A Comprehensive Review of Blockchain in Education: Applications and Future Prospects

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Abstract

Blockchain Technology (BCT) has revolutionized how records are kept, transactions are carried out, and trust is built in decentralized networks, which has sparked a lot of interest across a wide range of industries. Blockchain was the realization that Bitcoin's underlying technology could be used for other inter-organizational activities. Blockchain can completely transform several facts in education by providing solutions to numerous problems. Blockchain technology offers a distributed, transparent, and immutable distributed ledger system for stakeholders, and students. These attributes offer significant opportunities for safe archiving, verification, and sharing of credentials and academic data. This research investigates the transformative potential of blockchain in the educational sector, emphasizing its ability to address key challenges such as credential verification, data privacy, transparency, and student record management. Through a comprehensive State-of-the-art (SotA) literature review, the study explores existing blockchain applications and frameworks within educational institutions. It identifies current trends, technological hurdles, and implementation barriers, while highlighting the opportunities blockchain presents for enhancing academic processes, improving administrative efficiency, and ensuring secure and immutable credentials. The findings suggest that while blockchain presents innovative solutions for the sector, widespread adoption will require overcoming regulatory, technical, and scalability challenges. This research will contribute to the growing body of knowledge on blockchain in education and provide valuable insights for policymakers, educators, and technology developers to explore its potential in transforming educational systems worldwide.

Keywords — Blockchain Applications, Education, Prospects, State-of-the-Art (SotA) literature review

Introduction

Initially created as the foundation of cryptocurrencies, such as Bitcoin, Blockchain Technology (BCT) has rapidly emerged with the potential to revolutionize a wide range of industries outside finance completely. One

such sector is education, where BCT has the potential to transform conventional procedures, improve security, and promote openness in administrative and academic operations. Blockchain is a decentralized and immutable ledger system that records transactions across a network of computers. Each transaction, or "block", is cryptographically linked to the previous one, forming a chronological chain of blocks. This distributed ledger technology eliminates the need for a central authority as a consensus mechanism to ensure the integrity and validity of data shares among participants. Its decentralized and transparent framework enhances data security, promotes global collaboration, and aligns with broader sustainability objectives, such as the UN's Sustainable Development Goals (Samala et al., 2024; Savelyeva & Park, 2022). The blockchain provides several educational benefits that address current issues and inefficiencies. Academic record management and credential verification are the two key areas where blockchain can have a significant influence. Confirming academic qualifications entails laborious manual procedures that run the risk of error or fraud. Educational institutions can use blockchain technology to safely store and distribute certificates and student records in an open, tamper-proof manner. The employment process can be streamlined, and administrative hassles can be reduced by quickly verifying the legitimacy of credentials with employers, educational institutions, and other stakeholders. Blockchain technology has emerged as a revolutionary educational force, providing secure and tamper-resistant data storage solutions that address academic fraud and inefficient data management (Ahmadova, 2024; Azad et al., 2023). Researchers have highlighted blockchain's ability to facilitate inclusive and equitable access to education while enabling innovative learning models and operational efficiencies (Chan & Shan, 2022; Liu & Zhu, 2021).

This study employs State of the Art (SotA) literature review methodology to investigate blockchain's current state and prospects. This approach allows for a comprehensive analysis of existing scholarly literature, enabling the identification of key themes, trends, and gaps in the research landscape. The literature review involved accessing various academic databases, including IEE Xplore, Scopus, Web of Science, Google Scholar, JSTOR, and ScienceDirect, and other relevant journals, conference proceedings, and books. The search terms encompassed critical concepts or recent advances related to BCT in education. Boolean operators such as "AND," "OR," and "NOT" were employed to refine queries and ensure the retrieval of relevant literature. Eligible and non-eligible literature were chosen based on well-defined inclusion and exclusion criteria. Publications that met the following requirements had to be written in English, subject to peer review, and published within the last five years; studies published from 2019- 2024 were prioritized to ensure the inclusion of the most recent developments. Studies beyond the purview of the research topic, publications in languages other than English, and non-peer-reviewed sources were among the exclusion criteria.

There were several steps in the screening and selection process to find and include pertinent literature. Initially, the predetermined inclusion and exclusion criteria were used to screen titles and abstracts of the retrieved publications. Full-text publications were then evaluated to see if they should be included in the review. All the relevant literature about the historical evolution of BCT in education are included. The research team discussed and agreed on any differences or doubts regarding including papers. The extraction process involved systematically extracting relevant information, including methodology, conclusions, theoretical frameworks, and key findings from the chosen literature. The quality of the selected literature was assessed to ensure the validity and reliability of the findings. Ethical considerations were upheld throughout the literature review process to ensure the responsible and ethical conduct of research. Having established a methodological framework, the following paragraphs will open avenues for the applications, transformative impact, and the navigation of BCT's inherent challenges.

Applications of Blockchain in Education

The revolutionary potential of blockchain (Elsayed, 2023; Grech et al., 2022; Park, 2021; Delgado-Von-Eitzen et al., 2021; Bhaskar et al., 2020; Review et al., 2019b) in the educational sector is to improve educational systems' security, transparency, efficiency, and accessibility. The

blockchain applications include storing educational information, tracking student progress, and awarding micro-credentials. Apart from applications, there are a few hurdles to using blockchain in education, such as technical skill needs and regulatory concerns. Blockchain has great promises for transforming education, and more research and development are required to solve these problems and fully realize their potential. An investigation on blockchain technology's potential to transform education by introducing a new digital data management and learning paradigm focused on blockchain's potential to improve educational administration, learning sciences, and education as a social contract. General Data Protection Regulation (GDPR) introduces a novel blockchain framework designed for the secure issuance, storage, validation, dissemination, and retrieval of academic credentials in a way that complies with GDPR. This framework is intended to improve the management of academic credentials by ensuring their traceability, integrity, and authenticity, all while maintaining the privacy of personal information.

Blockchain technology has demonstrated numerous valuable applications in the educational domain. Ahmadova (2024) highlights that it can automate credential verification, reducing administrative burdens and operational costs. Furthermore, blockchain supports lifelong learning through secure digital credential wallets and facilitates personalized learning models, thereby enhancing accessibility and educational quality. Anggraito et al. (2023) have developed a blockchain-based prototype for smart city education, incorporating infrastructure, security, and application components to improve digital certificates' transparency, efficiency, and security. Chan & Shan, (2022) emphasize blockchain's role in tracking learner progression, managing educational assets, and safeguarding intellectual property rights. Additionally, blockchain enables efficient online and cross-regional education management by enhancing resource management and evaluation processes (Liu & Zhu, 2021). Integrating non-fungible token technology offers secure and decentralized platforms for academic assignments (Toutova et al., 2024).

Blockchain technology offers transformative possibilities in education, focusing on securely storing educational records, tracking student progress, and granting micro-credentials. The sections below discuss the applications where blockchain is implemented in detail.

i. **Educational Administration:** Blockchain can improve education administration by automating and safeguarding operations such as employing school staff using smart contracts, managing professional development, and handling performance and compensation from hire to retirement. It can also manage academic activities such as Massive Open Online Courses (MOOCs), track students' progress toward degrees, and verify the authenticity of academic certifications. This technology provides;

   a decentralized and transparent system for streamlining administrative tasks,

   ensuring the integrity of academic credentials and

   facilitates the global mobility of students and academics by allowing for more efficient certification and accreditation recognition and management.

ii. **Learning Sciences:** Blockchain's impact on learning sciences stems from its ability to disseminate information and share academic competence securely and publicly. It can keep track of learners' acquired competencies and previous learning history on a publicly distributed ledger, guaranteeing that both learners and educators are fully aware of obtained or lacking competencies. This feature enables formative assessment, the design and implementation of learning activities, and the recording of learning processes, all of which improve the evaluation and assessment of learners in a more fair, efficient, and secure manner.

iii. **Education as a Social Contract:** Viewing education through the lens of a social contract will help blockchain technology democratize learning by making smart-contract learning available to individuals worldwide. It can aid in creating a balance for measuring learning processes and outcomes, thereby giving credible and equitable proof of value to

all participants. This technique is consistent with the utilitarian principle of 'study to earn,' albeit with technological and sociological implications.

iv. **Securely Storing Educational Records:** Blockchain technology offers a decentralized platform for securely recording and keeping educational credentials. Universities can issue digital certificates stored on blockchain networks. Students can share these with employers directly. Each credential is cryptographically hashed and recorded on the blockchain, resulting in an immutable, tamper-proof ledger. This ensures the accuracy and verifiability of academic records, protecting them from fraud and manipulation.

v. **Tracking Student Progress:** Blockchain technology allows for real-time tracking of student development securely and transparently. The blockchain enables educational institutions to update and keep records of student achievements, course completions, and grades. This provides a complete and accessible summary of a student's academic journey, allowing for more individualized learning experiences and academic coaching.

vi. **Issuing Micro-Credentials:** Blockchain technology securely and transparently tracks student development in real-time. It also enables educational institutions to update and keep records of student achievements, course completions, and grades. This provides a complete and accessible summary of a student's academic journey, allowing for more individualized learning experiences and academic coaching.

vii. **Notarization of Intellectual Property Rights:** Blockchain technology provides a revolutionary approach to notarizing and managing intellectual property (IP) generated by educational institutions. Using blockchain technology, universities and other educational institutions can securely register, manage, and trace the creation and use of intellectual property such as research discoveries, academic publications, and inventions. This ensures a visible and temper-proof record of ownership and changes in IP rights, allowing for the equitable allocation of credits and royalties. Blockchain's immutable ledger gives conclusive proof of ownership and timestamp of creation, which is critical for preserving artists' and inventors' rights in academia.

viii. **Educational Funding:** The document also emphasizes the blockchain's potential to transform educational finance processes. Blockchain can expedite fund management, from tuition to scholarships and grants, by automating transactions and lowering overhead expenses. Smart contracts on blockchain systems can be set up to distribute payments depending on specific criteria or performance measures, ensuring openness and accountability in allocating and using educational resources. This could significantly assist underbanked or unbanked people, making education more accessible by removing financial barriers. Furthermore, blockchain-based solutions may allow for more efficient targeting of investments by private and governmental funding groups, ensuring that money is spent correctly to promote educational projects.

ix. **Learning Record Keeping:** Blockchain technology can securely store academic achievements, creating a transparent and immutable record of student learning outcomes that are accessible and verifiable internationally.

x. **Certificate Issuance and Management:** It provides a tamper-proof solution for issuing, storing, and confirming educational certificates, thereby minimizing fraud and streamlining the verification process for employers and educational institutions.

xi. **Decentralized Educational Ecosystems:** Blockchain enables the creation of decentralized platforms for educational resources, enabling the secure sharing, validation, and accreditation of learning materials and courses amongst institutions.

The UNESCO report (Grech et al., 2022) on education and blockchain technology investigates the revolutionary potential of blockchain in education. It focuses on how blockchain can improve digital identity verification, secure digital credential management, and facilitate lifelong

learning pathways. It also examines blockchain's use in education, such as notarizing intellectual property rights and providing educational finance. It underlines the need to understand blockchain's capabilities and problems, arguing for an interdisciplinary approach to maximizing its educational benefits while considering its environmental impact and long-term implementation solutions. The UNESCO report on education and blockchain technology discusses the significant role blockchain can play in enhancing the verification of digital identities, securing the management of digital credentials, and supporting lifelong learning pathways. Here are the key points from the document:

Verification of Digital Identities: Blockchain technology provides a strong foundation for digital identity verification, solving security breaches, fraud, and identity theft. It enables individuals to retain ownership over their data, promoting self-sovereignty and trust without centralized databases or third-party verifiers. This is critical for all digital services, including educational applications that need validating student and educator identities.

Secure Management of Digital Credentials: The document explains how blockchain technology can securely manage digital credentials like diplomas and certificates. Keeping these credentials on a blockchain becomes tamper-resistant and forever verifiable, lowering the danger of counterfeit credentials and making the verification process more accessible for employers and educational institutions. This safe administration includes issuing, storing, and exchanging micro-credentials and digital badges, allowing for more transparent and efficient recognition of learning successes.

Support for Lifelong Learning Pathways: Blockchain technology promotes lifelong learning by allowing for the secure and verified issue of micro-credentials and badges. These digital representations of specific skills or competencies are easily shared and validated, encouraging lifelong learning and professional development. Blockchain's ability to securely store and manage these credentials supports the concept of a lifetime learning record, allowing learners to build and display a complete and verified portfolio of their learning achievements over time.

Impact of BCT on higher education

Blockchain has the potential to improve higher education. It can increase transparency, accountability, and efficient resource use. Samala et al. (2024) comments that blockchain technology can reduce inequalities and give people more fair access to quality education through decentralized control. Blockchain also enables secure data management and system connections, supporting lifelong learning and academic openness (Delgado-von-Eitzen et al., 2021). Savelyeva & Park (2022) emphasize that BCT can help create sustainable educational programs that benefit marginalized communities and promote inclusivity and collaboration. Van Duy Tran et al. (2023) describe the development of Scorechain, a blockchain-based system for handling student data in education. It blends critical components to improve productivity, security, and privacy, providing a long-term solution. The system was thoroughly tested, highlighting its effectiveness, and a hierarchical employee management structure was adopted to improve operational efficiency. It ensures continuous communication inside the network while ensuring privacy and security. It has potential future improvements, such as user-friendliness, privacy and data-sharing platforms for different colleges and fine-tuning the blockchain network's consensus algorithms. Scorechain is a comprehensive blockchain-based solution meticulously designed to enhance student data management in educational institutions. Leveraging blockchain technology, it securely stores manages, and exchanges student data, encompassing grades, rewards, diplomas, and exam results. This system introduces a robust multi-role hierarchy, bolstering security and reliability and facilitating information exchange with key stakeholders such as parents, recruiters, and educational institutions. Moreover, Scorechain fosters seamless collaboration and data interchange among universities via a shared network, championing openness, accountability, and effortless integration into the education sector. Bucea-Manea-Ĕoniş et al. (2021) examines the impact of blockchain technology on higher education, highlighting its potential to improve student engagement, collaborative work, and learning outcomes. The project is intended to improve educational methods by connecting blockchain to decentralization, security, integrity, and

smart contracts. Using document analysis, a literature review, and surveys of 150 students from three universities, it discovers positive correlations between student motivation, collaborative work, engagement, and learning outcomes, highlighting the importance of blockchain-based tools in promoting these aspects.

i. **Student Motivation:** Blockchain technology directly impacts student motivation by offering a transparent and secure platform for tracking academic achievements. This encourages students to interact more with the learning material by ensuring their efforts are appropriately tracked and rewarded.

ii. **Collaborative Work:** The technology enables students to collaborate more effectively by allowing for the secure and efficient sharing of information and resources. Blockchain facilitates a decentralized learning environment by increasing peer-to-peer interaction and collaboration, which are critical for improving learning results.

iii. **Learning Performance:** The blockchain's ability to safely and transparently record and exchange academic achievements and comments facilitates tailored learning paths. This flexibility to individual needs and progress dramatically enhances student learning performance. Technology ensures that all stakeholders, including students, educators, and institutions, have access to accurate data, allowing for the detection of learning gaps and the formulation of tailored interventions.

Blockchain technology can transform the educational sector (Lutfiani et al.,2021; Sathya et al., 2021), demonstrating blockchain's potential to improve the integrity, security, and accessibility of educational data and credentials such as diplomas and certificates. By ensuring that educational achievements are accurately recorded and easily verifiable, blockchain technology can potentially eliminate fraud and increase administrative efficiency. The importance of continued blockchain innovation and implementation in education will address the changing demands of Education 4.0, encouraging a more transparent, efficient, and safe educational landscape. BCT dramatically improves the integrity, confidentiality, and accessibility of educational data and credentials like degrees and certificates. Blockchain's immutability ensures that once information is stored, it cannot be changed, preventing fraud, and ensuring the legitimacy of academic records. Its decentralized ledger enables the secure and transparent sharing of information, making educational achievements verifiable by anyone with permission, removing the need for intermediaries in the validation process. This technology enables educational institutions, employers, and other stakeholders to access and verify academic credentials readily, ensuring the credibility of educational degrees and facilitating student and professional mobility worldwide.

Bhaskar et al. (2020) conducted a systematic literature analysis on using blockchain technology in education to understand its existing benefits, limitations, and uses and identify areas for future implementation. It employs a bibliometric analysis of SCOPUS data to address research problems about blockchain's definition, assessment methodologies, and outcomes in educational settings. Despite its early stages, the research outlines blockchain's potential benefits for the academic sector. It offers areas for future application, providing foundational insights for educational institutions, governments, and researchers interested in exploiting blockchain technology. Blockchain technology in education provides various benefits, including improved security and integrity of educational records and certifications. It simplifies credential verification and digital certificate issuing, guaranteeing that credentials are securely kept, tamper-resistant, and easily verified. This technology also promotes data security and privacy in educational institutions by creating a solid barrier against illegal access and manipulation. Furthermore, blockchain allows the production of micro-credentials and badges that recognize specific skills or competencies, promoting lifelong learning and professional development.

Challenges of implementing BCT in education

Despite its potential, integrating blockchain into educational systems presents significant hurdles. Challenges associated with implementing blockchain technology in education focus on technical constraints and the fragile alignment with sustainability. Many researchers

(Bhaskar et al.,2020; Ma & Fang,2020; Park, 2021; Agarwal et al., 2021; Samala et al., 2024) look at the current state, difficulties, and obstacles of implementing blockchain technology in education. Different blockchain applications in education, including learner record keeping, certificate issuance and management, and the development of decentralized educational environments, have numerous challenges. It includes the technological and non-technical hurdles to blockchain adoption in education, such as scalability, security concerns, and the demand for qualified blockchain workers.

The high implementation costs, interoperability issues, and regulatory barriers also present further hurdles (Aulia & Yazid, 2021). Scalability problems and limited acceptance further constrain blockchain's promise in education, necessitating collaborative efforts among institutions to overcome these obstacles (Azad et al., 2023; Chan & Shan, 2022). Researchers emphasize the need for empirical investigations to address these barriers and develop practical solutions for integrating blockchain technology within educational settings (Samala et al., 2024).

i. **Scalability:** Scalability is an important consideration since the performance of blockchain networks may suffer as the number of users and transactions grows, resulting in slower processing times and more significant costs.

ii. **Interoperability:** The lack of interoperability across different blockchain platforms might impede seamless integration, and the initial setup costs, which include hardware, software, and experience, can be too expensive for specific organizations.

iii. **Technical Constraints:** Implementing blockchain technology in education involves significant technological challenges. One fundamental difficulty is the proof-of-work process required for blockchain activities, which becomes increasingly sophisticated and energy-intensive as the network grows. This technique, also known as mining, requires significant computational power and energy, prompting worries about its environmental impact. Bitcoin mining, for example, needs massive quantities of computer resources per second, resulting in significant energy, hardware, and maintenance costs. These issues are amplified in the case of global educational applications, where the environmental footprint and complexity of transaction validation may be significant. The report also examines the difficulties of quantifying specific learning components, which hampers the integration of blockchain technology into educational institutions.

iv. **Fragile Alignment with Sustainability:** Another fundamental difficulty is the misalignment of blockchain technology with a natural philosophy of sustainable educational development. The buzz surrounding educational blockchain overshadows the real-world challenges it seeks to address, resulting in a mismatch between technology's capabilities and the sector's requirements. The document criticizes the present approach to blockchain in education for focusing too narrowly on practical administrative duties rather than addressing more significant philosophical problems about education's goals and ideals. A more cooperative and commons-based approach to blockchain in education could provide a more sustainable and equitable way forward, emphasizing the importance of a defined educational philosophy to drive the use of blockchain technologies.

v. **Others:** Other obstacles include high energy consumption, privacy and data protection concerns, a lack of blockchain awareness and education among stakeholders, demand for blockchain-literate professionals and regulatory and legal barriers.

Conclusion and Future Research

BCT in education is a burgeoning field with the potential to revolutionize many aspects of the academic landscape. Decentralized learning platforms are one of the potential areas for future research, including BCT's involvement in transparent peer-to-peer assessment, collaborative learning and research, and other mechanisms for knowledge sharing. Research on user experience and adoption challenges associated with implementing BCT in education can be another area of focus. Learners' and educators' perceptions, attitudes, and behaviors towards BCT solutions can also be a subject matter of interest. Challenges like scalability, privacy concerns, and the necessity for

advanced technological frameworks propose directions for future research to mitigate these obstacles. The transformative impact of Blockchain and IoT on education should be considered, offering novel solutions to age-old issues and recognizing the challenges that must be surmounted to unleash their complete potential.

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