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Review

Exploring Governance for accreditation in the education sector using blockchain technology: a systematic literature review

Anju de Alwis[1] · **Anup Shrestha**[1] · **Tapan Sarker**[1]

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Abstract
The current education accreditation process poses a significant risk globally to the quality of education due to the increased falsification of academic certificates. Although previous studies have highlighted the potential benefits of blockchain technology in this context, there remains an opportunity towards a thorough investigation into the governance factors that influence the implementation of blockchain technology within the education sector. The accreditation system becomes increasingly important as a result of the emergence of a new learning ecosystem that enables the propagation of academic credits. It fosters an integrative learning approach by facilitating the accumulation of academic credits from a variety of higher education institutions, thereby promoting a learning ecosystem. The fundamental concept is to recognize the existence of a variety of learning pathways and to democratize educationTo this end, we conducted a comprehensive review of existing studies on the governance mechanisms for accreditation in the education sector using Blockchain technology. We identified 63 journal articles using four academic databases (EBScohost, Emerald, insight, Sage Journals, Scopus, Science direct) from 2018 to 2023. The literature appears devoid of proposals for a governance framework even though in the conventional paradigm such a framework is crucial in ensuring authenticity of credentials.

Keywords Blockchain · Governance · Micro-credentialing · Higher education · Verification

1 Introduction

Inclusive and high-quality education, aligned with United Nations (UN) Sustainable Development Goal 4, is a key priority in most countries' political and social agendas and is among the most impactful of the sustainable development goals (SDGs). To advance SDG 4 and promote equitable education, a robust educational accreditation system is crucial [1]. Emerging technologies, such as blockchain can enhance these systems [2]. However, a comprehensive governance framework is necessary to ensure the effective operation and management of the multiple stakeholders [3]. *Academic certification and accreditation* are formal processes to evaluate the standards and quality of the education provided by higher education programs [4–6]. Accreditation evaluates and assures the integrity of education, ensuring that necessary minimum standards are met [7]. This is important for the individual, employer and the broader public [7]. Accredited certification bodies issue credentials or certify third parties based on official standards. The accreditation process ensures that these parties can ethically test and certify while following quality assurance procedures. Program accreditation enhances the reputation of institutions and graduates and is periodically required to maintain quality and professionalism [4]. Accreditation of educational certifications refers to the formal recognition or validation by an authoritative body

✉ Anju de Alwis, anju@ultimateaccess.net; Anup Shrestha, Anup.Shrestha@unisq.edu.au; Tapan Sarker, Tapan.Sarker@unisq.edu.au | [1]University of Southern Queensland, Toowoomba, QLD 4350, Australia.

or organisation that a school, institution, or program meets certain standards of quality [8]. Therefore, accreditation facilitates the achievement of several key objectives, including quality assurance, industry and professional recognition, eligibility for advanced study or employment opportunities and compliance with relevant regulations [9].

Accreditation standards vary by country [10, 11]. A transparent accreditation process helps reduce fraudulent education certificates, a growing issue due to increased applications for skilled migration and international education [10]. The current accreditation process, largely a manual task, poses significant risks to validity [6, 11] and increases transactional costs [11]. A possible solution is using blockchain technology, which is immutable and resistant to manipulation, to build an accreditation framework and a certificate validation process [7, 12, 13]. The benefits of blockchain include consensus leading to the integrity of data, availability on a public ledger, secure cryptography for confidentiality, trust and non-central control [14]. Blockchain provides transparency, comparability and competitiveness to a variety of stakeholders, such as students, education bodies and government migration authorities [15] and is ideally placed to build a globally trusted higher education system [16]. The twenty-first-century job market, characterised by short career paths and a gig economy, is prompting universities to rethink curriculum structure and course duration [17]. This shift from "just in case" to "just in time" learning is driving growth in micro credentialing and scalable learning [16]. *Micro-credentialing* refers to the process of obtaining a certification for a particular skill, field of knowledge, or experience in a very short time, such as 2 or 3 months [18]. It is important to adapt to technological impacts on education [19]. While it has enabled both formal and informal education methods such as recognition of prior learning [20], micro credentialing poses challenges in the current process of accreditation, which only considers formal learning achieved through standard education bodies, thus, requiring intervention at the governance level.

Governance refers to the management, regulation and oversight processes that ensure decision-making, accountability and authority distribution among stakeholders. This review builds a foundation for further research on blockchain governance in education, advocating for a more structured approach to understanding its mechanisms. The process of accreditation of certificates and validation involves multiple stakeholders [21]. *Credential verification* refers to the process of confirming the authenticity of educational credentials (such as diplomas and transcripts) issued by academic institutions [22].

The primary problem identified in this study is the lack of a comprehensive governance framework for the accreditation of educational certifications using blockchain technology. Research has highlighted successful blockchain implementation by several educational institutions, such as the University of Nicosia [9], Sony Global Education [23] and the Open University (UK) [24]. While the technical feasibility and implementation of blockchain for issuing educational certificates is well-researched, there is a gap in developing operational governance structures. There is an opportunity to research and address how decision rights, accountability and incentives among blockchain stakeholders should be managed to ensure a robust and scalable accreditation system [3, 25]. Accreditation standards vary by country [11] therefore, establishing a country-wide governance framework involving multiple stakeholders is essential [3, 23]. The lack of such a framework hinders the broader adoption and effectiveness of blockchain technology in education [26, 27], highlighting the need for a detailed investigation into governance to support reliable and sustainable accreditation processes.

Addressing these governance gaps is essential to ensure that blockchain technology can fully realise its potential in providing a secure, transparent and scalable accreditation system. This study provides a systematic review of the existing literature on the application of blockchain technology in the education sector.

More specifically, the objective of this paper is to explore the following research question, RQ: What is the impact of blockchain technology on the accreditation process in the education sector?

The review methodology is the accepted methodology for systematic reviews and the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [28]. We used the Institutional library search engine containing all the subscribed databases, including Elsevier, Web of Science and ProQuest, among others. We reviewed 63 articles based on specific inclusion criteria outlined in the methodology section.

Recent research has emphasised the significance of blockchain technology in the process of internationalising education and promoting sustainable development, especially in developing countries [21]. Blockchain technology for credential verification and management has garnered significant interest due to its potential to reduce fraud and streamline verification. It also promises to decentralise education systems, enhance transparency and ensure data security. Additionally, blockchain could promote educational engagement through game-based incentives. The successful implementation of blockchain for certificate issuance by numerous educational institutions is hindered by the lack of a comprehensive, nationwide governance framework that includes multiple parties [29]. The changing dynamics of the knowledge economy, marked by abbreviated career trajectories and the emergence of microcredentialing [27], accentuate the necessity for strong governance frameworks. Rectifying these governance deficiencies is crucial to enable blockchain technology

to fully achieve its potential in delivering a secure, transparent and scalable accrediting system. This paper presents a thorough evaluation of the current literature on the implementation of blockchain technology in the education sector.

The remaining paper is structured as follows; Sect. 2 presents the literature review; Sect. 3 analyses the research methodology; Sect. 4 details the findings; Sect. 5 offers the discussion; and Sect. 6 concludes the study.

2 Literature review

The subsequent sections in the systematic literature review (SLR) highlight the application of blockchain technology in the accreditation process. Specifically, Sect. 2.1 provides background information on the use of Blockchain in education. Section 2.2 explores the necessity of accrediting microcredentials and the significant role blockchain technology can play in this context. This discussion aligns with the rapidly evolving learning ecosystems in regions, such as Europe and India. For instance, in Europe, countries are harmonising educational qualifications to enable interoperability between nations, with blockchain technology serving as a critical enabler [30]. However, to effectively manage both technological and operational processes within this system, implementing a governance framework is essential.

2.1 Introduction to blockchain in education

Blockchain technology, developed by Satoshi Nakamoto and popularized by Bitcoin [14], is revolutionising education with its decentralisation, transparency, robustness, auditability and immutability [31]. Significant investment is currently directed towards its development and adoption [31]. Blockchain technology stores information in secure, sealed data blocks, forming a growing ledger. Each block is linked to the previous one via a hash value, creating a chain. This one-way hash function (e.g., SHA256) uniquely signs each block [32]. A key feature of blockchain is that records cannot be amended or deleted [33].

Blockchain enhances the modern education system with its immutable and nearly indestructible nature, ensuring the integrity of identity and content [34, 35]. It provides a decentralized system for fee-free transactions and credit transfers [33]. Smart contracts and atomic exchanges enable seamless digital certificate and token exchanges within the network [36]. Blockchain also stores digital certificates and tokens in accessible wallets [37]. Its transparency and credibility facilitate the verification of certificates by employers, connecting talent supply and demand [38]. Overall, blockchain addresses traditional online education's administrative limitations, ensuring openness, credibility and transparency and supports continuous education in a rapidly evolving environment [39]. This will enable a learning ecosystem, which is defined as an interconnected network of learners, educators, institutions and resources that collaboratively support and enhance the educational process. This ecosystem includes formal and informal learning environments, digital tools, pedagogical strategies and community interactions, all aimed at promoting continuous learning and development [40].

2.2 Micro-credentialing and blockchain

Micro-credentialling refers to the process of obtaining a certification for a particular skill, field of knowledge or experience, within a very short period, for instance, 2 or 3 months [18]. It is crucial in the evolving education landscape, where technology transforms workforce training [11] and supports formal and informal education methods, including prior learning recognition [22]. However, it presents challenges in accreditation systems that only recognise formal education, leading to issues like certificate falsification and mismanagement that require governance-level intervention.

Blockchain technology-based certificate verification can be a useful solution to this problem [25]. This technology provides a fail-safe solution by storing education records in an immutable, decentralised network, making them impossible to manipulate once recorded [41]. The blockchain's consensus mechanism ensures data integrity, while relevant information is available on a public ledger accessible to authorised users. Authentication and authorisation of certificates are managed through secure cryptography, ensuring confidentiality and privacy [42].

Blockchain is proposed for evaluating the governance framework due to its inherent characteristics, such as immutability, security, trust and noncentral control [14]. It can maintain student records from accredited education providers, making it suitable for validating accreditation frameworks for micro-credentialing. Blockchain offers transparency, comparability and competitiveness for stakeholders, such as students, education bodies and government migration authorities [15]. Blockchain technology has been used by some education institutions to issue certificates [23, 24].

However, a governance framework for education accreditation for micro-credentialing concerning multiple stakeholders has not yet been established [25].

2.3 Learning ecosystems: a case study of Europe and India

The European Commission has launched initiatives such as the European Universities model to strengthen collaboration and cooperation among higher education institutions (HEIs) across the EU [34]. These transnational alliances aim to promote European identity and regional economic development by engaging with companies, municipal authorities and researchers [43]. Significant changes in the European higher education system include national education integration, the Bologna Process and a focus on openness and quality [30]. The Commission proposes further initiatives, including expanding European universities under Erasmus+, to continue advancing higher education [30].

The European Credit Transfer and Accumulation System (ECTS) and blockchain technology have the potential to significantly transform the European education ecosystem [30]. ECTS, a standard for comparing and transferring study credits across European HEIs, aims to promote mobility and facilitate the recognition of qualifications. Blockchain, on the other hand, offers advantages, such as secure and permanent record-keeping, direct access and control for learners and the ability to recognise flexible learning pathways. The combination of the ECTS and blockchain can harmonise accreditation standards across Europe, enhance efficiencyand empower learners by giving them control over their credentials [33]. However, the motivations and interests driving the development and implementation of blockchain certificates in the education sector are still unclear. It is important to determine whether the goal is simply a technological replacement or a disruptive innovation that can transform the entire education regime [36, 44].

Similarly, India currently has more than 41 million students in higher education and this number is likely to double in the coming years [45]. The Indian educational landscape urgently necessitates transformative reforms to rectify existing imbalances and elevate the standard of education. In this context, adopting the choice-based credit system (CBCS) has emerged as a promising strategy for fulfilling diverse academic requirements and individual ambitions of students within a competitive educational system. The integration of CBCSs within the Indian education system, though fraught with challenges, remains an imperative objective. This transformation necessitates extensive structural changes, including examination systems, the development of faculty skills and attitudes and significant government financial support. The CBCS framework adopts a modular design centred around credit accumulation, empowering learners to select from an array of elective courses and facilitating an interdisciplinary educational approach [46].

Presently, the incorporation of CBCSs in Indian universities is limited [46], with the majority adhering to traditional annual and semester-based examination systems. The University Grants Commission (UGC) has advocated for the widespread implementation of a choice-based credit system to promote inter-institutional student mobility and facilitate the partial completion of academic programs in specialised institutions. Nonetheless, the effective implementation of CBCSs demands a thorough re-evaluation of curricular content, term papers, assignments and the accessibility of diverse educational resources [45, 47].

In summary, the learning ecosystem is undergoing significant transformation. Key initiatives, such as the ECTS, aim to standardise accreditation and empower learners. The CBCS shows promise in meeting diverse academic needs. Micro-credentialing is becoming essential in this evolving landscape, promoting "just in time" education over traditional "just in case" models. However, challenges persist, including certificate falsification and mismanagement. Blockchain technology is proposed to mitigate these risks by enhancing transparency, robustness and security. It supports fee-free transactions, credit transfers and secure digital certificate storage, thus, addressing the shortcomings of traditional online education. While the literature supports blockchain's application in education, there is a notable gap in managing the ecosystem, highlighting the need for a comprehensive governance framework.

2.4 Regional variations in governance challenges and blockchain adoption in education

2.4.1 Blockchain implementation

Variations in educational systems: Blockchain has enabled credential verification and management of academic certificates in areas such as the EU, utilising the European Blockchain Services Infrastructure (EBSI) for cross-border educational verification (e.g., Belgium and Italy). This system facilitates interoperable and secure digital identification

frameworks, addressing issues such as certificate authenticity and fraud prevention while upholding privacy standards [22, 48].

Technical and policy infrastructure: Developed countries, especially in Europe, possess robust digital governance frameworks (e.g., Europass, EBSI) that facilitate blockchain applications in education. Nevertheless, such systems in developing countries encounter further obstacles due to deficiencies in digital infrastructure, reduced technical literacy and inadequate policy frameworks [49, 50].

Systematic integration against resource limitations: The adoption of blockchain for credential verification and accreditation is more progressed in developed areas, where governance frameworks such as the European Blockchain Services Infrastructure (EBSI) facilitate cross-border, standardised solutions. Conversely, developing nations, such as Pakistan with its Cerberus system, face difficulties in resource distribution, digital infrastructure and legislative consistency, frequently resulting in disjointed systems that grapple with scalability [51].

Fraud and verification: In developing nations, credential fraud poses a substantial challenge and blockchain presents viable solutions for verification and fraud mitigation. Nonetheless, implementations are obstructed by governance challenges, like corrupt officials or fraudulent educational institutions. Conversely, developed countries prioritise transparent, regulated blockchain networks backed by independent accrediting organisations and oversight entities [52, 53].

2.4.2 Governance and privacy considerations

Privacy and data security: Privacy-preserving protocols, such as those utilising Hyperledger Fabric, are prevalent in developed areas where data security requirements like GDPR are implemented, highlighting individual data governance [54]. EBSI's decentralised identification system enables users to securely manage their digital credentials. Conversely, underdeveloped nations may prioritise cost-effectiveness over strict data protection owing to constrained resources [55].

Data privacy and decentralisation: Developed countries have implemented stringent privacy regulations (e.g., GDPR), emphasising privacy-preserving blockchain protocols, whilst developing regions may prioritise cost-effective alternatives without comprehensive data privacy safeguards [56]. Tariq et al. (Cerberus) underscore the need for privacy preservation via selective data disclosure and transaction openness; yet, obstacles to adoption persist due to institutional corruption and inadequate enforcement of data security measures [49, 51].

2.4.3 Digital divide

Infrastructural deficiencies: In areas with inadequate internet and technology infrastructure, such as some developing nations, the implementation of blockchain for e-learning and credential verification is impeded. Research indicates that although IoT-based e-learning systems have progressed in developed nations, such initiatives face challenges in regions with insufficient internet access, illustrating a digital divide intensified by disparate levels of blockchain adoption and internet quality [52, 57]

Inclusivity and digital humanism: In Europe, digital humanism is incorporated into governance, emphasising the human dimension of technology and promoting inclusivity in digital education. This method is less prevalent in numerous developing countries where fundamental access is prioritised over comprehensive digital governance [50].

Digital proficiency and technological competence: The integration of blockchain in education necessitates digital literacy and adequate infrastructure. Developed regions have ample access to resources, technical assistance and policy-oriented education on digital instruments, hence facilitating adoption. In contrast, developing regions face elevated prices and restricted technological proficiency, hindering the implementation of blockchain-based educational solutions [22, 51].

These conversations highlight the regional variability of blockchain's potential in education, shaped by resource availability, regulatory frameworks and agendas. Blockchain deployment in industrialised countries typically emphasises privacy, cross-border interoperability and regulatory compliance, whereas developing regions have challenges related to foundational infrastructure and legislative matters that affect blockchain integration in education. The research demonstrates the necessity for customised tactics that tackle local issues while utilising the benefits of blockchain for educational governance.

3 Methodology

This SLR follows the PRISMA [28] criteria. The implementation of this systematic review strategy was crucial in optimising the process of selecting literature. First, an extensive search was conducted, resulting in the discovery of 309 research publications relevant to blockchain in education. The literature pool consisted of SCImago Journal ranking of Q1–Q3 journal articles, together with a curated collection from grey literature, ensuring a comprehensive and varied array of sources.

During the second phase of the methodology, a more targeted evaluation was conducted. Sixty-three journal articles and conference papers were screened and examined, including those from databases and hand searches. This assessment aimed to directly address the research question (RQ) on the impact of blockchain technology on the accreditation process in the education sector. The articles were classified to extract insights into the use of blockchain technology in the educational sector.

Blockchain technology, while initially gaining traction in financial sectors, has only recently begun to be explored for its potential in educational contexts. This is evident from the systematic review conducted by Alammary et al. [58], which highlights that the application of blockchain in education is still in its infancy, with significant developments and research interest emerging primarily in recent years. Loukil et al. [59] also support this timeframe, as it identifies the need for a comprehensive survey of blockchain adoption in education due to the nascent stage of its application and the various challenges that still need to be addressed. Furthermore, Hameed et al. [60] emphasise the gap in the literature regarding blockchain-based educational projects, indicating that systematic reviews and studies have only recently started to explore this area, with notable projects and protocols being developed from 2013 onwards [60] but gaining more attention and refinement in the subsequent years from 2018 [60]. These studies collectively suggest that the period from 2018 onwards marks a significant phase of exploration and implementation of blockchain technology in education, making it a relevant and justifiable timeframe for the literature review. This timeframe reflects a growing body of research and practical applications addressing blockchain's challenges and opportunities in educational settings. Reviewing literature from this period provides a comprehensive understanding of blockchain's current impact and relevance in education. Based on the above, our approach for this SLR focused on the academic discourse at the intersection of educational certification, blockchain and governance from 2018 to 2023. Our examination showed a significant increase in interest, with a growing trend in the chronological distribution of journal articles and conference papers during this period.

To ensure the findings' credibility and dependability, a thorough approach to quality control and bias reduction was used throughout the literature selection process. Initially, only peer-reviewed articles and conference proceedings were thought to maintain a high level of academic rigour. Each selected paper was then evaluated using established quality criteria, which included relevance to blockchain applications in governance, methodological soundness and clear reporting of findings. The database searches were conducted methodically, integrating various search terms and cross-referencing sources to limit the likelihood of missing relevant studies. This process was supervised to minimise bias throughout the literature selection process. These measures contribute to the review's objectivity and dependability, reinforcing the validity of the insights acquired from the selected literature.

Employing keywords such as blockchain, higher education, governance, certification and accreditation we conducted a thorough examination of the pertinent literature. The process resulted in the identification of key findings, constituting the initial segment of the research design. Adhering to the established inclusion and exclusion criteria, along with the predetermined parameters, enabled the development of a rigorous protocol for this SLR, as shown in Table 1.

4 Findings

The period from 2018 to 2023 marks a significant phase of exploration and implementation of blockchain technology in education [60], making it a relevant and justifiable timeframe for this SLR. During this period, blockchain gained traction in areas, such as accreditation, digital certifications and education, which are key to understanding its impact on the sector. To gather relevant peer-reviewed literature, we used an institutional library search engine, encompassing subscribed databases, such as Elsevier, Web of Science and ProQuest, research materials included

Table 1 Search protocol developed

Phase 1—Prior review & selection process	Phase 2—Selection process	Phase 3—Review
Step 1—Identify the Purpose * *Impact of blockchain technology on the accreditation process& Education Certificate Verification (ECV) in the education sector* * Identify gaps related to the use of blockchain in education accreditation process, ECV and governance	Step 4—Select, identify and sort articles related to education certificate validation, verification and blockchain and governance	Step 6—Review the study provided
Step 2—Document the protocol * Determine all steps of SLR processing * Select search criteria and include the database * Determine the inclusion and exclusion criteria	Step 5—With the support of the literature, discuss the Research Question: What is the impact of blockchain technology on the accreditation process in the education sector?	Step 7—Conclude the review by discussing the relevant theories and practical applications identified and outline potential future directions for research and implementation
Step 3—PRISMA Flowchart * Followed guidelines of PRISMA, searched articles in DB * Articles finalized (n = 63); Fig. 1 details the PRISMA flowchart		

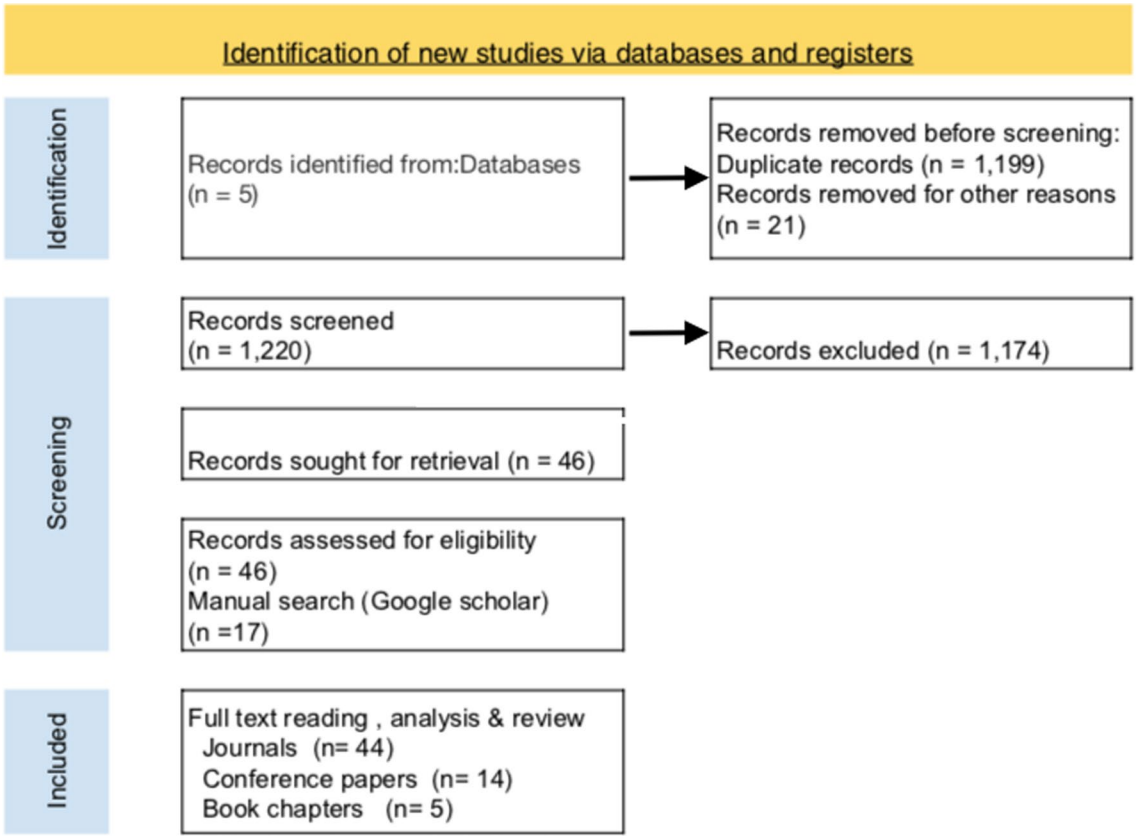

Fig. 1 PRISMA flowchart used in the research

articles, conference proceedings and book chapters published between 2018 and 2023. The targeted search terms, "blockchain," "education," "accreditation," and "governance," helped identify key studies related to the integration of blockchain in educational practices, governance modelsand accreditation processes. Specifically, "blockchain" captures the technological foundation, "education" frames the context in which it is applied, while "accreditation" and "governance" highlight two critical areas where its potential for improving transparency, security and efficiency is being explored. This targeted search strategy allowed us to comprehensively cover the relevant research and developments within our topic of interest, ensuring that the literature selected was both focused and applicable to the central objectives of our article.

The initial search yielded a total of 363 papers; however, only 63 articles were retained for the SLR following the removal of duplicates and the application of relevance-based selection (employing a PRISMA flowchart and adhering to the inclusion and exclusion criteria detailed below). The criteria for journal article selection were multifaceted and exclusions were not solely based on language. Articles were also omitted if they were not pertinent to the education sector. Thus, in addition to language restriction (English), relevance to the educational context was a mandatory condition for inclusion. In 2018, only four articles were published, increasing to eleven in 2019 and fifteen in subsequent years. Publications declined in 2021 and 2022, likely due to the COVID-19 pandemic, but recovered in 2023, surpassing 2022 numbers. This trend highlights the growing academic interest in the role of blockchain technology in educational certification and governance.

4.1 Research themes on blockchain usage in education

Given the decision to first categorise the papers by publication year, a trajectory in the research focus was noticed by the year of publication. There was a noticeable similarity in the papers in their focus (The details of this analysis are depicted in Appendix). The key trends and recurring themes over the years from 2018 to 2023 are as follows.

1. Credential verification and management: This theme consistently emerged over the years, with a focus on using blockchain for issuing, storing, verifying and managing educational credentials [10, 61]. The trend is driven by the need to combat fraudulent certification and enhance verification efficiency [51, 62].
2. Decentralisation of education: Another significant theme is blockchain's ability to decentralise education management, control and access [63]. This includes discussions on decentralised learning systems, public–private blockchain networks and decentralised data management, highlighting blockchain's potential to enhance transparency and equity in education [48, 63].
3. Data security and privacy: This includes discussions on controlled credential disclosure, secure data transactions, encryption and safeguarding of sensitive data [10, 64].
4. Integration and reform in educational systems: There is an evident interest in integrating blockchain technology into existing systems to streamline educational processes and ensure comprehensive educational reform [30]. This theme includes integration with current academic information systems, administrative process streamlining and blockchain's role in reimagining the purpose and value of formal education [46].
5. Incentive mechanisms: The potential of blockchain technology to introduce game-based incentive mechanisms to encourage participation and improve efficiency in educational processes, such as skill verification, is a noted trend [53, 65].
6. Expanded application of blockchain in education: There is increasing interest in applying blockchain beyond traditional uses, such as secure transactions, record security, digital badges, human resources, library access and academic research publications [66].
7. Global education and sustainable development: A more recent theme is leveraging blockchain technology to promote internationalisation, inclusivity and sustainable development in higher education [57].
8. Challenges and future directions: Acknowledging the challenges of blockchain adoption and the call for innovative solutions, SLRs and research is a recurring theme, indicating the continued scholarly interest and potential for future research in this area.

Although governance may not have been a primary focus in the listed themes, it is integral to many. A more explicit focus on governance frameworks could be an important area for future research in this field [67].

An article by Alnafrah and Mouselli [21], examined the challenges faced by higher education systems in low-income countries, specifically regarding the issuance and verification of academic records. The authors proposed a national hybrid blockchain-based platform incorporating various stakeholders, including students, universities, government agencies, policymakers and businesses, introducing a governance perspective to the higher education sector. Approximately 66% of the scholarly articles selected are from developing and emerging countries, demonstrating the use of this technology in these regions (Table 2).

This study assessed the blockchain platform's costs, benefits, potential commercialisation and feasibility in unstable low-income countries, such as Syria and Sudan [21]. The authors discovered that the platform can function as a marketplace for all stakeholders in the higher education system, promoting internationalisation and ensuring inclusive and equitable education [68]. This blockchain-based approach to governance enhances transparency, security and trust among stakeholders while streamlining the management and verification of academic records. Ultimately, this strategy aligns with the fourth SDG, aiming to provide lifelong learning opportunities for students from low-income countries [69]. In the 20 papers from 2022 and 2023, the focus was on the future, highlighting smart certification and cooperative or distributed learning. These studies explore how to integrate blockchain technology to streamline educational processes.

Table 2 Literature classification by lead author affiliation

Region	Total
Africa	2
Asia	28
Europe	13
Middle East	8
North America	8
South America	4
Total	63

4.2 Practical examples of blockchain in education

A significant finding in this preliminary analysis was that most papers draw from a few practical examples of blockchain technology and do not address the importance of governance in the education sector. Papers from 2018, 2019 and 2020 primarily describe blockchain's current use rather than its future benefits or expectations in education.

4.2.1 Classification of technology platforms in the literature

Several key entities and concepts emerged from the SLR and it is detailed in the Table 3. Notably, Sony Global Education was cited sixteen times, Blockcerts was mentioned in twenty publications and EduCTX appeared fifteen times. Ethereum led with twenty-one mentions, the University of Nicosia was cited fourteen times and Hyperledger Fabric was referenced nine times. The analysis highlights these key technology platforms at the intersection of blockchain and education.

Sixteen research articles elaborate on how Sony Global Education has leveraged blockchain technology to revolutionise its educational services, offering empirical evidence of the advantages of blockchain in an educational context. This recurring focus highlights the importance of practical case studies in demonstrating blockchain's potential in education. Further research should expand the range of case studies to validate these findings and explore potential issues or drawbacks of blockchain implementation in different educational contexts.

From 2019 to 2023, academic literature increasingly cited and discussed the 'Blockcerts' platform, highlighting its impact on technological advancements in educational credentials. Blockcerts, known for its centralised and immutable mobile application, ensure the authenticity and transparency of academic credentials [18, 84, 85].

A review of 20 major academic journals revealed extensive references to Blockcerts, underscoring its growing importance and potential as a catalyst for further research and innovation.

Another study proposed EduCTX, a unified global higher education credit platform based on the ECTS framework [51]. EduCTX aims to create a universal, trusted and decentralised system for higher education credits and grading. This system aims to provide a globally harmonised perspective for students, higher education institutions and other stakeholders, including corporate entities and organisations [16]. To demonstrate the efficacy of EduCTX, researchers developed a prototype using the open-source Ark Blockchain Platform. The EduCTX system operates on a global peer-to-peer network, managing and regulating ECTS-like tokens that represent credits earned by students. HEIs act as peers in this blockchain network. The EduCTX platform represents a significant advancement towards a more transparent and technologically advanced higher education system by uniting various HEIs to create a streamlined, universally accessible educational environment, that addresses linguistic and administrative barriers. Researchers have invited HEIs to join the EduCTX blockchain network. This research paper detailing EduCTX has gained significant attention, being cited in 15 prominent scholarly journals.

The 63 publications provide a brief history of blockchain and names Nakomoto as the originator [23, 37, 70, 71, 74, 80, 84, 86, 87, 90, 97]. Other papers discuss Bitcoin's history within blockchain technology, tracing its evolution from a decentralised autonomous organisation (DAO) to smart contracts and cryptocurrency [74, 86, 87, 94]. An introductory paper highlights that Bitcoin's emergence brought blockchain technology into the spotlight, particularly in business contexts. To fully comprehend blockchain technology's potential in education, it is essential to explore the different blockchain types and their functionalities [86].

Understanding conditions like scalability, security and interoperability is crucial for effective implementation. Despite blockchain's promising opportunities, challenges remain that need to be addressed. Garcia-Font's study [87] explores

Table 3 Use cases as investigated in the literature

Technology Platform	Total references	References
Sony Global Education	16	[20, 21, 23, 37, 38, 60, 70–79]
Blockcerts	20	[36, 49, 55, 56, 60, 62, 71, 73, 78, 80–88]
EduCTX	15	[43, 51, 62, 65, 71, 78, 80, 82, 85, 86, 89–93]
Ethereum	21	[37, 38, 56, 62, 65, 74, 81, 82, 84–88, 90, 92–97]
University of Nicosia Research Project	14	[22, 36, 49, 51, 54–56, 62, 71, 74, 79, 82, 83, 88]
Hyperledger fabric	9	[55, 73, 86, 88, 90, 93, 97–99]

challenges like data privacy, regulatory compliance and the technological infrastructure needed for blockchain in education. By assessing both opportunities and threats [87, 90], educators and policymakers can make informed decisions on blockchain integration. By 2020, the global interest was reflected in a diverse geographical distribution of research, with 15 articles originating from various countries. The North and South American regions saw contributions from the United States and Brazil. Asian research came mainly from China, India and Saudi Arabia. Europe was notably engaged, with Italy, Portugaland Spain participating. South America, though less represented, had contributions from Ecuador and Brazil. These findings highlight the global interest in blockchain applications in education.

By 2021, more developing countries were producing papers on blockchain, focussing on its potential for the developing world [21, 62, 72, 89]. Several Asian/non-Western use cases of blockchain [100] were also provided. Research demonstrates the application of blockchain in education in Syria, Rwanda, Jordan, Somalia and Afghanistan in terms of HEIs, certificates, resources, targets, peace engineering, refugees and peace building.

4.3 The global impact of blockchain in education

Given that developed countries have established robust educational ecosystems and enterprise systems, blockchain technology could offer significant benefits to developing countries by addressing gaps in IT-driven education systems [52]. However, practical challenges, such as blockchain's high electricity consumption, could hinder its immediate implementation in these regions [36, 74], for instance, [36] noted that "it is widely known that within 1 year, the Bitcoin PoW (proof of work) takes the amount of electricity needed to power a country like Switzerland." Developing and power-hungry countries cannot bear this burden, however, the discourse on using technology to overcome existing system inefficiencies is of paramount importance. Future research could address mitigating the impact and burden of electricity costs and paying for mining hours.

Peace engineering is a field that uses science and engineering solutions, integrated with innovative technologies, to address global challenges and promote peace [101, 102]. Some research also points to "peace" as a possible outcome of this emerging technology [89, 103]. The alignment of blockchain technology with peace engineering principles has the potential to transform higher education by promoting transparency and trust in content delivery, course management and certification issuance [89, 104, 105]. The authors of the research [89, 104, 105] reviewed the advantages and potential drawbacks of implementing blockchain in higher education and explored the use of smart contracts to enhance engineering education programs, revealing that peace engineering leads to sustainable development in developing countries. Alnafrah and Mouselli [21] emphasised the need for higher education institutes to provide certificates, resources and targets, in countries such as Syria, Ukraine, Somalia and Afghanistan, where lost documentation and high costs pose significant challenges. They opine that blockchain technology can be used in such situations to lessen the burden on refugees and students.

Alshahrani's [106] paper explores blockchain's potential to revolutionise higher education certification, enhancing trust, security and efficiency [94]. The 2022 study builds on this, providing empirical evidence for a Blockchain-based Smart Certification System, reinforcing Alshahrani's foundational ideas [78]. The 2023 review [107] critically examines blockchain's scalability and energy consumption challenges. Though focused on general blockchain technology, these concerns are highly relevant to its implementation in education, as large-scale adoption in higher education would encounter similar issues. Together, these papers provide a comprehensive view of blockchain's potential in education, progressing from theoretical promise [94] to empirical application [78] and finally to an evaluation of long-term sustainability and technical challenges [107]. This forms a cohesive narrative that introduces the concept, tests it and assesses its broader implications, with a focus on sustainability. Alshahrani (2020) explores the transformative role of blockchain in higher education, particularly in the certification process. The paper emphasises blockchain's potential to enhance transparency, security and efficiency in issuing academic credentials. By using blockchain, academic institutions can create a more trustworthy and streamlined certification system, reducing fraud and improving the verification process for credentials. Building on this, the 2022 study empirically analyses a blockchain-based smart certification system, addressing the practical challenges and opportunities of implementing blockchain in higher education. This research tests the feasibility of using smart contracts and automation within certification systems, demonstrating how blockchain can improve security and efficiency in educational administration. The study also advances Alshahrani's vision by examining whether blockchain technology is ready for widespread use in educational institutions. In 2023, the studies shifted the focus to the sustainability and scalability of blockchain technology [54]. This paper critically examines issues such as energy consumption and the ability of blockchain networks to scale as they grow. With the large-scale adoption of blockchain in higher education, the environmental and technical challenges become significant [97]. This study by

Kumutha and Jayalakshmi [97] emphasises the significant challenges posed by blockchain technology in terms of energy consumption and scalability, particularly in the context of academic certificate verification systems. They highlight the need for sustainable blockchain solutions, drawing attention to the increasing power demands and the limitations in scaling such systems for broader implementation. The review further highlights the need for solutions to these scalability issues to ensure blockchain remains both functional and sustainable as it is increasingly integrated into education systems. The key themes uniting these works are blockchain's transformative role in certification processes, the practical implementation of smart certification systems and the sustainability and scalability challenges of blockchain technology. Together, they offer a comprehensive perspective on blockchain's potential and challenges, spanning from theoretical concepts to practical applications and long-term sustainability considerations.

The scalability and application of blockchain were analysed within Estonia's educational plan [72], highlighting benefits for student record maintenance in an open-source environment. Additionally, a pilot project in Mexico involved uploading teacher certificates to the Ethereum blockchain as a public–private partnership [81]. Chronic challenges in Ecuador's education system can be mitigated by adopting "connected, open and reliable environments" [83], leveraging blockchain's decentralised nature. Additionally, the rise in Brazilian immigrants to Portugal, driven by historical and linguistic ties [62], highlights concerns about educational credential authentication. While European diplomas are readily acknowledged, the validation of Brazilian diplomas is a lengthy procedure that can incur additional expenses and consume lengthy periods of delays [85]. This issue is particularly urgent for refugees lacking official documentation, highlighting the need for blockchain-based systems to address these challenges. Next, we present two case studies on the use of blockchain technology in the education systems of China and India, both emerging economic superpowers.

4.3.1 The prominence of blockchain research in China

Out of the 63 scholarly articles, 19% originated from China. An analysis of these publications led to the identification of several key themes that are central to the intersection of blockchain technology and education in China.

1. Integration of blockchain in online education: This was a predominant theme across multiple articles, with the consensus that the integration of blockchain technology in online education platforms is an evolving trend in China [93, 107–110]. The articles suggested that blockchain could offer potential solutions to several challenges currently faced in online education, such as the absence of a reliable results certification system, issues related to privacy and the lack of a comprehensive sharing mechanism. The studies praised blockchain technology for its potential to create a decentralized and shared online education system, marking it as a forward-looking approach [38, 67].
2. Authenticity and verification through blockchain: A significant proposition in these articles was using blockchain for establishing the authenticity of educational credentials, leveraging its immutability and consensus-based approach to create a secure system for reliably recording and verifying academic achievements [10, 67, 111]. This could reduce instances of fraudulent academic claims and improve the credibility of the online education system.
3. Education institute validity: Students and other responsible authorities involved in certificate verification are highly concerned about the genuineness of academic credentials, either due to the nonexistence of issuing institutions or insufficient record-keeping. Previous research advocates for a decentralised blockchain network that ensures the secure storage of academic diplomas and student assessments through the use of double encryption [54].
4. Competency tracking and skill evaluation using blockchain: Several articles have discussed the applicability of blockchain technology in skill evaluation and competency tracking, suggesting that it could enable a more scientific and authorised system for assessing and validating competencies [18, 34, 58].
5. Blockchain-based network for education: The concept of a blockchain-based network, as presented in these articles, overcomes the shortcomings of traditional online education and has great potential for future educational informatisation [67, 112].
6. Educational digital asset management and personalized learning: There was notable interest in using blockchain technology for managing educational digital assets, including student learning data and teacher-generated courseware [12, 113]. Such a system could analyse the development status of students and offer personalised learning solutions.
7. Privacy protection and dispute resolution in online examinations: In the specific context of online examinations, a system using biometric authentication and blockchain technology was proposed to ensure participant authenticity, data integrity and fine-grained access control [10, 114]. Interestingly, the system also aimed to provide a resolution mechanism for disputes by determining the real initiator of malicious behaviour.

The assessment of articles originating from China underlines the potential of blockchain technology in transforming online education systems. Blockchain is envisioned as a tool to promote trust, security and more equitable access to educational opportunities. These themes signal a paradigm shift in the educational landscape and underscore the pivotal role of technological innovations in shaping the future of education. Wu and Li [70] highlight in their paper the competition within schools in China as a way to inspect learning achievement and teaching quality. One paper has reviewed the impact of blockchain on online education, emphasising its credibility [23]. Two other papers explore blockchain in different contexts: one focuses on outcome-based evaluation [115] and the other examines blockchain's use in operational skill evaluation, measured through a balanced scorecard [70].

4.3.2 The prominence of blockchain research in India

The deployment of blockchain technology in India holds significant importance and shows considerable promise for multiple reasons. First, its inherent security features provide a robust defence against data manipulation and cyber threats, as unauthorised alterations require compromising all nodes in the network simultaneously [116]. Second, the transformative potential of blockchain technology lies in its capacity to revolutionise various industries by unifying all stakeholders on a single platform, thereby enhancing organisational communication and efficiency [33]. Additionally, its immutable and robust nature makes it an ideal candidate for applications where maintaining the integrity of identity and content is critical, such as in the creation of self-sovereign digital identities within the educational domain [117]. Moreover, the utility of blockchain extends to various sectors in India, including but not limited to government identification, insurance, real estate and energy sectors [72]. These aspects collectively underscore the significance and rising prominence of blockchain implementation in the Indian context. Of the 63 scholarly articles, 13% originated from India, emphasising blockchain's role in addressing fraudulent academic certificates and enhancing trust, security and efficiency in education [82, 97, 118]. Beyond education, its potential extends to other sectors such as agriculture and supply chain management [72, 119].

4.4 Adoption of blockchain technology in education for verification

Sahonero-Alvarez [89] notes that diplomas alone cannot fully capture learning achievements. In light of recent challenges with blended and online learning, a system that allows students more control over their data and enables verification of all certifications on a single platform would be beneficial [89]. Several papers have highlighted blockchain's advantages for enhancing the education sector. Jaramillo and Piedra [83] highlight the concept of passport learning, which requires collaboration among multiple institutions and it is yet to be fully realised. They also suggest that removing intermediaries could significantly advance the industry. Additionally, blockchain can support self-actualisation and lifelong learning [73], which provide efficient solutions in public affairs and administration [62, 74]. These benefits will aid lifelong learners and those taking modular courses by creating a comprehensive record of their achievements. Therefore, this study proposes blockchain as a crucial solution for education, emphasising the need for a verification system that ensures the credibility of credentials for students, universities and employers.

4.4.1 Blockchain within higher education

Many of these papers identify significant opportunities for improvement in traditional, higher and online education systems, particularly in administration, due to issues like fraud, certificate loss and time spent retrieving physical documents [37, 56, 84, 85, 88]. Traditional methods of recording, issuing and verifying academic credentials are described as expensive, inefficient and prone to security vulnerabilities [82]. As a result, producing "secure, immutable and trustable academic credentials" is deemed essential [53], with digital systems still facing these limitations. Extant research proposes that blockchain can mitigate these negative impacts and consequences. Its decentralisation is highlighted as a key strength, as it can provide enhanced information security and transparency. Moreover, its distributed model promotes collaboration between institutions while eliminating centralisation, making it a valuable tool for addressing current challenges in education [83].

HEIs must share academic outcomes as part of student mobility initiatives, such as the European Union's Erasmus Program. Nevertheless, the present method is deficient in terms of sufficient technology assistance and a thorough framework for incorporating prospective technological solutions into existing Academic Information Systems. Research has highlighted blockchain technology as a potential solution to challenges in the EU Erasmus program, improving data

administration and reliable information sharing [120]. Another study identified three key beneficiaries: educational institutions needing better data management, individuals seeking secure information exchange and employers requiring trusted methods to verify skills and credentials [36]. Several papers propose blockchain as a solution to eliminate fraud and streamline credential verification in education [21, 65, 78–80, 90], they highlight its importance for businesses, where employers need secure verification of professional accomplishments and skills [74]. Additionally, blockchain's utility extends beyond education to administration and staff, promoting collaboration within communities through social contracts.

Some studies [21, 80] highlight the practical challenges of paper certificates compared to blockchain in education. Others [70] focus on frameworks and systems for education, including operational skill competition evaluation. Studies also [121] explore outcome-based education (OBE) in engineering, noting traditional models' difficulties in managing diverse content. They propose that blockchain's decentralisation and immutability can resolve these issues, with case studies offering practical applications in engineering education.

4.4.2 Blockchain within online education

Online education has emerged as a vital option for career advancement and skill development, especially after the COVID-19 pandemic [71]. Despite its rapid growth, issues like decentralisation, tampering, inconsistency and lack of public recognition persist due to the absence of a unified system [23]. Blockchain is proposed as a solution, offering decentralisation, time-stamps and tamper-proof records, which could eliminate fake certificates and paper fraud. It also automates complex processes without human intervention, aiding certificate verification for job seekers. Security concerns in online education have also been addressed, proposing blockchain systems to ensure honesty in exams and user security [38, 114]. However, blockchain itself faces challenges and limitations. The following section outlines some such challenges explained in the literature.

4.5 Challenges

Many papers highlight challenges with blockchain technology, including issues of scalability [94], low ease of adoption, privacy and security concerns [36] and feasibility [94]. Researchers have also identified two further obstacles: the time required for verification and the limited number of transactions that can be processed per second on permissionless networks [36].

Research [83] cautions that the decentralised nature of blockchain, requiring high computational resources for consensus mechanisms, incurs significant costs, leading to increased institutional budgets for maintenance and real-time use. Other challenges include low throughput, delays, rollback difficulties, bottlenecks and lack of effective audits [37, 87]. While blockchain records are permanent, their potential to worsen disparities raises concerns, akin to those from intelligence testing. This study advocates shifting from technological innovation to using blockchain for sustainable education to promote social justice and mitigate external regulatory constraints [74].

Despite its potential to improve openness and integrity, implementing blockchain for higher education certification faces numerous substantial hurdles. Privacy considerations [122] are crucial, as blockchain's transparent nature runs the danger of revealing sensitive academic material to the network. In addition, the lack of common standards for credential verification [34] impedes interoperability and cross-border recognition of blockchain-stored records. The high processing needs for data replication, combined with latency difficulties, result in significant costs and scalability constraints [34, 66], which may impede wider use. Security management, particularly the use of public and private keys, adds complexity and potential weaknesses [66]. Blockchain's immutability, while preserving data integrity, limits the flexibility required for updates or record changes. Furthermore, the decentralised nature of blockchain hampers integration with traditional institutional systems and poses problems to traditional management structures [34]. These hurdles suggest that building privacy-preserving, scalable and integrable blockchain technologies is critical for facilitating widespread adoption in the education sector.

5 Discussion

We next present the theoretical and practical implications of our SLR findings.

5.1 Theoretical implications

In this SLR, three predominant theoretical frameworks were applied in select studies out of the sixty-three scholarly articles reviewed: the theory of trust [34, 123, 124], the theory of cost management [35] and agency theory [125]. These theories, though diverse, are interlinked in their applicability to education accreditation verification and blockchain technology.

The theory of trust, the most frequently invoked theory, underscores the importance of trust in collaborative relationships and transactions [126, 127]. In the context of educational accreditation, trust is a critical component as stakeholders need confidence in the process and the legitimacy of outcomes. Blockchain's transparency and immutability can promote this trust by guaranteeing that accreditation verifications are accurate, unchangeable and easily traceable [9, 128]. The University of Rome "Tor Vergata" case study demonstrates blockchain's transformative impact on credential management by enhancing trust and efficiency in issuing and verifying digital diplomas. Its secure, decentralised nature reduces administrative costs, minimises forgery risks and streamlines the certification process, showcasing its potential for global certificate authentication.

Cost management theory advocates for the efficient allocation of resources to minimise costs [129]. Implementing blockchain technology in education accreditation verification could reduce the costs associated with manual verification processes, document storage and fraud prevention [130]. The journal article "Immutable Ubiquitous Digital Certificate Authentication Using Blockchain Protocol" by Rahardja et al. [131] focuses on the application of blockchain technology in education, specifically in the management and authentication of digital certificates. It demonstrates how blockchain enhances data security, reduces operational costs and improves the authenticity of educational certificates. By decentralising data management, blockchain significantly lowers administrative expenses while ensuring data integrity. Its application in educational institutions, especially for certificate authentication, creates a global trust network with immutable, authenticated data. This research highlights blockchain's potential to transform educational systems, improve human resource quality and manage certificates more efficiently and securely.

Finally, agency theory centres on the relationships between principals (those who delegate work) and agents (those who carry out the work) [132]. Agency theory examines the relationship between governments (principals) and universities (agents), focusing on aligning their diverse goals. It is especially useful in understanding how performance agreements, acting as negotiated contracts, can help balance governmental expectations with academic priorities. A major challenge in this relationship is the information gap between both parties, which impacts governance. Outcome-based incentives to align university activities with government objectives have been proposed [133], potentially bridging this gap and motivating universities to prioritise government objectives. This highlights agency theory's role in enhancing the government-university dynamic. In accreditation, educational institutions act as principals, while accrediting bodies serve as agents. Transparency and immutability can enhance this relationship by increasing accountability and reducing information asymmetry [14].

5.2 Practical implications

5.2.1 Governance for accreditation and validation in education

A well-structured education technology strategy, supported by a robust governance framework, is essential for implementing a blockchain-based certificate accreditation and validation system in academia [98]. Effective planning, including adherence to regulations and standards, is crucial for navigating the complexities of blockchain in education. Integrating technical and governance considerations is key to successful implementation. Saleh et al. [55] emphasise a privacy-preserving protocol by implementing blockchain technology such as Hyperledger Fabric with a new protocol known as Decentralised Control Verification Privacy-Cantered (DCVPC) protocol [55] can enhance security by encrypting individual node transactions and ensuring the secure delivery of educational records on a distributed network. This approach addresses issues related to centralised accreditation systems and compliance with regulations such as GDPR [50, 111]. By integrating these principles and technologies, educational systems can overcome challenges such as data silos, lack of interoperability and vulnerability to cyber-attacks, ultimately providing a more secure and efficient governance framework for educational institutions.

Research on governance and its impact has emerged only recently, starting in 2021. The digital governance strategy emphasises principles, such as inclusion, openness, adaptability, consistency and data protection, all crucial components of a robust governance framework [98]. Additionally, the challenges faced by current digital governance solutions in education systems highlight the importance of unified data formats, interoperability and integration with various stakeholders, such as universities and employers, further emphasising the need for a well-structured IT strategy underpinned by a robust governance framework [50]. These papers collectively stress the significance of governance structures, accountability and standardisation in ensuring the effectiveness and security of digital systems in education and beyond.

Governance frameworks are essential for managing blockchain applications in education, ensuring data security and privacy [98]. Establishing rules, policies and procedures is crucial for effective blockchain use in educational systems. Effective governance addresses challenges, such as data ownership and vulnerability to cyber-attacks and enhances data security, interoperability and integration with stakeholders. It is vital for establishing trust, assuring data integrity and preventing security breaches in blockchain-based educational applications.

5.2.2 Implications of blockchain, governance, in education certificate accreditation and verification

The application of blockchain technology in distance learning can revolutionise the way educational content is delivered and accessed, enabling seamless collaboration and personalised learning experiences. Some potential threats and vulnerabilities need to be carefully considered [73]. Alsaadi and Bamasoud [73] highlight the aspects of blockchain governance and how it can revolutionise education by promoting secure, cost-effective and transparent systems. Blockchain offers real-time democracy and justice, transforming communication and accessibility. It enables educational institutions to expand globally by widening admissions and providing secure, transparent and cost-effective solutions. This study examines current technology in Saudi Arabia and includes an in-depth analysis of over 70 papers, 35 of which are noted in the review. Overall, Alsaadi and Bamasoud [73] emphasise blockchain's potential as an enabler for the accreditation and verification of education certificates.

5.3 Future directions

We note that most papers do not critically address the governance of blockchain technology in higher education. Although blockchain was designed to challenge traditional governance structures, its role in education certification necessitates verification by a recognised authority. Thus, a lean governing body is imperative.

While some papers briefly mention governance, they often lack a critical analysis of governance mechanisms, which limits blockchain adoption in education. This gap indicates two things: first, governance is not yet recognised as crucial for blockchain adoption in education, despite its challenges and near failure as cryptocurrency. Second, there is a perception that governance may not be relevant, even when proposed as a solution for certificate validation. This highlights the need for a deeper analysis of governance in this paper and suggests areas for future research.

The future research themes emerging from 2023 papers highlight several key areas in blockchain technology's application in education:

1. Adaptability in massive repositories: It is crucial to assess the challenges and impacts of implementing large-scale e-certificate repositories, which involve collaboration among educational stakeholders, such as universities, students and employers [134, 135].
2. Enhanced security features: Further exploration is needed into security concerns, such as scalability, flexibility, authorisation, mutual authentication and resistance to attacks in blockchain for educational use [67, 135].
3. Integration with next-generation technologies: Research should focus on merging blockchain with next-generation technologies for Education 4.0, emphasising confidentiality, integrity, availability, scalability and flexibility [135].
4. Metaverse and blockchain integration: Research should investigate the potential of combining the metaverse with blockchain to create collaborative platforms in education, ensuring enhanced engagement and learning opportunities [136].
5. Blockchain-based microcredentialling systems: There is a need to identify and address research gaps in the literature on blockchain-based microcredentialling in higher education, focusing on intelligent platforms for managing these microcredentials [137, 138].

These themes underline the continuous evolution and expansion of blockchain applications in education, stressing the importance of addressing technical, security and collaborative aspects to fully harness its potential.

The importance of governance in blockchain applications for education is a critical area of future research. Governance in this context includes the establishment of frameworks and procedures to ensure that blockchain technology is used safely and appropriately in educational environments [3, 139]. Key aspects include addressing ethical responsibilities, formulating governance processes at the ecosystem level and scrutinising the roles, accountability and motivations of stakeholders. The research underscores the necessity of enhancing blockchain adaptability and upgradability while considering broader ethical implications in its governance. The significance of governance at the ecosystem scale is emphasised, as is the exploration of stakeholder responsibilities and capabilities. Effectively addressing these governance challenges is vital for the successful deployment and utilisation of blockchain in educational contexts [3]. This study provides key insights. First, governance enhances blockchain adaptability and upgradability, yet broader ethical considerations are often overlooked in current governance objectives. Second, governance is integral to blockchain development, but comprehensive ecosystem-level governance processes are lacking. Third, the study briefly touches on stakeholder responsibilities and capabilities but requires deeper exploration into their decision rights, accountability and incentives. This research offers practical guidelines for academic and industry practitioners for use throughout blockchain's lifecycle and outlines future directions to aid researchers in this evolving field.

5.4 Limitations of blockchain technology in education

Implementing blockchain technology in education faces practical challenges, including limitations of existing systems, the need for standards and rules and the requirement to address diverse interests across countries [136]. Integration of universities' internal systems and coordination among organizations also complicate certificate authenticity [140]. Security flaws, particularly with advancements in quantum computing and government roles in decentralizing economic structures, pose additional challenges [67]. Moreover, the transparency principle may necessitate public access to educational records, requiring coordinated policies across nations [42]. Overall, addressing these challenges is essential for the effective implementation and widespread adoption of blockchain technology in education.

5.5 Limitations of the systematic study

The principal limitations of a systematic mapping study are multifaceted, encompassing publication bias, selection bias, inaccuracies in data extraction and misclassification [141]. Publication bias arises when the published research is not representative of all conducted studies, often favouring those with positive or significant results, thereby skewing the overall findings [142, 143]. Selection bias occurs when the studies included in the review are chosen based on criteria that may introduce bias, potentially compromising the validity of the study's conclusions [59]. We have attempted to reduce the selection bias by having a pre-planned search protocol [144]. The scope of this study is confined to examining the influence of blockchain technology on the accreditation process within the education sector, excluding other factors that may influence accreditation.

6 Conclusion

This research confirmed the validity of the main research question: what is the impact of blockchain technology on the accreditation process in the education sector? Empirical studies reveal various blockchain applications that address accreditation challenges. We identified significant hurdles in validating educational credentials and emphasised the need for a standardised governance system for certification validation, especially in higher education. This need is prompted by factors, such as increasing labour mobility, the rise of micro-credentials for lifelong learning and geopolitical disruptions affecting displaced populations. These elements undermine the integrity of previously obtained educational certifications. Blockchain technology, with its attributes of immutability, security and trust, is proposed as a solution to this issue. Beyond preventing certificate falsification, blockchain can enhance trust and agency theory and reduce administrative costs associated with physical validation and verification, supporting cost management theory. Thus, integrating blockchain into educational certification systems requires thorough exploration to ensure the accuracy and effectiveness of future credentialing practices.

The literature review encompassed a total of 63 articles, exploring various dimensions of blockchain technology in education. These articles were published in a range of high-impact journals, including many ranked in SCImago Q1 and Q2 ranks. The review covered publications from the years 2018 to 2023, reflecting the evolving nature of blockchain applications in educational contexts. Regionally, the articles originated from diverse geographic areas, including the United States, China, India, Saudi Arabia, Portugal and South Africa, among others. The types of articles reviewed varied widely, encompassing empirical studies, theoretical papers, systematic reviews and case studies. The research predominantly focused on themes such as digital credentialing, document verification, gamification and the integration of blockchain with other emerging technologies, such as AI and robotics. This comprehensive analysis highlights the global interest and multifaceted potential of blockchain technology in transforming educational systems.

The technology's inherent attributes of immutability, security and trust present a robust solution to these accreditation challenges. Its adoption not only combats certificate falsification but also supports theories of trust, agency and cost management by reducing administrative expenses. Future research should focus on the use of blockchain technology in education, highlighting key areas such as adaptability, better security features, integration with next-generation technologies, metaverse and blockchain integration and blockchain-based micro-credentialing systems. These themes emphasise the importance of technical, security and collaborative factors in realising the full potential of blockchain technology. Governance is also an important topic of research, as it ensures the safe and appropriate usage of blockchain technology in educational settings. Addressing ethical obligations, developing ecosystem-level governance mechanisms and examining stakeholder responsibilities and capabilities are all important considerations. Governance improves blockchain adaptability and upgradeability, but larger ethical concerns are sometimes disregarded. This study provides practical suggestions for academic and industry practitioners across the blockchain lifecycle and suggests future directions for academics in this rapidly expanding topic.

This literature review highlights the transformative potential of blockchain in education, advocating for its thorough integration into certification systems to enhance the veracity and efficacy of credentialing practices. The insights gained from this review lay the groundwork for future explorations into blockchain governance, aiming to establish a reliable, secure and efficient framework for educational accreditation.

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Code availability Not applicable.

Declarations

Competing interests The authors declare no competing interests.

Appendix: The following themes were identified in the research

Year	Theme	Description
2018	Use in online education & online testing	Transparent sustainable tools for managing learner credentials. Blockchain enables personal encrypted credentials and supports lifelong learning
	Gaming for schools	Leveraging blockchain technology in digital education can enhance operational simulations and games, improving teaching quality and learning outcomes
2019	1. Increased Application of Blockchain in Education	The rise of blockchain technology for various functions in education, such as certificate issuance, storage and verification, is driven by the need to mitigate fraudulent certification and improve verification efficiency
	2. Controlled Credential Disclosure	The emergence of the concept enables credential recipients to control the amount of credential-related information exposed during the verification process, demonstrating blockchain's potential for enhanced privacy
	3. Integration of Public and Private Blockchains	A proposed network structure combining public and private blockchains for e-learning assessment, digital certificate issuance and secure storage, potentially creating a fairer and more open e-learning environment
	4. Use of Incentive Mechanisms	Introduction of game-based incentive mechanisms for skill verification process participation, highlighting the innovation potential within blockchain-based systems
	5. Broadened Application of Blockchain	Proposed uses of blockchain beyond credential verification, including secure data transactions, student records security, digital badges, human resources, library access and academic research publications
	6. Role of Blockchain in Peace Engineering and Sustainable Development	Interest in leveraging blockchain technology to manage information globally, potentially revolutionizing how knowledge is managed, produced and shared in higher education institutions
	7. Need for Systematic Literature Reviews	Indication of the need for systematic literature reviews on blockchain-based educational projects to explore the technological gap and potential in the education sector
2020	1. Credential Verification	Application of blockchain technology for issuing and verifying academic certificates in a decentralized manner, combating fraudulent certificates using smart contracts and multi-signature schemes
	2. Decentralization of Education	The trend towards decentralized, blockchain-enabled educational systems provides improved control and management over educational data and activities
	3. Data Management and Security	Blockchain is viewed as a secure and reliable means to manage and protect various forms of educational data
	4. Integration with Existing Systems	The trend towards developing blockchain solutions that integrate with existing academic information systems to streamline processes such as academic marks exchange
	5. Incentive Systems	Exploration of blockchain as a tool to incentivize participation and improve efficiency in certain educational processes
2021	1. Blockchain for Credential Verification	Focus on using blockchain technology to establish the authenticity and verifiability of academic credits and certificates
	2. Enhanced Data Security and Privacy	Emphasis on blockchain's potential to bolster data security and uphold student privacy
	3. Decentralization and Trust through Blockchain	Emphasis on blockchain's ability to promote trust and decentralization in educational data management
	4. Addressing Challenges of Blockchain Adoption	Acknowledgement of challenges of blockchain adoption, such as scalability and compliance with international regulations and the call for innovative solutions
	5. Blockchain for Global Educational Inclusivity	Proposal of blockchain as a tool to facilitate internationalization and inclusivity in higher education
	6. Streamlining Administrative Processes with Blockchain	Focus on blockchain's potential to make administrative processes more efficient and reduce bureaucratic hurdles
2022	1. Blockchain in Certification	Emphasis on the potential application of blockchain technology in the certification system for issuing authentic and shareable student credentials

Year	Theme	Description
	2. Decentralization in Health Professions Education (HPE)	Proposal of blockchain technology as a data management framework that could reshape HPE institutions by supporting decentralized learning systems
	3. Blockchain in Comprehensive Educational Reform	Emphasis on a whole-systems approach to adopting blockchain technology in education, moving beyond record keeping and certification
	4. Multidimensional Humanized Teaching Framework	Proposal to employ blockchain technology to construct a comprehensive, cooperative educational service platform

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