



Blockchain In Education: Global Research Trends, Gaps, And Opportunities

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Abstract

Blockchain technology, originally developed for cryptocurrency, has emerged as a transformative force in education, offering solutions to persistent challenges such as credential fraud, inefficient academic record management, and a lack of data sovereignty. This study presents a bibliometric analysis of global research on blockchain applications in education, drawing on 545 Scopus-indexed publications from 2016 to 2024. Using tools such as VOSviewer and Bibliometrix, this study maps publication trends, key contributors, thematic clusters, and citation patterns. The findings reveal a surge in publications since 2018, with significant contributions from India, China, and the United States. Thematically, research has concentrated on digital certification, academic records, and micro-credentials in higher education. However, gaps persist in empirical validation, real-world implementation, and applications in K–12 and vocational education. This study also highlights the underexplored intersections between blockchain and emerging technologies such as AI and IoT. Ethical concerns, data privacy, and regulatory complexities remain critical barriers to their use. By synthesizing fragmented literature and identifying research gaps, this study offers a roadmap for future interdisciplinary efforts aimed at integrating blockchain technology into inclusive, secure, and scalable educational systems. The findings inform scholars, policymakers, and practitioners seeking to leverage blockchain technology for educational innovation and equity in a post-pandemic digital landscape.

Keywords: *Blockchain, vocational education, K-12, Scopus indexing, VOSviewer, Bibliometric*

Introduction:

Blockchain technology, initially conceptualized as the infrastructure behind Bitcoin in 2008, has matured into a versatile digital innovation with transformative potential in multiple sectors. Blockchain functions as a decentralized and immutable ledger that records and secures transactions across a distributed network. (Alhat, 2024). By enabling transparency, traceability, and resistance to tampering, blockchain technology has emerged as a foundational technology in the global transition toward a digital trust infrastructure (Bidry et al., 2023). In recent years, its application in education has gained significant traction, particularly as institutions and learners have navigated an increasingly digital and decentralized learning ecosystem (Bennet et al., 2024).

In the educational context, blockchain is being explored as a solution to persistent challenges such as credential fraud, inefficiencies in academic record management, and the growing demand for portable, verifiable learning achievements. Applications include the issuance of secure digital diplomas, blockchain-based micro-credentials, decentralized lifelong learning portfolios, and trusted systems for learner identity verification. These innovations align closely with the goals of learner autonomy, data sovereignty, and global interoperability, which have become increasingly critical in the post-pandemic era of remote cross-border education (Pokharel et al., 2025). As of 2025, several pilot projects and national initiatives have experimented with blockchain to enhance transparency, mobility, and trust in education systems.

Despite growing enthusiasm, research on blockchain technology in education remains fragmented and uneven. Although the number of publications has increased rapidly since 2018, particularly after the pandemic-driven shift toward digital learning, existing studies often remain siloed within technical or theoretical domains and lack empirical validation and interdisciplinary integration in their findings. Moreover, the literature is spread across multiple fields, such as computer science, educational technology, information systems, and public policy, with limited consolidation of findings. This fragmentation makes it difficult for scholars, educators, and policymakers to comprehensively understand the field's development, leading to overlapping efforts, underexplored questions and inconsistent terminology.

In this context, a bibliometric study provides a valuable method for synthesizing the current landscape of blockchain research in education literature. Bibliometric analysis can identify leading contributors, influential journals, institutional collaborations, and thematic trends by systematically mapping the volume, scope, and structure of academic publications ([Reis-Marques et al., 2021](#)). This approach allows for the detection of research gaps and emerging directions that may otherwise remain obscured in traditional literature reviews ([Satpathy et al., 2024](#)). Given the dynamic and interdisciplinary nature of this topic, such a study is especially timely in 2025, as educational systems worldwide evaluate digital innovations to ensure resilience, trust, and equity in the learning experience.

This study aimed to map the global evolution of blockchain research in education, highlight current trends and key contributors, and uncover thematic concentrations and underexplored areas in the literature. The study was guided by questions such as the following: What are the publication patterns and geographic distributions in this field? Who are the most influential authors, institutions, and sources? What themes dominate the discourse, and where do significant knowledge gaps exist? To answer these questions, this study conducted a bibliometric analysis based on data retrieved from the Scopus database using VOSviewer to construct and visualize bibliographic networks related to co-authorship, citation, and keyword co-occurrence.

The remainder of this paper is organized as follows: It begins by outlining the methodology and data collection procedures used in this study. This was followed by a presentation of bibliometric results, including publication trends, influential entities, and thematic clusters. The discussion interprets the findings in relation to current developments in the field and proposes a future research agenda. The paper concludes by summarizing the key insights and their implications for scholars, practitioners, and policymakers involved in the field of educational innovation.

2. Theoretical Background and Literature Review

2.1 Theoretical Background

Blockchain technology is a fundamentally decentralized and distributed digital ledger system that enables secure, transparent, and tamper-resistant data recording ([Robusti et al., 2025](#)). Initially conceived as the backbone of cryptocurrencies, blockchain technology has evolved into a versatile technology with significant implications across various sectors, including education. Its core principles - decentralization, immutability, transparency, and consensus - ensure that once data are entered into the blockchain, they cannot be altered without agreement from network participants ([Jimmy, 2024](#)). This property has sparked growing interest in how blockchain can be applied to solve persistent challenges in educational data management, credentials, and learner autonomy.

Several theoretical models offer useful frameworks for understanding how blockchain can be adopted and integrated into educational contexts. For example, the Technology Acceptance Model (TAM) posits that the likelihood of technology adoption depends on users' perceptions of its usefulness and ease of use ([Al-Hattami, 2024](#)). Applied to blockchain, users (e.g., institutions and students) are more likely to embrace the technology if they perceive it to streamline processes, such as certification, or enhance security ([Jain et al., 2024](#)). Similarly, Rogers' Diffusion of Innovation Theory explains the adoption of new technologies based on factors such as compatibility with existing systems, complexity, and ability to observe outcomes ([Jain et al., 2024](#)). The potential of blockchain for transparency and trust aligns well with these determinants but may be hindered by perceived technical complexity or a lack of institutional readiness.

Blockchains also intersect with key educational frameworks. In the context of digital learning ecosystems, it provides infrastructure for issuing and managing lifelong, verifiable learning records. This is especially relevant in an era where learners engage in diverse and often informal educational experiences beyond traditional institutions ([Kuleto et al., 2022](#)). From a data security perspective, blockchain enables self-sovereign identity models that give individuals control over their personal educational data, thus enhancing privacy and trust. These developments are underpinned by sociotechnical theories that consider the dynamic interplay between technology, people, and institutions. This study adopts a sociotechnical lens to investigate the state of blockchain research in education, focusing on technological capabilities and educational implications.

2.2 Literature Review

The literature on blockchain in education has grown substantially since 2018, reflecting heightened interest in the technology's potential to reshape key educational functions. Much of this research has emerged in response to the systemic need for more efficient credentialing, secure data management, and learner-centric educational models. Educational institutions, policy bodies, and EdTech innovators are increasingly exploring blockchain as a means of establishing trusted, interoperable digital systems capable of supporting lifelong learning and the transnational recognition of qualifications.

A literature review revealed several prominent areas of application. One of the most researched applications is digital certification, wherein blockchain is used to issue tamper-proof academic credentials, diplomas, and badges ([Viswanathan & Lakshmi, 2025](#)). This application addresses concerns regarding credential fraud and verification delays. Another major area is academic data management, where blockchain enables the decentralized storage of student records accessible across institutions and borders ([Gaikwad et al., 2021](#)). There is also growing interest in integrating blockchain with online learning platforms and MOOCs to validate learner identities and achievements ([Morales-Chan et al., 2024](#)). Emerging studies have explored the use of blockchain for learner autonomy through self-sovereign identity systems and, increasingly, for incentivizing learning through gamified, token-based environments.

The thematic analysis of the literature identified four broad clusters: technological infrastructure, pedagogical innovation, policy and governance, and adoption and implementation ([Zeydan et al., 2024](#)). The technological cluster addresses issues related to blockchain design, scalability, and integration with existing systems. Pedagogical studies explore how blockchain can support competency-based learning and new assessment models. Governance-related literature focuses on regulatory compliance, institutional policy, and ethical concerns ([Chatterjee, 2025](#)). Finally, adoption studies examine stakeholder perceptions, organizational readiness, and the cultural factors that influence implementation.

Despite the surge in publications, much of the literature remains conceptual. Numerous studies have proposed theoretical models or blockchain-based educational platforms without empirical validation ([Al-Hattami, 2024](#)). Empirical studies, where they exist, are often limited to case studies or small-scale pilots. Quantitative research is relatively scarce, and mixed-method studies are still emerging. This imbalance has led to a lack of robust evidence regarding the effectiveness of blockchain in educational settings ([Hakiki et al., 2024](#)). Moreover, geographical analysis shows that most contributions originate from a few countries, notably China, Spain, and the United States, indicating the need for broader, more inclusive research across regions and educational systems.

However, several gaps persist in the literature. There has been limited exploration of large-scale implementations, and little is known about the long-term pedagogical impact of blockchain or how it influences equity and access. Contradictions also exist: while some studies highlight the potential of blockchain for transparency and trust, others raise concerns about data privacy, technical complexity, and the lack of clear legal frameworks ([Bennet et al., 2024](#)). These inconsistencies underscore the fragmented and interdisciplinary nature of this field.

Given this fragmentation, a bibliometric review is timely and necessary. Bibliometric analysis allows researchers to systematically map the structure of knowledge in a given field, identify leading contributors and thematic trends, and uncover gaps and opportunities for future research in the field (Mohammed et al., 2024). By applying this method to the field of blockchain in education, this study aims to provide a comprehensive overview of how research has evolved, where it is concentrated, and where further work is needed in this field. This meta-level perspective is essential for guiding a cohesive and strategic research agenda in the coming years.

3. Research Methodology

This study employed a bibliometric methodology to explore the global research landscape of blockchain applications in education. Bibliometric analysis allows for a systematic and quantitative examination of scholarly literature, providing insights into publication trends, authorship patterns, collaborative networks, citation dynamics, and thematic developments. The Scopus database was selected as the primary data source because of its comprehensive indexing of high-quality, peer-reviewed literature across multidisciplinary domains, including education, computer science, and social sciences. Scopus's structured metadata and compatibility with bibliometric tools make it particularly suitable for such studies.

To retrieve relevant records, a carefully constructed search string was applied using the fields of title, abstract, and keywords: TITLE-ABS-KEY ("blockchain" AND ("education" OR "learning" OR "e-learning" OR "educational technology")). This search was limited to documents published in English between 2016 and 2024 and filtered to include only journal articles, conference papers, and review articles within relevant subject areas. The initial search yielded 2508 records. A screening process was then conducted to remove duplicates, non-English papers, and documents that lacked clear relevance to the educational context. Editorials, book chapters, and documents with incomplete bibliographic data were excluded. Following this process, 545 articles were deemed suitable for inclusion in the final analysis.

The analysis was performed using VOSviewer, a widely used software tool for creating and visualizing bibliometric networks. This facilitated the mapping of co-authorship patterns, citation relationships, and keyword co-occurrence networks (Chhtrapati et al., 2021). The Bibliometrix R package was used for data preprocessing and statistical analysis, while Microsoft Excel was used for tabulation and further organization of the dataset. The analysis covers various dimensions, including publication output by year, geographic and institutional distribution, leading authors and journals, citation metrics and thematic clusters. For example, the annual publication volume showed steady growth, with notable increases from 2018 onward, peaking in 2021. Prominent contributors include Gregorio Convertini, Ahmed Alzahrani, and María Elena Martín, each with multiple publications in the field. Highly cited works, such as those by Chen et al. (2018), Turkanovic et al. (2018), and Liscano et al. (2019) played a foundational role in shaping the discourse on blockchain technology and its applications in education.

The scope of this study was global, with no geographical exclusions, reflecting the international and interdisciplinary nature of the topic. However, certain methodological limitations must be acknowledged. Citation lag may affect the visibility of recently published works that have not yet accumulated citations. The exclusive use of Scopus may also introduce a database bias, potentially omitting relevant literature indexed elsewhere. Additionally, restricting the dataset to English-language publications may result in language bias, excluding non-English contributions that could provide valuable regional insights into the topic. Despite these limitations, this bibliometric study offers a robust and comprehensive overview of the field, identifying trends, gaps, and opportunities that can inform future research and policy development at the intersection of blockchain and education.

Results

A study on blockchain in education reveals a steady growth in the number of publications over the past few years, reflecting the increasing global interest in the technology's potential to address educational challenges. As shown in **Figure 1**, the number of publications peaked in 2023, with 121 articles, and an even higher number is projected for 2024, with 127 articles. This upward trajectory demonstrates the growing recognition of blockchain as a transformative tool in the education sector, particularly in areas such as credentialing, student record management, and education system transparency.

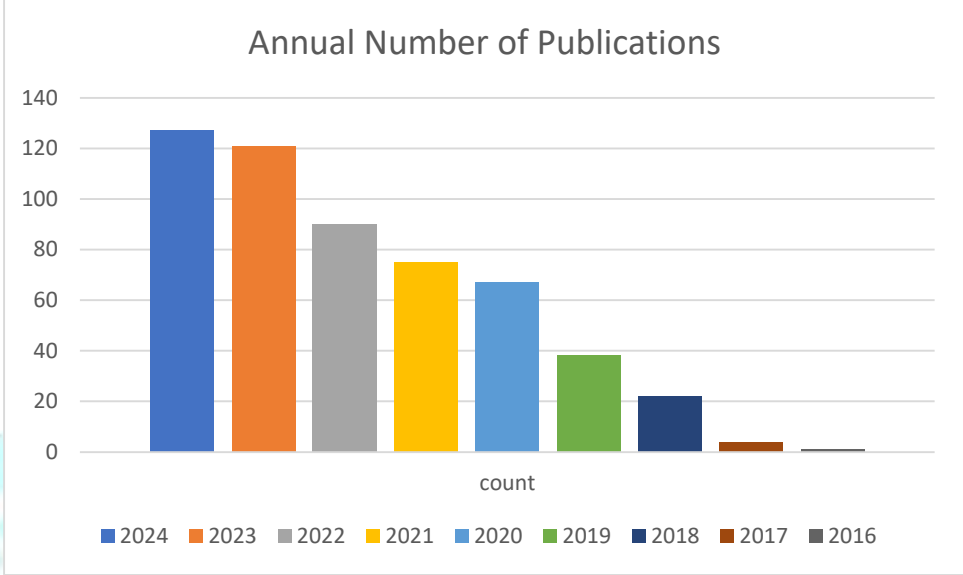


Figure 1. Annual Number of Publications on Blockchain in Education (2016 -2024)

A notable aspect of this study is the geographical distribution of research on blockchain technology in education. **Table 1** indicates that India (16.1%), China (15.0%), and the United States (13.2%) are the leading contributors, showcasing the increasing investment in blockchain technology within their educational sectors. India, in particular, is a significant player because of the rapid adoption of blockchain in higher education and governmental initiatives for securing educational credentials. Conversely, the United States has adopted a more decentralized approach, with widespread interest across various states, reflecting a diverse range of pilot projects and research efforts. The increasing research output in these regions is closely tied to both technological advancements and growing institutional interest in leveraging blockchain to improve educational processes.

Table 1. Frequency of Author Affiliations by Country (Top 5)

Rank	Country	ISO Code	Frequency	Percentage (%)
1	India	IN	209	16.1%
2	China	CN	195	15.0%
3	United States	US	171	13.2%
4	Indonesia	ID	91	7.0%
5	United Kingdom	GB	85	6.5%

The keyword co-occurrence analysis, depicted in **Figure 2** and **Figure 3**, emphasizes the concentration of terms such as "blockchain," "education," "higher education," "education system," and "blockchain application." These central terms suggest that most research has focused on integrating blockchain technology into existing education systems. In particular, the intersection of blockchain with "higher education" and "education system" is a prominent theme, signifying its application in credentialing, student identity management, and the broader digitization of academic records.

The heatmap further reveals that blockchain's role in "education" is closely tied to applications in "digital certification," "academic records," and "micro-credentials." These findings align with the current focus in the literature on using blockchain technology to provide secure, tamper-proof certificates and verifiable academic achievements. This trend underscores the technology's potential to mitigate long-standing issues, such as credential fraud and inefficiencies in managing academic records across institutions.

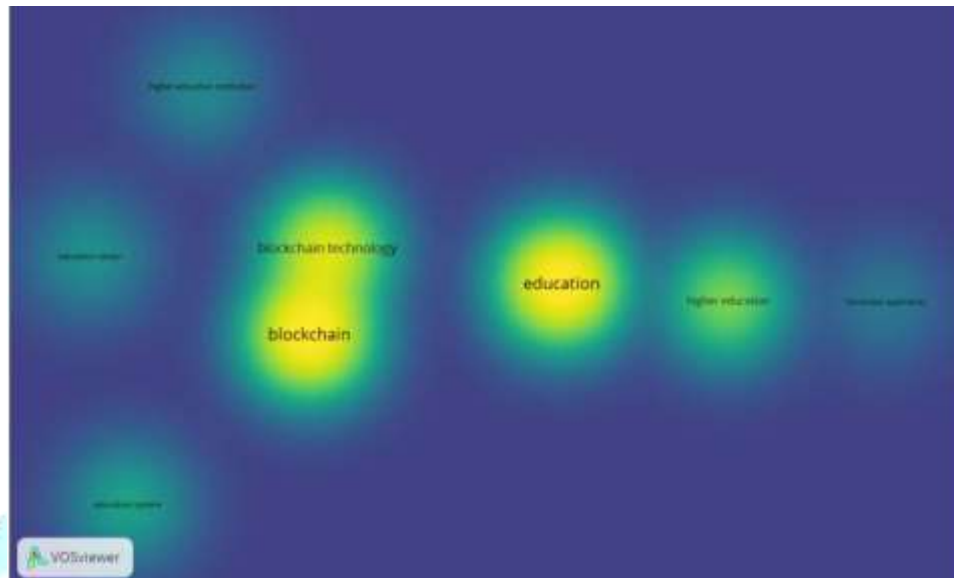


Figure 2. Keyword Co-occurrence Heatmap

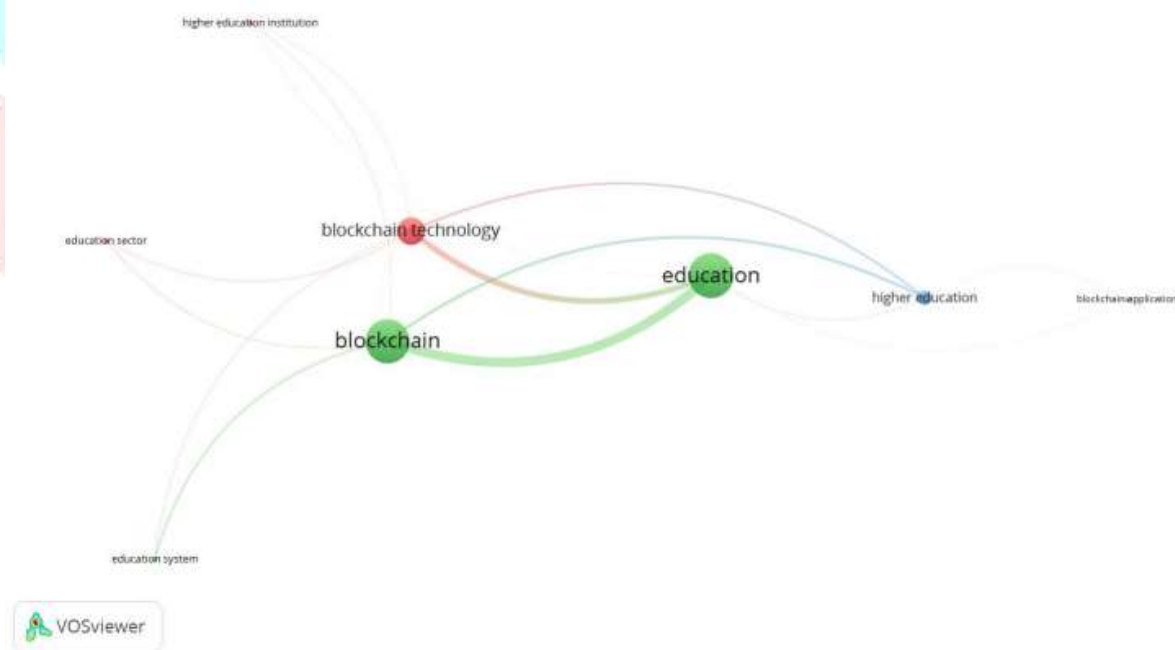


Figure 3. Keyword Network

The analysis of highly cited articles highlights the foundational work that has shaped the field. Notable among these are the studies by Chen et al. (2018) and Turkanovic et al. (2018), which explored blockchain applications in student record management and the establishment of blockchain-based credit systems for higher education. As shown in Table 2, these articles have received substantial attention, with Chen et al.'s work on exploring blockchain for educational applications amassing 648 citations and Turkanovic et al.'s study on EduCTX receiving 595 citations. These articles have been instrumental in establishing blockchain as a viable solution to several systemic issues in education systems.

Table 2. Top 5 Most Cited Articles

Authors & Year	Title	Citations
Guang Chen, Bing Xu, Manli Lu, Nian-Shing Chen (2018)	Exploring blockchain technology and its potential applications for education	648
Muhamed Turkanovic, Marko Holbl, Kristjan Kotic, Marjan Hericko, Aida Kamisalic (2018)	EduCTX: A Blockchain-Based Higher Education Credit Platform	595
David Lizcano, Juan A. Lara, Bebo White, Shadi Aljawarneh (2019)	Blockchain-based approach to create a model of trust in open and ubiquitous higher education	236
Merija Jirgensons, Jānis Kapenieks (2018)	Blockchain and the Future of Digital Learning Credential Assessment and Management	218
Hong Lin, Shicheng Wan, Wensheng Gan, Jiahui Chen, Han-Chieh Chao (2022)	Metaverse in Education: Vision, Opportunities, and Challenges	190

The analysis of prolific authors (see Table 3) also identified the leading contributors to the field. Qurotul Aini, with 11 publications, and Untung Rahardja, with 10 publications, emerge as key figures in blockchain education research. This concentration of authorship suggests a collaborative effort, often within specific research groups or institutions, driving the discourse on blockchain's educational applications.

Table 3. Top 5 Most Prolific Authors

Author	Number of Publications
Qurotul Aini	11
Untung Rahardja	10
Ninda Lutfiani	6
Marviola Hardini	5
Shofiyul Millah	4

Despite the rapid increase in publications, several gaps remain in the literature. One of the key challenges identified in this study is the limited focus on the challenges of real-world implementation. While much of the existing research presents theoretical models or conceptual frameworks, there is a need for more empirical studies that evaluate the effectiveness of blockchain in practical, real-world educational settings ([Oriekhoe et al., 2024](#)). Specifically, large-scale case studies examining blockchain adoption in diverse educational contexts, particularly in non-Western regions, are lacking ([Hubenova et al., 2024](#)).

Additionally, while higher education remains the dominant focus, there is a significant gap in research related to blockchain applications in K-12 education, vocational training, and adult learning. As educational systems become more diverse globally, there is a growing need to understand how blockchain can be applied across different levels of education, each with its own set of challenges and requirements ([Ghosh & Ravichandran, 2024](#)). A promising emerging trend in blockchain research is its intersection with other advanced technologies, such as Artificial Intelligence (AI) and Machine Learning (ML) ([Balcioğlu, 2024](#)). The role of blockchain in personalized learning, adaptive assessments, and intelligent education systems represents an exciting area for future exploration. Moreover, the potential for blockchain to support cross-border credentialing and create universally recognized qualifications is an important avenue for further research, as it would enhance student mobility and global access to education. In terms of regulatory and technical challenges, there is a growing need to explore the ability of blockchain to address data privacy concerns in educational contexts ([Chan et al., 2025](#)). As concerns about data breaches and privacy violations in education continue to rise, the promise of blockchain technology for secure, decentralized data storage offers a compelling solution. However, research on navigating the legal complexities of implementing blockchain in global educational systems, particularly in regions with varying data protection regulations, is limited.

The results of this study highlight several key areas for future research. There is a pressing need for studies that investigate the long-term pedagogical impact of blockchain technology on learning outcomes and institutional

practices. Additionally, the integration of blockchain with other technologies, such as AI, IoT, and Big Data, could open new possibilities for enhancing the efficiency, transparency, and personalization of education. Another important area for future research is addressing the ethical and legal considerations of blockchain use in education, particularly in relation to data ownership, privacy, and the digital divide. Researchers should also explore the scalability of blockchain solutions, especially in less developed regions, where infrastructure and regulatory frameworks may pose significant challenges. The growing interest in blockchain technology in education presents a wealth of opportunities for interdisciplinary research involving collaborations between educational institutions, policymakers, and technology developers. By focusing on these emerging areas, researchers can contribute to building more inclusive, secure, and efficient educational systems in the digital era.

Discussion

The results of this study provide a comprehensive overview of the current state of blockchain research in education, reflecting the rapid expansion of interest in the field and the emerging trends that are shaping its trajectory. The increasing number of publications and the concentration of research in key regions, such as India, China, and the United States, signal the growing recognition of blockchain as a transformative technology for education. However, as the field matures, several key challenges and research gaps remain that must be addressed to fully realize the potential of blockchain technology in educational contexts.

The steady growth in blockchain-related publications since 2018, especially in 2023, and the projected increase in 2024 highlight the urgency with which educational institutions and governments are exploring the potential of blockchain. Notably, India and China have emerged as global leaders in blockchain education research. This is likely due to these countries' ongoing investments in educational technology and their increasing interest in blockchain to secure credentials, improve record management, and facilitate cross-border education mobility ([Mijwil et al., 2025](#)). In contrast, while the United States contributes significantly to research, its approach is often more decentralized, with a broader focus on exploring blockchain applications across a range of educational levels ([Samala et al., 2024](#)). The concentration of research in these regions reflects the practical steps taken to integrate blockchain technology into educational systems. Countries such as India, with their vast and varied educational landscapes, are particularly well-positioned to leverage blockchain technology to streamline administrative processes and ensure the security and validity of academic credentials. As blockchain adoption continues to expand, it will be crucial for future research to explore the nuances of blockchain implementation across different geographic and institutional contexts.

The thematic trends identified in the *Results* section reveal that the application of blockchain in education is predominantly focused on credentialing, academic records, and digital certifications. This is unsurprising, as the core attributes of blockchain - decentralization, immutability, and transparency - are well-suited to address the persistent challenges of credential fraud and verification inefficiencies ([Viswanathan & Lakshmi, 2025](#)). The integration of blockchain for issuing tamper-proof digital diplomas and micro-credentials has become one of the most researched areas, aligning with the broader goal of improving educational outcomes and learner autonomy. Despite the enthusiasm surrounding blockchain applications in higher education, there is a noticeable gap in research focused on its potential in K-12 education, vocational training, and adult education. These underexplored areas represent significant opportunities for future studies. Blockchain can play a transformative role in these educational sectors by enabling secure and accessible records for learners, irrespective of age or educational background ([Bidry et al., 2023](#)). Given the rapid growth in non-traditional learning environments, especially post-pandemic, it is crucial to investigate how blockchain can support lifelong learning and enhance the recognition of diverse educational experiences.

One of the most striking findings of this study is the gap between theoretical research and real-world implementation. Although the theoretical potential of blockchain in education is well explored, there is a lack of empirical studies assessing its effectiveness in real-world applications. This gap is particularly noticeable in non-Western regions, where blockchain adoption may be hindered by infrastructure limitations, regulatory constraints, and cultural barriers. Future studies should explore how blockchain can be integrated into these varied contexts and identify the challenges and opportunities specific to different regions. Furthermore, while blockchain promises to enhance data security and learner privacy, concerns regarding the technology's

scalability, regulatory compliance, and integration with existing educational frameworks persist. As educational institutions grapple with these issues, research is needed to identify the best practices for overcoming these hurdles, particularly in countries with varying data protection laws and institutional readiness for blockchain adoption.

Several promising areas for future research emerge from this study. The intersection of blockchain with other emerging technologies, such as Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT), offers exciting opportunities for developing more personalized and adaptive learning systems. Blockchain can serve as a secure and transparent infrastructure for AI-driven educational tools, enabling personalized learning pathways, dynamic assessments, and data-driven insights into student performance. Research on how these technologies can be integrated could significantly enhance the educational experience, making learning more accessible and tailored to individual needs.

Another key area for future research is the use of smart contracts in education. Smart contracts, which are self-executing contracts with terms directly written into code, can be used to automate administrative tasks such as course registration, fee payments, and diploma distribution. While early research has explored the potential of smart contracts in blockchain-based education, more empirical studies are needed to assess their feasibility, efficiency, and scalability in educational environments. The role of blockchain in cross-border credentialing is another vital area of exploration. As education becomes increasingly globalized, there is a growing demand for universally recognized qualifications. The ability of blockchain to create tamper-proof, verifiable records could revolutionize the way educational achievements are recognized across borders, promoting greater international mobility for students. Future studies should investigate the regulatory, cultural, and logistical challenges that may arise when implementing blockchain-based credentialing systems globally.

The ethical and legal implications of blockchain adoption in education cannot be overlooked. Data privacy, ownership, and consent are critical issues that must be addressed before the widespread implementation of blockchain technology in educational settings. While blockchain promises to offer a secure and transparent means of managing sensitive educational data, its integration raises questions about who owns the data and how it can be shared across platforms. Research on the ethical considerations of blockchain in education, particularly regarding student privacy and consent, is urgently needed to ensure that this technology benefits all stakeholders equitably. Additionally, developing clear regulatory frameworks for blockchain use in education is essential to ensure compliance with national and international standards. Governments and educational institutions must work together to create policies that support the secure and ethical use of blockchain technology while protecting the interests of students, educators, and other stakeholders.

Conclusion

The study concludes that blockchain technology holds significant promise for transforming education by addressing issues such as credential fraud and inefficiencies in record management and enhancing transparency and security in academic systems. While research in this area has grown rapidly, especially in countries such as India, China, and the United States, the focus has predominantly been on higher education, leaving gaps in K-12, vocational, and adult education. Theoretical applications of blockchain are abundant, but empirical studies assessing its real-world impact are limited, particularly in non-Western countries. Future research should focus on large-scale case studies, explore the integration of blockchain with emerging technologies such as AI and IoT, and investigate its potential in cross-border credentialing and smart contracts. Additionally, more attention is needed to develop ethical, legal, and policy frameworks to address data privacy concerns and ensure equitable access to blockchain-based educational systems. By addressing these gaps, future research can help unlock the full potential of blockchain technology in creating more secure, efficient, and inclusive educational systems globally.

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