIT Media Lab stores digital diploma hashes on a blockchain, allowing third parties to verify their authenticity without accessing the personal information of the document owner (Azahra, 2024). This process speeds up the validation of academic credentials, reduces reliance on central authorities, and gives individuals greater control over their documents (Steiu, 2020).

From a technical perspective, blockchain provides a complete, tamper-proof audit trail. Every activity, from document uploads to academic data changes, is recorded in blocks that have been collectively verified by the network. Systems such as EduChain enable real-time data synchronization between various stakeholders, including educational institutions, universities, and ministries. In the event of data discrepancies, the system will automatically detect them and trigger a cross-validation mechanism (Liu et al., 2021). In addition, the use of cryptographic techniques, such as zero-knowledge proofs, enables the verification of data authenticity without directly revealing the contents of the document, in line with the privacy principles set out in regulations such as the General Data Protection Regulation (GDPR).

From an institutional perspective, applying blockchain also strengthens governance by increasing structural transparency. All records are permanent and traceable, so that manipulative actions such as issuing false documents or changing data without authorization can be detected immediately. This creates moral and systemic pressure for educational institutions to be more accountable. In addition, open verification mechanisms enable independent oversight by stakeholders, ultimately strengthening public trust in the education information system and enhancing the institution's overall legitimacy.

5. Implementation Studies and Challenges in Educational Institutions

Although blockchain technology offers innovative solutions for managing and archiving educational data, its implementation in educational institutions remains challenging. To comprehensively understand these potentials and constraints, implementation studies conducted in various countries serve as important references for assessing their feasibility in local contexts. These studies not only demonstrate the effectiveness of the technology but also reveal the structural, technical, and social barriers that accompany its adoption.

One pioneering example of blockchain implementation in the education sector is the Massachusetts Institute of Technology (MIT) through its Blockcerts project. This system allows students and third parties to independently create, store, and verify digital certificates. Certificates are stored as encrypted hashes on a public blockchain, ensuring document authenticity without requiring direct authorization from MIT (Azahra, 2024). This approach not only increases efficiency but also strengthens security and user autonomy in managing academic documents.

A similar application has been implemented by the University of Malta, which integrates blockchain technology to store digital transcripts to support cross-institutional recognition and student mobility. Similarly, the University of Bahrain has adopted a blockchain-based approach as part of the digital transformation of higher education in the Middle East. In addition, the EduChain platform is an example of a consortium-based blockchain implementation involving educational institutions and government regulators. In this system, students' personal data is stored locally, while its authenticity hash is

recorded in the blockchain. Thus, third-party data verification can be carried out without granting access to the original data, thereby balancing security, transparency, and access control (Liu et al., 2021).

However, implementing blockchain technology in educational institutions is not without challenges. One of the main obstacles is the limitation of digital infrastructure, especially in developing countries. A field study at SDN Laihobu showed that student data management is still carried out manually through physical documents. Although the school responded positively to the idea of using blockchain, limitations in hardware and internet access, and low digital literacy among educational staff are major obstacles(Hana & Tanaem, 2024).

Another challenge stems from institutional and managerial aspects. Many institutions still hesitate to adopt blockchain-based systems because they are perceived as complex, expensive, and requiring significant structural changes. The lack of understanding of blockchain principles, even among policymakers, has slowed down the adoption process of this technology (Saputra et al., 2024).

Legal and ethical considerations are also important. The immutable nature of blockchain systems raises questions about correction mechanisms for recording errors. The absence of regulations specifically governing the use of blockchain in the education sector reinforces resistance among institutions (Fitri, 2023). Therefore, policy support and a clear legal framework are key prerequisites for ensuring the responsible and sustainable implementation of blockchain.

In addition, scalability should be considered. Public blockchains such as Ethereum have limitations in transaction processing capacity, making them less than optimal for large-scale use. To overcome this problem, a number of developers have begun shifting to permissioned or hybrid blockchain models that offer higher efficiency at reduced decentralization (Leng et al., 2020). The choice of model must be tailored to each institution's specific needs and technical capacity.

Data privacy is another crucial challenge. Although blockchain stores data in encrypted form (hash), the original data is still stored outside the network (off-chain), thus requiring additional protection systems. Therefore, implementing strict security protocols, structured access rights management, and data deletion mechanisms in accordance with the right to be forgotten principle set out in the General Data Protection Regulation (GDPR) is essential (Steiu, 2020).

Nevertheless, various implementation studies have shown that applying blockchain to education systems is not utopian. A phased strategy through pilot projects can be a safe first step to test the system's effectiveness while building institutions' internal capacity (Baharmand et al., 2021). Cross-sector collaboration between educational institutions, government, technology providers, and policymakers is key to building a digital ecosystem that is adaptive, sustainable, and resilient in the face of future challenges.

6. Implications for Education Archiving Governance

The integration of blockchain technology into the education data archiving system not only requires changes in technical aspects but also has significant consequences for the overall governance of education information. These changes include a shift in authority, a restructuring of institutional structures, and adjustments to regulations governing the management of academic data and documents. Therefore, this transformation must be understood as a systemic change that affects various layers of educational archive management.

Structurally, the use of blockchain shifts the center of data control from a single entity, such as an educational institution or education agency, to a more distributed system. In conventional systems, institutions serve as the sole authority for verifying, storing, and publishing academic documents. In contrast, blockchain enables these functions to be distributed among various network participants, including government agencies, consortium partners, and even students themselves. This multistakeholder governance model requires greater coordination but also strengthens transparency, accountability, and equitable authority in the management of educational archives (Liu et al., 2021).

From a regulatory perspective, implementing blockchain requires a review of policies on digital identity, the validity of electronic documents, and the protection of personal data. In this decentralized model, academic documents can be accessed and verified directly by third parties without going through the issuing institution. This raises new legal questions, such as who is responsible for recording errors and how corrections can be made in a system that does not allow data changes (i.e., an immutable system). Therefore, a new legal framework is needed that covers hash cancellation procedures, error reporting, and digital dispute resolution (Sharma et al., 2024).

Another implication lies in the shift in students' roles from mere administrative objects to legitimate owners of their academic data. With a blockchain-based digital wallet system, students can store their lifelong learning portfolios, share them with relevant parties, and transfer them between institutions independently. This shift supports the principle of data sovereignty, which places students at the center of a new educational governance architecture.

For this system to run effectively, educational institutions need to restructure their document management processes, including training educational staff, investing in digital interoperability systems, and implementing open data standards. The application of this new technology must also be accompanied by updates to operational procedures and a clear division of roles between units within the institution. In this way, institutions will not only adapt technically, but also institutionally and culturally.

In this context, the government plays a strategic role as both a regulator and an infrastructure and technical assistance provider. Government involvement is necessary to create an inclusive and sustainable digital ecosystem and to ensure that every institution, at both the central and regional levels, can adapt to this new governance system. Adequate public policy support and incentives are also needed so that the adoption of blockchain technology does not become an additional burden, but rather a measurable solution for managing educational archives.

CONCLUSION

Archiving educational data in the digital age requires a secure, efficient, and transparent system. Blockchain technology offers a solution through decentralized, encrypted, and immutable recording, thereby improving data integrity and reliability. Implementation studies show that this system speeds up the document verification process and gives students greater control over their academic data. Despite its potential, its implementation still faces obstacles in terms of infrastructure, digital literacy, and the lack of supporting regulations. Therefore, a phased implementation strategy, supported by policy and cross-sector collaboration, is needed to realize an adaptive and sustainable education archiving system.

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