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Review

Challenges of Using Blockchain in the Education Sector: A Literature Review

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Abstract: Blockchain is one of the latest innovations that is increasingly attracting the attention of various stakeholders in different fields, including the education sector. This is primarily due to its attractive features, such as decentralization, transparency, traceability, security, and reliability. Despite its advantages, blockchain still faces several challenges, and the acceptance rate of this technology is still low. Thus, the purpose of this study was to conduct a review of published articles that have discussed the challenges of adopting blockchain in the education sector. The review contained scientific papers published from 2017 to 2022 and, from the screened records, 32 articles were analyzed in full-text form. In this review, 14 challenges were reported and classified, based on the technology-organization-environment (TOE) framework. In addition, this review showed that organizational and environmental barriers received little attention in the literature, compared to technological barriers.

Keywords: blockchain; distributed ledgers; blockchain challenges; blockchain in education; decentralized education

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1. Introduction

Blockchain is a decentralized, immutable database made up of a series of "blocks" that hold data, including transaction dates, timings, amounts, and/or participants [1]. When a user initiates a transaction with another user through a peer-to-peer network, a cryptographic identification mechanism is used to uniquely identify the participants. The transaction is then sent to the blockchain network storage pool and waits for verification. The new block will be created by reaching a particular number of authorized nodes; this is referred to as reaching a consensus. After consensus, a new "block" will be created, and every node updates its corresponding blockchain ledger copy. A consensus algorithm is used to complete the consensus phase. This process is called mining. The common consensus mechanisms include proof of work (PoW) and proof of stake (PoS) [2].

Blockchain technology offers various attractive features [3] such as decentralization, transparency, immutability, and traceability. Decentralization refers to the fact that the technology does not require a centralized node to record, store or update data on the blockchain; instead, data can be recorded, stored, and updated in a distributed manner [3]. Therefore, instead of centralized organizations, mathematical methods are used to build trust among the distributed nodes. Since blockchain is a distributed ledger that is maintained by thousands of nodes, blockchain is immutable. This is due to fact that tampering can only succeed if 51% of the ledgers are changed through the network [3]. In addition, blockchain is transparent, as data recording is transparent for each node on the network, even when updating data [1]. Furthermore, blockchain is traceable as all blockchain transactions are sorted chronologically, and a block is associated with its two adjacent blocks using a hash function. Thus, by checking block information, each transaction may be tracked [2].

The advantages of blockchain technology in education are varied, from handling information to the verification of data, without sacrificing accuracy [4]. Because blockchain-based solutions speed up and simplify administrative work when a validation process is needed, blockchain could streamline and simplify student activities associated with the validation of issued credentials, such as degrees, transcripts, and students' qualifications, successes, and professional ability [4]. In addition, blockchain solutions keep ownership and control over obtained credentials on students, thus avoiding the need for an intermediary to verify them [5]. Furthermore, as explained in the same study, "blockchain could mainly facilitate management and operational activities of higher educational institutions for payment management (e.g., receipts of students' payments), international collaboration management (e.g., automatic recognition of awarded points), accreditation processes (e.g., a certificate issued by the government that the higher education institution is licensed to carry out specific tasks), etc." [5].

Educational institutions can also benefit from blockchain technology in a variety of ways. For example, the procedure of internationalization of higher-education institutions via student exchanges or joint programs can be simplified by eliminating time-consuming and expensive processes. One more example is the "blockchain-based gamification of learning" [5], which would make managing the issued certificates easier.

Additionally, blockchain can be used as an academic publication platform. Furthermore, processing tuition fees, grant funding, simplifying diploma verification and the virtual Lifelong Learning Passport are some instances where the blockchain is used [5]. Therefore, blockchain helps educational institutions to minimize their administrative costs and bureaucratic procedures [4]. Another initiative for higher-education institutions is blockchain record-keeping, which includes several case studies, for example, "securing the certificates permanently, verifying the accreditation, automatic recognition of credits, and intellectual property management" [5].

Depending on their structure and design, blockchains have different "flavors". The content contained in blockchain blocks as well as the activities carried out by the different participants on blockchain networks can be controlled, according to how the blockchain is set up and how it is expected to meet the desired business objective [6]. Public and private blockchains are the two most common types. They are widely used in numerous cryptocurrency networks and private companies. A third type, permissioned blockchains, has also earned popularity.

On the one hand, in a public blockchain, everyone is allowed to join in the basic blockchain network activities [7]. However, despite the agility of the public blockchain, there are some limitations to this type. The most important one is the high electricity consumption needed to sustain the distributed public ledger. Other problems include the lack of privacy and anonymity [7]. On the other hand, the private blockchain grants only verified participants the ability to join the network [7]. It is a cryptography-based distributed ledger that acts as a closed, secure database. Therefore, not all participants have permission to run a full node, conduct transactions, or verify blockchain changes. The third type is the permissioned blockchain, which has both private and public blockchain attributes. Permissioned blockchains have become increasingly popular, due to their ability to assign distinct permissions to different network users [6]. This involves allowing any participants to enter the permissioned network after proper verification of their credentials and assigning selected and designated permissions to undertake only specific network operations [7].

Nowadays, some educational institutes have adopted blockchain technology in education; the majority of them use it to support academic degree management and summative assessment for learning outcomes [8]. For example, blockchain technology can record entire transcripts, such as the content and results of learning, students' achievements, university degrees, research experience, competencies, and individual interests [6]. These records can be securely stored and properly retrieved on a blockchain network.

In the past, several cases of degree fraud have been reported [2]. However, blockchain technology helps in the reduction of degree fraud [8], for example by using a digital signature scheme and timestamps using blockchain [2], or by employing the time-stamping feature of blockchain to avoid illegal actions from diploma issuers, and the integrity and immutability characteristics to store diploma data and track the important updates of records [8]. Beyond evaluating and managing certificates, blockchain technology also offers a wide range of applications for formative evaluation, design, the implementation of learning activities, and the tracking of learning processes [8].

Despite all these advantages and opportunities to apply blockchain in the education sector, there are still several challenges [7,9]. For example, blockchain, according to Saberi et al. [10], is still regarded as an immature technology because it is still in the early stages of development. Therefore, it still suffers from various issues related to scalability, interoperability, security, and privacy. In addition, since the educational systems have collected enormous volumes of data on many students, this increases the number of blocks and transactions in the blockchain, which requires more time to process, considering that each transaction needs peer-to-peer verification [11]. Furthermore, the consensus protocol for the verification of new blocks expends a substantial amount of power [12]. Another significant concern is the lack of interoperability between the numerous blockchain networks. This is due to the lack of common standards that would enable multiple networks to interact with each other. Furthermore, there is also the issue of how to integrate blockchain technology with legacy systems [7,13–15].

Despite blockchain being known for its security and the community's efforts to make the platform stable and secure, security remains a challenging issue, and there are specific blockchain security issues and vulnerabilities that must be considered [16]. However, the literature reported other challenges in terms of privacy, a lack of qualified professionals, legal and financial issues, and stakeholder awareness, among other problems [7–9,17–20].

In other literature reviews, previous research attempted to partially summarize the available knowledge regarding blockchain for education applications. Some discuss, for example, blockchain-based applications and opportunities in the field of education [2,6–9,11,18,19]. However, these reviews did not focus primarily on the challenges of adopting blockchain in education. For example, one study [18] is a systematic review of research exploring blockchain-based educational applications. Thus, these reviews focused on the educational applications that have already been built with blockchain technology, and on the advantages that blockchain technology could bring to education. However, the same study [18] discussed only briefly and generally the issues of adopting blockchain technology in education; for example, the security issue in [18] was discussed in just one line of the study. In addition, several challenges were not discussed or reported at all, such as the lack of standardization, sustainability, legal issues, the lack of skills, and more. Therefore, it did not provide a complete review of all the blockchain challenges in education. Furthermore, the reported challenges were not classified or organized using any type of classification framework. Gabrielli et al. [6] published a systematic literature review that reviewed the advantages, barriers, and applications of blockchain in the education sector. It briefly presented only some of the technical challenges such as security data unavailability and scalability, with very limited or no discussion of other types of challenges such as organizational and environmental issues.

Another literature review [7] presented a systematic overview of blockchain projects and solutions in higher education. In addition, the challenges of implementing a specific blockchain-based platform named EduCTX were reported. However, the reported challenges were related to implementing a specific educational solution for managing certificates; it is, therefore, not a complete review of all the technical, organizational, and environmental challenges of the adoption of blockchain in the education sector.

Other researchers proposed solutions for some issues related to the adoption of blockchain in the education sector [10,16,21–40]. However, they focused on a specific issue. In addition, although the literature has discussed some of the obstacles to the application of blockchain in education, it is still fragmented. Therefore, this review is important in providing a state-of-the-art overview of all types of challenges of adopting blockchain in education. In this way, this review makes a unique and timely contribution to the literature on education technology by examining barriers to the acceptance of blockchain technology in education. In addition, this review classified the identified challenges according to the TOE framework [29] into technological, organizational, and environmental contexts. Furthermore, the current review will help academics, policymakers, and managers interested in gaining knowledge of this promising technology to assess the applicability of blockchain in the educational field.

The rest of the paper is organized as follows. Section 2 describes the methodology used to search and filter articles. Section 3 focuses on analyzing and presenting the findings obtained from the selected articles. The findings are followed by the discussion and future research in Section 4. Finally, Section 5 discusses the study's limitations and challenges.

2. Methods

This study set out to answer the following research question: "What are the challenges of using blockchain in the education sector?" This research question was used to determine the content and structure of the review, to design strategies, locate and select studies, critically evaluate studies, and analyze their results.

2.1. The Review Process

The selection process for the review was as follows: the first step was to search for databases on the topics to be addressed. The search terms in Section 2.2 were used in these databases. Once the duplicates have been deleted, the two authors of the current article proceeded to a meticulous reading; the definitive ones are selected according to the eligibility criteria given in Section 2.3. To ensure up-to-date information, filtering by publication date has also been used, so that articles published before 2017 were deleted. To ensure the validity and reliability of the materials, a second filter rule was chosen, which required that the material should be a peer-reviewed article. After applying all filters, the results for each database were as follows: ScienceDirect (2642 articles), Web of Science (2571), Springer (2036 articles), IEEE Xplore (334 articles), and MDPI (144 articles).

Relevant articles have also been discovered by reviewing references to previously identified articles (backward search) and finding newer works that incorporated the cited material (forward search).

2.2. Search Method

A review of the literature concerning the adoption of blockchain technology in the education sector was conducted using ScienceDirect, Web of Science, Springer, IEEE Xplore, and MDPI. The following combinations of keywords were used to find relevant data: (blockchain OR block chain) AND (challenge OR barrier OR obstacle) AND (academic OR learn* OR educat* OR teach*). Further relevant papers were also located by reviewing the references from previously identified papers (backward search) and finding newer publications that referenced the cited article (forward search).

2.3. Eligibility Criteria

The blockchain area of study began to attract attention among academics after 2016, at the beginning of cryptocurrency exchanges and the adoption of cryptocurrency as a means of digital payment in various economies around the world. The technology has been used in all major areas of research, including education, healthcare, banks, supply chains, governance, the Internet of Things, etc. [6]. In the education field, blockchain technology is considered new and has begun to receive attention since 2017, where it has grown steadily in importance and seems set to grow in the coming years [6]. Therefore, articles published from 2017 to 2022 will be considered. In addition, the articles were reviewed to meet four other basic criteria. Only articles published in peer-refereed journals would be considered; the studies needed to be written in English, the articles had to focus on blockchain, and the studies should be centered on educational issues and challenges. Studies that did not focus particularly on the blockchain were not focused on the education sector, and did not focus on challenges were all excluded.

2.4. Data Extraction

Information concerning the challenge types, solutions, and study design characteristics was extracted from the articles. The information collected for each study was concerned mainly with blockchain solutions and objectives, the platform used, and the limitations of blockchain. We have also taken note of the findings of the research and the conclusions drawn by the authors. To determine eligibility and extract answers to the research question, the authors have independently reviewed each of the relevant articles. Any differences between the opinions of the authors were resolved by discussion and agreement. Any discrepancy between the codification of the authors was minimal and was resolved effectively.

3. Results

At each level of the selection process, the number of studies identified, screened, and included or rejected is shown in Figure 1. In total, 7727 articles were extracted from the four selected electronic databases and 692 of them were removed for duplication. Then, 6961 were excluded after screening their titles and abstracts. At this point, 76 articles were evaluated for the full-text review, and 44 were excluded; 31 articles did not focus on blockchain, 10 did not focus on the education sector, and 3 articles were not available in full-text. Finally, 32 articles were included as valid sources of data for qualitative synthesis.

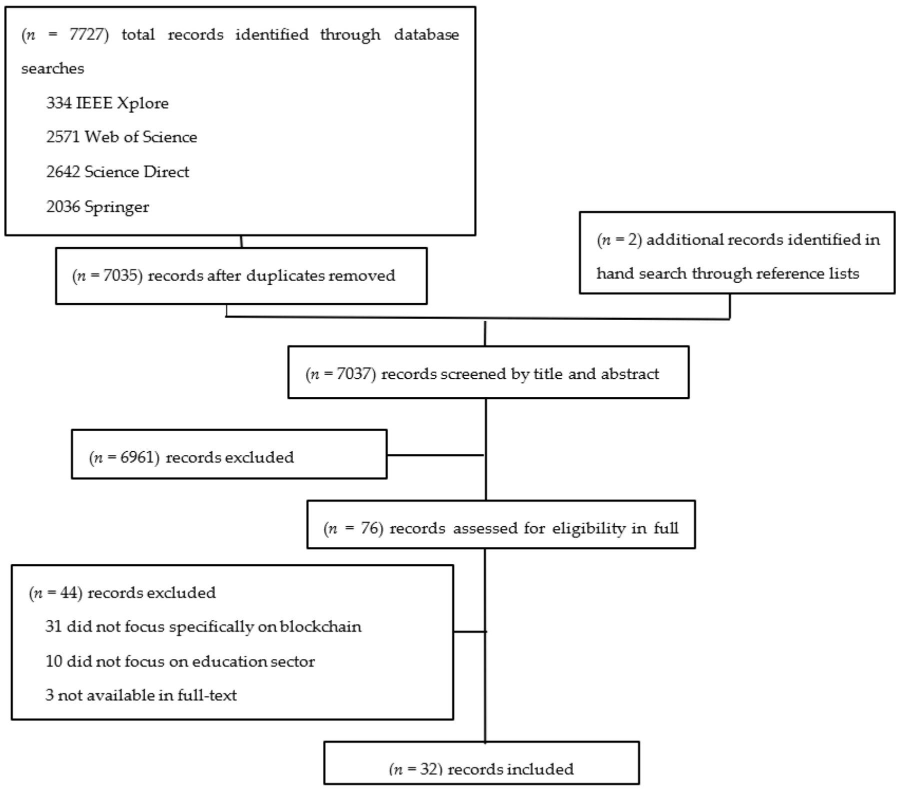

Figure 1. Flow diagram for the screening and selection process.

3.1. Characteristics of Research Studies

The highest number of articles (10) was published in 2021 (31%) (see Figure 2), while eight (25%) were published in 2020. In 2022, the number of publications at the time of research was two (9%). The number of papers published in journals about the blockchain in the higher education sector is clearly growing, although interest in this field and early initiatives in researching the topic began in 2013.

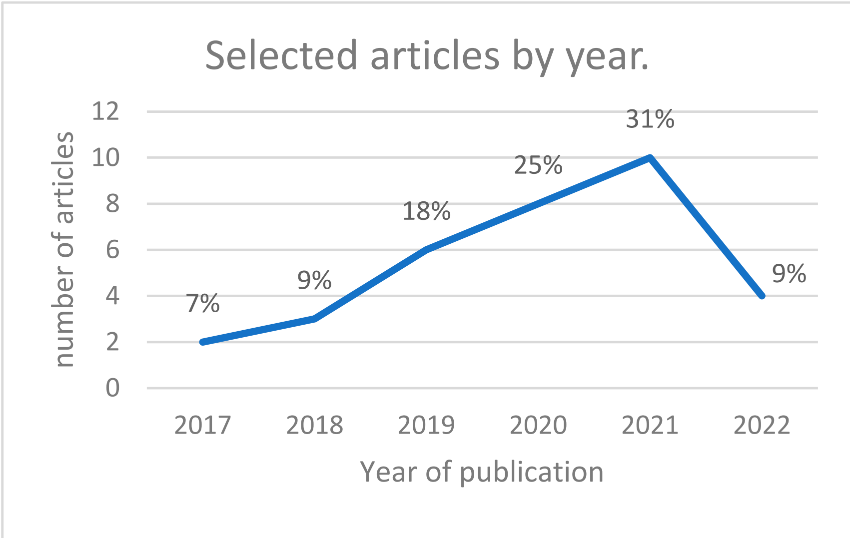

Figure 2. Publication year of included articles.

3.2. Challenges of Blockchain in Education

The 32 reviewed articles highlighted different challenges. These challenges should be considered when using blockchain in the education sector. We used the technology, organization, and environment (TOE) model [29] to categorize the challenges. Researchers have utilized this approach widely to analyze the adoption of information technology. The technological, organizational, and environmental aspects are all utilized in this framework to define technological advancement adoption decisions. The technological perspective defines the technological attributes that are related to the adoption of blockchains, such as security, privacy, scalability, immutability, and cost-effectiveness. The organizational perspective identifies the organizational aspects and assets of an organization, such as organizational readiness that are important to the acceptance of technology. The environmental setting represents the environmental aspects in which the organization performs its essential services such as laws and regulations support. Table 1 presents these categories and selected articles that are included in each of these categories. The technological challenges are as follows: poor usability, lack of scalability, limited interoperability and standardization (classified under the immaturity of blockchain challenge), the complexity of integration, security issues, privacy, immutability and lack of flexibility, and data unavailability. In the organizational context, there is a lack of adequate skills, financial barriers, and a lack of management commitment and support. In the environmental context, there are legal issues and a lack of regulatory compliance, market and ecosystem readiness, and sustainability concerns.

Table 1. The reviewed articles' categories.

Context	Challenges		Refs.
Technological	Immaturity	Poor usability	[6,9,23,31,33]
		Lack of scalability	[7,8,11,12,18,26]
		Limited interoperability and standardization	[19,33]
	Complexity of integration		[2,13–15]
	Security issues		[16,23–25,41–44]
	Privacy		[7,27–29,44–46]
	Immutability and lack of flexibility		[9,19,43,47,48]
	Data unavailability		[1,18]
Organizational	Lack of adequate skills		[20]
	Financial barriers		[7,9,12,18,19]
	Lack of management commitment and support		[9,11,20]
Environmental	Legal issues and a lack of regulatory compliance		[11]
	The market and ecosystem readiness		[11,25]
	Sustainability concerns		[8,20]

3.2.1. Technological Barriers

Rogers [30] defined the technological context as comprising the technical capability, complexity, difficulty, and availability of the technology being considered for adoption. For the adoption of blockchain, this category includes barriers arising from the blockchain's technological limitations [30]. Therefore, this review classified immaturity, the complexity of integration, immutability, lack of flexibility, security, privacy, and data unavailability as falling into the technological group (see Table 2).

1. *Challenge 1: Immaturity*

The first challenge is related to the immaturity of blockchain technology. Fourteen articles [6–9,11,12,18,19,23,26,27,31–33] reported that blockchain still suffers from certain immaturity problems. The blockchain, according to Zheng et al. [12], is still regarded as an immature technology because it is still in the early stages of development. Thus, technical issues, such as a lack of scalability, poor usability, and limited interoperability and standardization, arise as a result of immaturity [49,50]. Therefore, this review classified these challenges as falling into the immaturity barriers group (see Table 2).

Table 2. The blockchain technologies used in the identified publications.

Refs.	Blockchain Technologies Used	Limitations
[14]	Hyperledger Fabric (permission-based private blockchain network)	There is a need to design customized digital contracts and certificate authority verification policies among stakeholders and automate (smart contract) them, along with the digital signature.
[15]	The Ethereum blockchain	This adds a monetary cost to the process. Adding a certificate to the blockchain, for example, entails transaction costs that must be paid by the certifier.
[16]	An agent-based blockchain technology to secure data against insider threats, based on Ethereum's Proof of Authority (PoA) consensus algorithm	The overall cost of transacting on the Ethereum blockchain.

Table 2. *Cont.*

Refs.	Blockchain Technologies Used	Limitations
[19]	Ethereum and BigChainDB, used to securely store and retrieve student transcript records	Cost of transacting
[23]	SH-256 re-encryption	Hash-encryption SH-256 ECDSA signature algorithm, public key infrastructure, public architecture, permissionless.
[24]	Adding OpenLearn badges to a private blockchain. the Open Blockchain platform is implemented on the open-source Ethereum infrastructure4 which supports the creation of Distributed Applications comprising sets of Smart Contracts. All transactions are timestamped and are cryptographically signed. Peer-to-peer transactions: no-host educational institution is needed	There is a need to integrate badges from other educational institutions with FutureLearn5 and, additionally, to set badges on the public Ethereum blockchain.
[25]	Permissionless public network	Public-based educational verification design that simplifies credential security issues and the implementation issues in the EduCTX project.
[51]	The Stellar blockchain (Stellar uses less energy than Ethereum because it relies on its federated Byzantine fault tolerance (FBFT) consensus algorithm, rather than expensive proof-of-work computations)	Stellar does not allow for public verification of smart contract execution, nor does it allow for the execution of sophisticated non-financial transactions. This has an impact on audibility because contract computations are not publicly verified.
[27]	Secure storage is accomplished by merging blockchain and a storage server. For records sharing, to accomplish cross-institutional sharing of learning records, smart contracts are established, and the sharing process is handled by smart contracts on the blockchain. Finally, an anti-tampering inspection method is utilized to protect records in the storage server.	There is a need for a professional platform for deploying, scheduling and managing smart contracts.
[33]	Ethereum platform	Restricted to the public network, permissionless, Conceptual model, and the overall cost of transacting on the Ethereum blockchain.
[40]	Ethereum platform	Because Blockchain encryption is a time-consuming procedure, it is crucial to investigate the alternatives. In addition, the overall cost of transacting on the Ethereum blockchain is a consideration.
[41]	The open-source Ethereum	For real-time applications, the time required to write academic records to the blockchain is insufficient.
[42]	No customized digital contracts policy	Restricted to a desktop application, with the absence of an endorser and order administration.
[43]	Conceptual modular architecture	Ethereum architecture that used multichain, hash encryption SH-256, and restricted access to a permissionless network.
[44]	Permissionless network (Consortium nature)	Restricted to the specific region, this is a conceptual model.
[46]	Verification system using a QR code	A conceptual model and a security SH-256 encryption are used.

Table 2. *Cont.*

Refs.	Blockchain Technologies Used	Limitations
[48]	Public network architecture	Limited to the case study, the verification process is based on a public network architecture.
[6,8,20,31]	No specific blockchain settings were used (qualitative or quantitative studies)	No experiment or solution within certain settings.
[1,2,6,7,9,11–13,18,37,47]	No specific blockchain settings were used (literature reviews)	No experiment or proposed solution within certain settings.

- *Poor usability*

Usability is defined as the degree of ease of use of software, and the quality of its fit for end-users [51]; the usability issue is considered one of the main obstacles to the widespread adoption of any new technology [51]. In the education field, the usability of blockchain technology is a major key barrier; this review showed that five articles [6,9,23,31,33] considered usability when designing and implementing a blockchain-based solution for educational institutions. However, usability was not the main focus of the researchers, and other issues, such as security and privacy, received more attention.

Gabrielli et al. [6] investigated users' key prospects, preferences, and matters concerning the adoption of blockchain-based personal data-sharing platforms in the education and health fields. This research presents a multidimensional evaluation of the KRAKEN blockchain-based solution, which was evaluated by 15 participants who represented major target-user groups in the health and education pilot areas. The significance of the usability aspect was emphasized by participants during group interviews, where the majority of participants evinced interest and trust in using the blockchain solution if the user experience was good [6]. However, participants were only moderately satisfied with the prototype's usability and suggested additional enhancements to the user experience [6].

Kosmarski [31] showed how blockchain-based solutions have been adopted in academia. A critical evaluation of projects, the related literature, and qualitative studies served as the foundation for this study. Findings showed that one of the most significant concerns and challenges to blockchain adoption in education was usability. This is due to the complexity and poor user experience of the investigated blockchain-based applications [31].

Poor usability is also due to the fact that the terminology of blockchain technology is still new and is under development [18]. In addition, users need to manage a range of aspects, such as smart contracts, and the private and public keys that make security more complicated [23]. Furthermore, it is remarkable that the complexity of settings, the difficulty of terminology, the lack of technical expertise, and the wide range of different specifications can make it very difficult for the learners, educators, and other professional parties in the chain to understand and use this technology application [18,31]. Thus, several educational institutions are reluctant to share all data in a blockchain network and cannot decide what kind of data and services should be offered via the blockchain network [19].

The usability of blockchain should therefore be improved through new design interfaces that better meet the needs of users, while training should be offered to students, and academic and administrative staff [25]. For example, Raimundo and Rosário [9] proposed a usable blockchain-based smart contract solution for managing students' scholarships in India; this solution offers a user-friendly environment for learners and maintains a transparent relationship between the learners and their education boards. In addition, the web interface of the solution was successfully verified against different types of attacks. Risius and Spohrer [23] proposed a user-friendly solution for the certificates and academic credits in the Brazilian education system, wherein a transparent paradigm based on blockchain is used. This system helps students to enroll in educational institutions and register their academic credits in the blockchain using the Brazilian public key Infrastructure for identity management. Ocheja et al. [32] introduced a blockchain-based method for sharing learning data between educational institutions and related organizations. However, these solutions were implemented without the main focus being on usability; the focus of the study was on other blockchain features, such as security.

- *Lack of scalability*

Blockchain was first presented as a decentralized cryptocurrency; however, with the development of distributed ledger technologies (DLTs) and the emergence of smart contracts, this technology has grown significantly and is used in non-crypto currency domains, such as education, health care, and the supply chain [52]. With this growth in the number of users, scalability issues arise. Scalability is defined as the ability of a system to continuously respond and operate after increasing the input size to meet user demand [49]. In the context of blockchain, Arndt and Guercio [18] defined scalability as the challenge of slow-speed blockchain transactions. However, this review showed that six articles [7,8,11,12,18,26] reported that blockchain applications in education may suffer from scalability issues, which limits their broad use in the education domain.

Educational systems have collected large amounts of data on many students, resulting in an increase in block sizes [11]. With the increasing number of blocks, transactions in the blockchain need more time because each transaction needs peer-to-peer verification [11]. Therefore, a major technological challenge of blockchain, especially for public blockchains, is the network's technical scalability, which can hinder its general adoption, as is the case with the education sector [7,52]. In comparison to other systems, blockchains are slow, with generally long transaction times [26] and limited storage capability [27], which could be a significant constraint in some academic settings. The ability of legacy networks to perform thousands of transactions per second is well-known. Visa, for instance, can process around 1667 transactions per second [53]. In terms of transaction speeds, however, the two most popular blockchain networks, Bitcoin and Ethereum, remain far behind. While the Bitcoin blockchain can achieve 3 to 4 transactions per second, Ethereum can process around 20 transactions per second [53]. However, the scalability issue relating to the speed of blockchain transactions is dependent on the type of educational application that was developed [11]. Slow blockchain transactions for credentialing, for example, can be a smaller problem, but processing educational tokens or trying to pay university fees on the blockchain, given the remarkably low number of transactions possible per second, may be a bigger problem [11]. In addition, there is a difference between public and private blockchains. Private blockchains may be implemented in a stricter context, where it is vital to restrict who can enter and participate in the network, whereas public blockchains are not constrained in terms of access permissions and allow all users to append new blocks [24]. Therefore, a lack of scalability is not a problem for private blockchain networks, as network nodes are designed to manage transactions within a trusted environment [54].

Another potential scaling issue is that proof-of-work, the widely used consensus protocol for the verification of new blocks, expends a substantial amount of electrical energy [12]. For example, it is well known that Bitcoin proof-of-work wastes enough electricity per year to supply a country the size of Switzerland [11]. In this context, Park [8] argues that proof-of-work is the most challenging issue in the education sector. Therefore, due to its high electricity usage, the proof-of-work blockchain in education poses a risk to climate change and imposes a greater carbon footprint [55,56]. However, the blockchain platform type used in educational applications must be considered; for example, some solutions [15,16,19,33,40,41] used the Ethereum platform (see Table 2) because it offers a stable and secure solution for their needs. Other solutions [57] have used other types of platforms, such as the Stellar blockchain, which uses less energy than Ethereum because it relies on its federated Byzantine fault tolerance (FBFT) consensus algorithm, rather than expensive proof-of-work computations.

The issue of a lower number of educational applications, it was argued, is related to the challenge of proof-of-work, which problem would be worsened as the number of blockchain nodes grows. However, there is no typical example of a vast and worldwide education blockchain on a scale equivalent to that of cryptocurrencies (which is in the millions) [8]. There is no clear and convincing inducement or motivation for executing its proof-of-work, although this condition may change with the forthcoming merger of Ethereum 1.0 and Ethereum 2.0, which will use a new verification mechanism, named "proof-of-stake" [8].

However, there are a few promising solutions to the scalability problem. The Lightning Network, for example, involves adding a new layer to the main blockchain system to speed up transactions [58]. Sharding is another solution that sets subgroups of nodes into smaller networks called "shards," each of which is responsible for its own set of transactions [59]. However, different blockchain systems, including Hyperledger, Ethereum, and Multichain, have varied capabilities and features that may or may not be appropriate for all sorts of applications. For example, blockchain systems allow a variety of consensus algorithms, which has an impact on the types of applications that can use it. Therefore, in blockchain-based applications in the education sector, blockchain platforms must not be thought of as a one-size-fits-all solution; proper settings may be necessary to ensure optimal performance [18,52].

Although blockchain provides a set of features, including tamper-proof storage and transparency, scalable blockchains bring a new aspect to the efficiency estimation process, namely the DSS trilemma, which comprises decentralization, security, and scalability. Therefore, to get the best solution, an application design for the education sector should consider the trade-off between these three features [52].

- *Limited interoperability and standardization*

Another substantial concern is the lack of interoperability between the numerous blockchain networks. Interoperability is the capacity of various systems, individuals, or entities to properly collaborate, in order to exchange and share data in a format that is accessible and convenient to the users of both interoperating systems [60]. This review identified two articles [16,27] that reported the interoperability issue in blockchain-based solutions in the education field.

Zhong et al. [33] proposed a blockchain-based conceptual paradigm for integrating e-learning systems. For engaging in learning activities, a learning reward system is suggested, where all nodes in the peer-to-peer network can share the learning resources. All learning records are integrated into a single block that can be examined easily, to track learners' interactivity and interoperability development. However, the current lack of a clear standardization for blockchain is due to the fact that there is no single dominant ledger technology in the first place but, rather, a proliferation of platforms and technologies. Thus, most projects use a variety of blockchain platforms and solutions, with different protocols, programming languages, consensus methods, and data protection measures [19].

Additionally, Astill et al. [61] argue that the distributed nature of blockchain offers great freedom for blockchain programmers and developers. Therefore, due to the absence of common standards, different blockchain platforms cannot collaborate and communicate well with each other without translation software that realizes and facilitates this process. Therefore, due to a lack of common standards that would enable multiple networks to interact with each other, the blockchain environment is in a "state of disorder" [61]. In addition, the absence of uniformity among blockchain protocols compromises the consistency of basic processes such as security, making adoption nearly impossible [61].

While the consensus mechanism of blockchain technology efficiently enforces a list of specific rules on users of a certain blockchain, this does not imply that blockchain is standardized [19]. For example, most providers using blockchains to issue certificates store only the certificate hash in the blockchain; the vendor's software handles other non-standardized operations off-chain, such as issuing, sharing, and validation [19]. As a result, it is feasible that several educational institutions will issue certificates within the same blockchain, with each certificate requiring distinct software and vendor agreements to be used [19].

Several other solutions claim to enable interoperability between different blockchain networks, such as Ark [62], which offers universal interoperability, as well as cross-blockchain communication and transfers using the SmartBridges architecture. Cosmos [63] is another solution that uses the Interblockchain communication (IBC) protocol to permit blockchain economies to operate outside the silos and to transfer files.

2. *Challenge 2: The Complexity of Integration*

While data exchange between two separate blockchain systems poses a significant difficulty, there is also the issue of how to integrate blockchain technology with legacy systems, which is still difficult for educational institutions. This review showed that four articles [2,13–15] addressed this issue.

In most cases, if the educational institutions choose to employ blockchain, they must entirely reorganize their old system or develop a mechanism to adequately integrate the two systems. Chen et al. [2] stressed that problems could arise when processes need to be restructured and/or aligned, and other interfaces have to be created to enable data communication and sharing between blockchain processes and associated legacy systems, such as the enterprise resource planning system. Upadhyay [13] raised doubts about the current realization of completely functional blockchain systems, claiming that the way blockchain interacts with legacy systems is still unclear. In addition, Upadhyay [13] argues that the ultimate objective of free and homogeneous data exchange between blockchain technology and legacy systems is currently in limbo, in terms of restructuring systems, processes, and IT structures. Furthermore, the complexity of integration increases as educational institutions often do not have access to the required pool of blockchain expertise to participate in the integration process, due to a shortage of skilled developers. However, this issue can be mitigated by relying on a third party [13].

Gräther et al. [15] used the Hyperledger Fabric, which is a distributed ledger solution that is built on modular architecture and provides flexibility and scalability. It consists of one or more networks, each of which manages different transactions, assets, and agreements among the various sets of member nodes. It is designed to be able to support the pluggable implementation of many components. They argued in [15] that blockchain technology could become a standardized platform for tasks such as issuing, verifying, auditing, and tracing immutable records, allowing the universities and the Federal Education Ministry (FEM) to integrate, attest, and investigate forge-proof versions of certificates quickly and easily. However, a regulatory authority such as the Higher Education Commission (HEC) plays a key role in managing degree attestation and verification standards, for example, the secrecy and integrity of candidate certificate credentials, system quality and reliability, safety, data protection, and the exchange of records between academic institutions and regulatory education authorities [14].

Gräther et al. [15] proposed a blockchain solution for the education sector, in the form of a Quorum-based platform for generating, managing, and verifying reliable certificates. This solution provides machine-readable certificates using an enhanced version of Open-Learn badges [15]. In addition, an API is used to make it easier to integrate with other platforms, such as Moodle.

New technologies have recently been established that allow legacy systems to integrate into the blockchain infrastructure. One such alternative is the Modex blockchain database, a product created to support users without a technical background, to gain access to the advantages of blockchain technology while preventing the risks posed by data loss [64].

3. *Challenge 3: Security Issues*

Despite blockchain being known for its security and the community's efforts to make the platform stable and secure, security remains a challenging issue [16]. Since some educational institutions throughout the world have begun to use distributed ledger technology (DSLT), security must be prioritized and blockchain security and vulnerabilities must be considered. Eight of the reviewed articles [16,23–25,41–44] highlighted different types of security attacks on the blockchain that could affect educational applications.

External attacks on platforms such as Bitcoin and Ethereum are constant, attempting to exploit the existing and anticipated vulnerabilities [40]. Storing academic material in blockchain poses a risk because errors in the application, platform, or data input can occur.

After all, participants do not adequately protect their private keys [42]. In addition, data leakages that could pose a security risk can occur as a result of frequent upgrades and the addition of new features. Cernian et al. [65] argued that while blockchain technology provides privacy and security, malicious attacks and data leakage pose a threat, making it difficult for educational institutions to trust the system. In addition, the lack of standardization in blockchain affects its security as there is no central expert, authority, or organization that can be called upon to make a decision [16].

Juričić et al. [44] reviewed various blockchain security attacks, such as the 51% rule regarding attacks that happen when a user in a blockchain gains control of a blockchain's mining power. In theory, data information may only be leaked or altered if more than 51% of nodes are targeted and hijacked by attackers at the same moment. Therefore, the attackers will have over 50% of mining power and will be able to mine at a higher level than everyone else. Malicious actors can then modify segments of a blockchain and roll back transactions [44]. This attack causes a delay in the new transactions, which leads to a failure in the network.

Another potential attack reported by Juričić et al. [44] is known as the Eclipse attack. As a distributed blockchain network does not enable all computers to connect to all other computers in the network at the same time, attackers may be able to create connections by inserting malicious code. In this way, the attackers isolate a certain user or users instead of mounting an attack on the entire network [66].

Despite advancements in mathematics, encryption, and computing technology, it is difficult to ensure that algorithms will not be broken in the future, resulting in the leaking of information from learners and educators [66]. In addition, all transactions are open and transparent, and all information can be tracked and queried at any time. In this way, certain conclusions can be drawn or the state and behavior of educators and learners can be predicted, which is inconsistent with protecting their privacy. Therefore, it is vital to be aware of how data can be accessed and securely used while still protecting privacy [40]. Despite identities being protected by both private and public keys in blockchain systems, transactional privacy is not ensured because public keys are visible [23–25]. Furthermore, if students lose the private key information required to establish ownership, they may lose their academic diplomas [34].

4. *Challenge 4: Privacy*

Ensuring privacy while providing security on the blockchain is challenging, but it is critical, particularly when a learner's educational diplomas and certificates are under threat [18]. Seven of the selected articles in this review [7,27–29,44–46] discussed privacy issues in the educational field.

Since privacy in the blockchain is difficult to achieve, it is a challenge in several academic usage scenarios that deal with sensitive data. The issue of transactions being open to anyone in the blockchain may compromise privacy, as this data could be collected and publicly revealed elsewhere [18]. Many educational institutions nowadays adhere to strict privacy policies that are legally mandated. Students put their trust in those holding their personal information. However, if all this information is kept in a public ledger, it will no longer be considered private. Here, even when encrypted, public blockchains are ineffective for storing this data [27]; hence, a private blockchain or consortium could be useful, where the students will have restricted access and all of their personal information will be kept private, as it should be [44]. Despite this, several regulations in various countries for securing personal information should be considered. For example, the European General Data Protection Regulation (GDPR) [46] is a significant limitation in Europe and does not allow the storage of personal data in an unchanged storage system, such as a blockchain [45]. In addition, the data must be anonymized. Therefore, this is a contentious issue that needs to be resolved before blockchain can be used to register learners' and educators' personal information in the educational field. However, hashing personal data, as utilized in several projects, cannot be considered an anonymization approach under the GDPR rules [29,44–46].

An asymmetric cryptography mechanism is used to protect the information in distributed ledgers. However, while password security solutions allow users to update their passwords if they are stolen or lost, there is no mechanism in distributed ledgers to recover lost private keys. Thus, when a user in a blockchain loses their private key, they lose all of their data and assets permanently [29]. Furthermore, in the case of the education arena, if the accreditation authority's private key is hacked or lost, the entire system may be compromised [46]. Therefore, this privacy issue is a core reason why the public may not adopt blockchain technology.

Additionally, the blockchain's immutability makes it hard to change or remove data, even for legal reasons, which conflicts with the GDPR's right to be forgotten. However, one study on blockchains in the education field aimed to employ blockchain and its immutability properties to secure the issuing of academic certificates for students, offering a way to revoke digital certificates that have been granted improperly [7].

To address the privacy issues in the blockchain, different privacy-preserving solutions, such as secure multi-party computation (SMPC) techniques, commitment schemes, zero-knowledge proofs (ZKP), ring signatures, zkSNARK, and homomorphic hiding are emerging as ways to provide users with techniques to become anonymized and keep control of their data throughout any transactions in the blockchain [67].

5. *Challenge 5: Immutability and Lack of Flexibility*

An immutable record in a blockchain is one where the state cannot be changed after it has been created [9]. Thus, security and the traditional properties of confidentiality, integrity, and availability are all linked to immutability [19]. However, in five of the reviewed articles [9,19,43,47,48], immutability was considered a challenge in terms of adopting blockchain in the education sector.

Because a blockchain block is constantly replicated in several different locations, it cannot easily be modified. In addition, when using asymmetric cryptography as part of a blockchain protocol, the security and confidentiality of any transaction become virtually unbreakable [19]. Therefore, it is particularly hard to update data units after they have been recorded; as a result, there is more trust in the data's integrity, and the risk of fraud is reduced [19]. In addition, for any transaction on a blockchain to be approved as a valid transaction, all members involved in the transaction must approve its legitimacy and no one can tamper with it after a transaction has been recorded in the ledger. Therefore, if a transaction is incorrect, it must be corrected by creating a new transaction, so these two transactions will be available in the ledger. Thus, any attempt to modify data in one place will be seen by other members as illegitimate and as an attack on the data's integrity; therefore, it will be refused [19].

The immutability of blockchain technology is a key quality for building more trust among all parties engaged in the chain. Once a student's credentials are recorded on a blockchain, no one can change them. This feature, however, would be a double-edged sword [9]. It would eliminate the capacity for certain students' records to be modified for valid reasons. Furthermore, the immutability property of blockchain technology may constitute a barrier to its acceptance in the sector of education as it may be challenging for educational institutions to comply with new data-storage laws [9].

The immutability aspect of blockchain technology can also be troublesome, as it precludes those in the educational system, learners, and external stakeholders from erasing educational data for valid reasons. These can be changed by authorized parties, but the original data will still be stored in the blockchain indefinitely, which conflicts with the GDPR's right to be forgotten [9].

The benefit of issuing certificates instantly on a ledger is that the diplomas themselves become irreversible and everlasting, rather than merely acting as proof of their signing [19]. In addition, issuing certificates on a blockchain will turn a digital certificate that a learner typically receives privately into an automatically valid piece of information that can be checked by third parties on a public blockchain, via an immutable proof mechanism [19]. However, the revocation of diplomas is one of the most significant difficulties. Even though this is a rare operation, it can be employed in special circumstances when diplomas are revoked. However, the published certificate in the blockchain cannot be changed [43]. As a result, immutability may limit the use of the blockchain for private student data, such as enrollment, diploma verification, and tests that require the right to remove [43]. However, several solutions have been proposed to solve this problem, such as the issuer offering a list of diplomas that have been revoked; the verification in this scenario is contingent on the issuer's availability [55]. Another solution in the Ethereum platform is offered through the use of smart contracts [48]. A similar issue is the diploma expiration date, in some cases. This issue's solution will most likely be identical to the previous one [47].

6. *Challenge 6: Data Unavailability:*

Another challenge identified by two articles [1,18] is the unavailability of data. According to Arndt and Guercio [18], keeping data management in the hands of the users themselves could make this data unavailable and could affect the applications that rely on this data. In addition, due to the decentralization of the blockchain, the data are distributed and saved on the distributed ledger, which makes the ownership rights of students' data unclear [1]. Currently, the educational institution's administration department is in charge of data handling. However, with the blockchain, all data are stored in the blockchain, which reduces the management department's responsibilities. Then, new issues arise: Who owns the digital data? Who is entitled to use it? Who has access to the data analysis results? [1]. Therefore, for the further implementation of the blockchain in education, it is necessary to study and address these problems caused by data ownership rights [1].

The use of blockchain as a distributed ledger technology depends, to a large extent, on several technological factors that affect the availability of data in the blockchain: the specific block size of the information transferred, the communication speed of the network, the basic proof-of-work protocol, and the authentication of the miners' data on each node [67]. For example, currently, the block size is limited to 1 megabyte per block, as the original thought was that larger blocks could be technically problematic and compromise the nature of the network's decentralization [67]. Due to the restricted size of the blocks, the number of allowed transactions is fairly small, compared to Visa and PayPal [67]. Guo and Yu [67] argued that these factors represent a performance challenge because transaction throughput and latency remain a weakness for blockchain networks, which struggle to cope with rising transaction volumes. However, these technological factors may affect the availability of data for some educational applications.

3.2.2. Organizational Barriers

Organizational barriers are related to an organization's size and scope, management structure, and the organization's ability to adapt to the technology [68]. Reader [69] stated that organizational barriers relate to those barriers resulting from the internal activities of the organizations. Therefore, the organizational challenges must be considered with regard to the educational institution's intention to adopt blockchain technology as part of their educational systems. This review revealed three organizational obstacles to the adoption of blockchain in higher education institutions: a lack of adequate skills, financial barriers, and a lack of management commitment and support.

7. *Challenge 7: Lack of Adequate Skills*

Since there is a critical lack of blockchain engineers and those with expertise, with the implementation of blockchain in many sectors of the industry, the demand for qualified blockchain resources has increased [7]. In particular, human resources with a sound technological and mathematical base are a major challenge for the education sector. However, only one of the reviewed articles [20] reported the lack of adequate skills as a challenge.

For the development of a blockchain-based solution, experts are needed for both growing organizations and established organizations seeking this technology [20]. In addition, high-level expertise is required to design a secure and trusted blockchain education system with complete functionality and outstanding usability [20]. Learners, educators, and other specialized parties in the chain have difficulty understanding blockchain technology, platforms, and smart contracts [7,61]. It seems practical to assign the responsibility for development to computer engineers, but the solutions they develop are generally less comprehensive than the requirements of the educational stockholders [61].

The lack of human resources and skilled professionals is recognized as a major barrier in organizations that are increasingly opposed to blockchain technology [68–74]. For example, in the education sector, several educational institutions are still wary about adopting blockchain technology because there is a lack of knowledge and skills needed to manage student data in a blockchain network. Therefore, this could be one of the reasons for the lack of confidence in this technology [20]. In addition, the number of available experts and professionals is affected by the type of blockchain technology used in educational solutions. For example, Ethereum has the biggest and most active developer community around the world, with skilled people from various domains actively contributing to the ecosystem [57].

The key step for the successful implementation of blockchain technologies in educational institutions could be to train the academic and administrative staff on how blockchain technology can be used and maintained internally [20]. In addition, since the institution's administrative staff, not its academic staff, is considered to be the main actors that ultimately decide whether an institution would adopt a blockchain solution, raising awareness and educating academic governance staff about the benefits, application, and maintenance of blockchain solutions in education is considered an important step to achieving the use of blockchain technology in the higher education sector [20]. In addition, it is very important to understand their motivations for resisting this technology. For example, blockchain's novelty and/or the reduction of the costs associated with administration operations can make managers resist this technology [20]. Therefore, this can be addressed by appropriate training and by raising awareness about the benefits of blockchain [59].

8. *Challenge 8: Financial Barriers*

The adoption of blockchain technology is an expensive endeavor, and the transaction costs should not be ignored when blockchain technology is used in the education sector. Therefore, this section analyzes the variety of costs considered in the selected articles. Six articles [7–9,12,18,19] handled this subject from different angles, including infrastructure costs, the costs of handling large amounts of academic data, the time costs due to slow transactions, and the cost of computational energy [71]. In addition, the addition of new features would result in additional costs each time [19].

Consensus protocols consume a burst of energy and resources (i.e., storage, computing, bandwidth, etc.), especially those used in public blockchains [7]. Moreover, since the entire blockchain must be stored on each node of the network, most blockchains have exceptionally high storage and power consumption costs, due to the computing resources needed to perform cryptography [7]. For example, a terabyte hard disk costs around EUR 60.00, while the same capacity of storage on the Ethereum blockchain costs around EUR 6000.0083 [19]. In terms of energy consumption, a single Bitcoin transaction will consume 160 kWh of electricity, which is sufficient to supply a US family for six days [19]. This would certainly lead to an enormous increase in global electricity consumption if it were continuously scaled up to a large number of transactions per second [19].

To save storage, as an alternative to explicitly storing records on a blockchain, only the ciphertext of those records is saved [9]. However, even this is not sufficient to meet the energy and storage requirements of blockchain technology [9]. Therefore, some blockchain systems now merely save the hash of their transaction content in the ledger [9]. A cryptographic approach, known as a Merkle tree, which is a hash of other hashes, is a typical way to achieve this type of storage [8], where the real data encoded by the hashes, including certifications, identities, personal information, contracts, etc., must still be saved off-chain in such systems [8].

In the education sector, the use of the blockchain can lead to significant costs. This is dependent on the characteristics of the intended application, complexity, the type of blockchain used, the blockchain platform, how its features are valued (e.g., immutability, availability, etc.), and other technology stacks [19]. For example, the Ethereum transaction pricing market is volatile, resulting in unexpected transaction-fee increases. The underlying asset used to power these transactions, "gas," has a block-level restriction, and any transaction that fails to pay the needed amount of "gas" will be discarded by the other peers. In addition, Ethereum itself is costly, which raises the entire cost of transacting on the Ethereum blockchain [57]. On the other hand, Stellar is a blockchain designed to keep transaction costs low [57]. Furthermore, building a decentralized application on a public blockchain, such as Ethereum, will be much less expensive than creating an enterprise blockchain on a private platform [9]. In addition, when creating a blockchain application from scratch, the cost will be increased by adding the costs for infrastructure improvement, smart contracts, transaction fees, cryptography, consensus algorithms, and more expenses [9].

Based on the consensus algorithm used, the acquisition of blockchain is accompanied by a high demand for electricity [18]. This is due to the fact that the consensus algorithms, such as proof-of-work (PoW), include the use of computing power to verify the reliability of the data being entered into the blockchain. To mitigate this situation, solutions such as the use of advanced mining equipment and the adoption of alternative consensus algorithms, such as proof-of-stake, are used [18]. In addition, the costs of data space, due to data redundancy and scalability, are closely linked to this aspect. However, this means more data load that could also slow down the system. Furthermore, the transfer of an entire database and the related processes from a centralized structure to a decentralized framework entails its own costs [18]. It is also necessary to acquire new hardware and software resources. This also implies the cost of educating and training the education staff in all departments, not only those in the IT team, to ensure that they are aware and informed [12].

The cost of employing a developer to develop a blockchain application is determined by their location, skill level, and project scope [19]. A blockchain developer is expected to possess two different skill sets. On one side, the developer must be familiar with building blockchain frameworks, such as Ethereum and Hyperledger. In addition, knowledge of blockchain programming languages, such as Vyper, Solidity, and Sophia is needed. On the other hand, to develop a mobile or web application that provides blockchain logic, expertise in programming languages and frameworks, such as JavaScript, NodeJS, and Golang is vital [19].

9. *Challenge 9: Lack of Management Commitment and Support*

This review identified two articles [9,11,20] suggesting that the lack of awareness and involvement of senior management may hamper an organization's willingness to use blockchain technology. According to Haugsbakken and Langseth [20], the commitment of the top management is critical for adopting blockchain and, in some cases, senior management fails to make the long-term commitment necessary to facilitate and implement new technology. A lack of top management commitment causes an obstacle to blockchain adoption because the consistency of sustainable educational blockchain system processes could be affected [11]. In addition, this will affect resource management and spending decisions that could affect the availability of the necessary support for blockchain adoption [20].

The commitment of educational stakeholders to collaboration is the first requirement for integrating the blockchain in the education sector [73]. For a variety of reasons, the open exchange of information is not something that stimulates all organizations since information can be private or can be considered a competitive advantage [73]. Therefore, the educational stakeholders should be dedicated to the open exchange of information, as the blockchain essentially facilitates information transparency. In addition, the lack of enthusiasm around blockchain technology is related to its novelty and complexity; ethical and privacy issues could hinder the blockchain's adoption by educational institutions [9].

According to Haugsbakken and Langseth [74], staff will feel more empowered as the level of organizational support for blockchain technologies grows, and if the upper-level staff shows clear leadership, organizations will be less reluctant to implement blockchain implementation. In addition, according to the status quo bias theory, individuals may become reluctant to adopt new technology because of their bias or tendency to remain loyal to their current technology [74]. The status quo bias entails evaluating the potential costs and benefits of moving to a new technology vs. their present status, as well as the cost of adoption [74]. For example, as the range of blockchain benefits increases, this will have a strong impact on the adoption of blockchain technology since users will be aware of the possibilities that may be available [74].

The organizational support for the transition to a new blockchain system is identified as the support of an organization that simplifies the adaptation of blockchain technology [74]. The transition from the status quo needs rules and guidance from the administration to make enabling the change simpler for personnel. If the required rules and standards are in place, and the educational institution displays support and adoption of blockchain technology, administrators' resistance will be reduced [74].

3.2.3. Environmental Barriers

The environmental perspective includes factors, such as market adoption and industry dynamics, government relations, and regulation, that affect an organization's day-to-day operations [75]. This review discussed three important environmental challenges that affect the adoption of blockchain technology in the education sector, as follows: legal issues and the lack of regulatory compliance, sustainability concern, and market and ecosystem readiness.

10. *Challenge 10: Legal Issues and the Lack of Regulatory Compliance*

One article [11] reported the legal issues and/or lack of regulatory compliance as a challenge. The European General Data Protection Regulation (GDPR) [46], for example, states that citizens have the "right to be forgotten," which is incompatible with the blockchain's immutability [11].

Santos and Duffy [49] discuss two key GDPR principles that are related to blockchain technologies. The first indicates that "in relation to each personal data point, there is at least one natural or legal person—the data controller—whom data subjects can address to enforce their rights under EU data protection law. These data controllers must comply with the GDPR's obligations." [49]. When it comes to GDPR regulations, however, there is a concern that blockchain aims for decentralization, which may confuse how "controllership is defined" and that it "hampers the allocation of responsibility and accountability" [11]. Therefore, it appears that the EU considers blockchain a threat to individuals' data ownership rights and duties [11]. The GDPR's second assumption is that "data can be modified or erased where necessary to comply with legal requirements, such as Articles 16 and 17 GDPR" [11,49]. The contradiction arises in this scenario because blockchain does not allow any data updates, in order to maintain data integrity and trust [25]. The fundamental conflicts that arise when assessing blockchain compliance with GDPR cause a number of problems, one of which is whether or not data on the public blockchain count as sensitive personal data [11]. If the data are considered personal data, GDPR law must be respected. Another argument is whether the data can be properly anonymized to comply with GDPR legislation [11].

Besides EU data protection legislation, the United States has several data protection laws, including the California Consumer Privacy Act (CCPA) [11,50]. Fedorova and Skobleva [41] outlined the complications that exist when ensuring the conforming of blockchain with the CCPA. As with the GDPR issues, the distributed ledger and data immutability may conflict with the CCPA's obligations [50]. Therefore, it is difficult to identify and maintain responsible controllers in the blockchain [50]. Educational institutions and suppliers thus confront numerous issues in ensuring that their solutions comply with data protection legislation, such as that in the GDPR and the CCPA. However, educational institutions can improve their chances of implementing blockchain systems that comply with data privacy laws. They can, for example, limit or even eliminate the step of saving personal data on the blockchain, try to assess if blockchain technology is truly required to meet a specific business or social purpose, or adopt permissioned blockchains with more stringent usage regulations [11,50]. In addition, to preserve data integrity, one option is to avoid saving sensitive personal data on the blockchain and instead store simply a hash of the data. For example, Kratos [57] reduces the risk of data theft and storage by suggesting the implementation of distributed file storage to encrypt data and enable decryption only through the platform, while using standard key management solutions (KMSes) significantly lowers the risk of data theft.

Due to the transparency of public blockchains, all transactions are available to everyone. As a result, higher-education institutions may need to establish more stringent privacy protections, such as deploying private or permissioned blockchains or protocols, such as the zero-knowledge proof [11], with rigorous usage constraints to control data access. Therefore, we should underline that the deployment of blockchain technology in education requires the solving of different legal difficulties [11].

11. *Challenge 11: The Market and Ecosystem Readiness*

Two articles [11,25] reported the market and ecosystem readiness as a challenge. There is a lack of awareness, education, and understanding among external stakeholders (governments, academics, and industries) about the advantages and the use of blockchain [76]. The authors of [76] emphasize the importance of training external stakeholders on the possibilities of blockchain for economic and social development, to adopt appropriate innovations, and attract new customers. There is a gap concerning how and where a blockchain can be used efficiently, as well as its actual consequences and benefits, which needs substantial ecosystem stakeholder education [76]. Knowledge about blockchain technology's business models, technological features, and governance is necessary not just for a broader understanding of the technology but also for its usage [76–79].

Steiu [11] evaluates the market acceptance of blockchain in education solutions by examining the perceptions of potential stakeholders (e.g., governance stakeholders in educational institutions, as well as governments) and the major actors who may affect the adoption of such solutions. The findings are based on available research, as well as interviews with higher-education institutions [11]. Several educational institutions are still hesitant to accept blockchain technology. The lack of necessary information and abilities on how to manage educators' data on a blockchain network could be one of the causes for this reluctance. Steiu [11] argued that joining the Digital Credentials Consortium was driven by a desire to improve the university's governance and the staff's poor understanding of how to successfully adopt and maintain such technological innovation in the long term. Therefore, creating awareness and training academic governance authorities on the benefits, deployment, and management of blockchain solutions is an essential step in boosting market adoption in higher education around the world [11].

Steiu [11] argued that the government is another crucial player that might have a great impact on blockchain adoption in the education sector. In countries such as India, around 20 million university students are annually excluded because the traditional higher-education system cannot meet demand [11]. As a result, open education online is an important and affordable option for individuals who are thus excluded [25]. However, the formal accreditation of competencies by employers is a major difficulty with online education. Traditional degrees are valued by employers over online qualifications and other informal educational approaches. In this situation, blockchain credentialing can increase trust among all the parties involved by confirming the legitimacy of certificates obtained using non-traditional educational approaches [25]. Therefore, the government might be a crucial partner in helping blockchain credentials providers to produce credible solutions [25]. In this context, it is worth highlighting that the large-scale adoption of blockchain technology in education may be easier to achieve via collaborations with government and other educational institutions' governance stakeholders [11]. These concerns demonstrate that several stakeholders (governments, academics, and industries) must work together and overcome different problems (lack of incentives, financing, and expertise) to enable the successful and long-term integration of blockchain technology in education [11].

12. *Challenge 12: Sustainability Concerns*

Two of the reviewed articles [8,20] consider the sustainability of education as a challenge to blockchain adoption in the education sector. Park [8] claims that blockchain is a challenge to education sustainability. According to Park [8], the main reason for the low level of actual applications of blockchain technology in education is its lack of alignment with a genuine philosophy of educational sustainability. For example, with permanent recordings of students' talents and successes, the education blockchain might create a new type of social stratification that is potentially worse and more widespread than the intelligence quotient [8]. Therefore, the type and extent of the arbitrariness of institutional trust and value could hamper global attempts to establish a sustainable future [8]. Despite the great promise and usefulness of blockchain technology, without a clear philosophy of what the aim is of education and where we want to be, the question of "What problems can blockchain technology solve in education?" would continue to be unanswerable [8]. It is reasonable that blockchain empowers students by granting them ownership and control of their qualifications, but it can also disrupt the goal of education by creating a new form of social inequality and inequity [8]. Park [8] claims that "blockchain, rather than serving hyper-capitalism or authoritarian social control of education and development, should ideally serve an education that prioritizes peer-to-peer collaboration and sustainability". Thus, the education blockchain is "not the technology for the sake of technological novelty per se but, rather, education's primary goals of social justice and sustainable development" [8]. This means that blockchain technology would have brought many more benefits if there were a clear philosophy of sustainable and decentralized development of education, where the main objective is beyond the limits of bureaucratic efficiency, scientific evidence, and the "learning is earning" type of monetary incentives and social control [8]. On the other hand, Haugsbakken and Langseth [20] claim that blockchain technology has the potential to reduce bureaucracy. Bureaucracy steals valuable time and attention away from the basic activities in higher education [20]. In several Nordic countries, approximately half of the budget is spent on administrative positions in certain higher-educational institutions [20]. Therefore, blockchain technology has the potential to reduce bureaucracy. One example is the use of a blockchain to issue credentials. Another example is the usage of blockchain technology to handle books in libraries.

Another challenge that affects environmental sustainability is climate change and a higher carbon footprint due to high blockchain electricity consumption [8]. The proof-of-work (PoW) protocol used for the verification of new blocks consumes a substantial amount of electrical energy [12]. For example, it is well known that Bitcoin proof-of-work wastes enough electricity per year to supply a country the size of Switzerland [11]. In this context, Park [8] argues that PoW is the most challenging issue in the education sector. Therefore, due to its high electricity usage in PoW, blockchain technology in education poses a risk to climate change and necessitates a greater carbon footprint [55,56].

4. Discussion and Future Directions

The purpose of this study was to review published articles describing the challenges of using blockchain technology for higher-education institutions. These barriers have been divided into three contexts, based on the TOE framework: technological, organizational, and environmental contexts. The technological challenges are as follows: poor usability, a lack of scalability, limited interoperability, and standardization (classified under the immaturity of the blockchain challenge), the complexity of integration, security issues, privacy, immutability, lack of flexibility, and data unavailability. In the organizational context, there is a lack of adequate skills, financial barriers, and a lack of management commitment and support. In the environmental context, there are legal issues and a lack of regulatory compliance, market and ecosystem readiness, and sustainability concerns (see Figure 3).

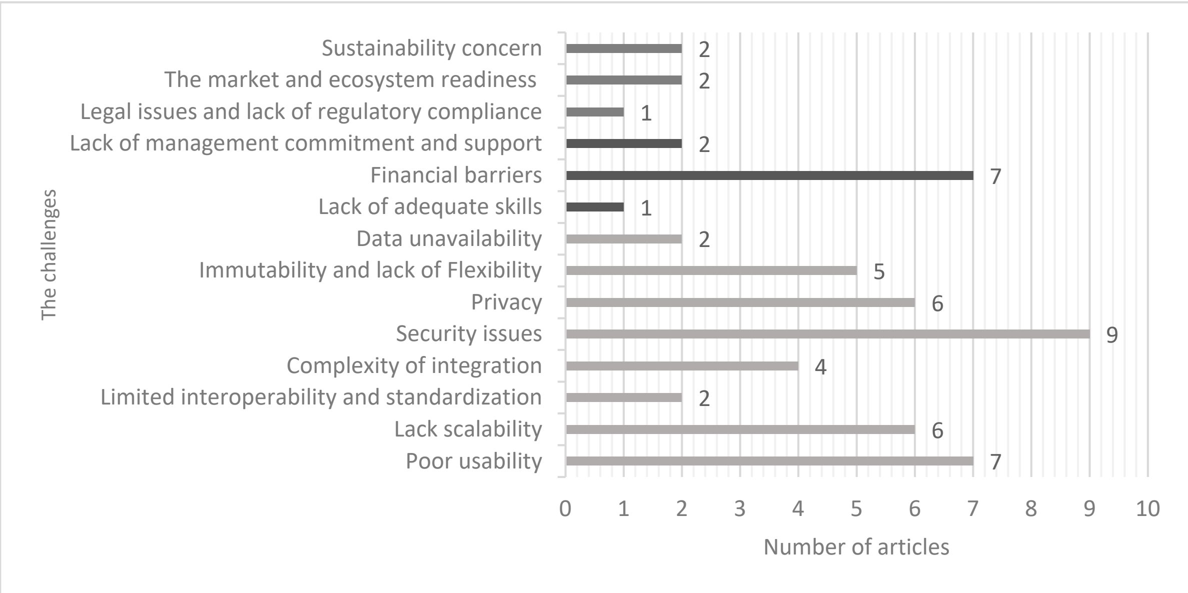

Figure 3. The challenges reported by the selected articles.

This review showed that technological challenges received more attention from the reviewed articles than challenges in the other two contexts. Eight technological challenges were reported in 29 articles, three organizational challenges were identified in 10 articles, and three environmental challenges were reported in five articles (see Figure 4).

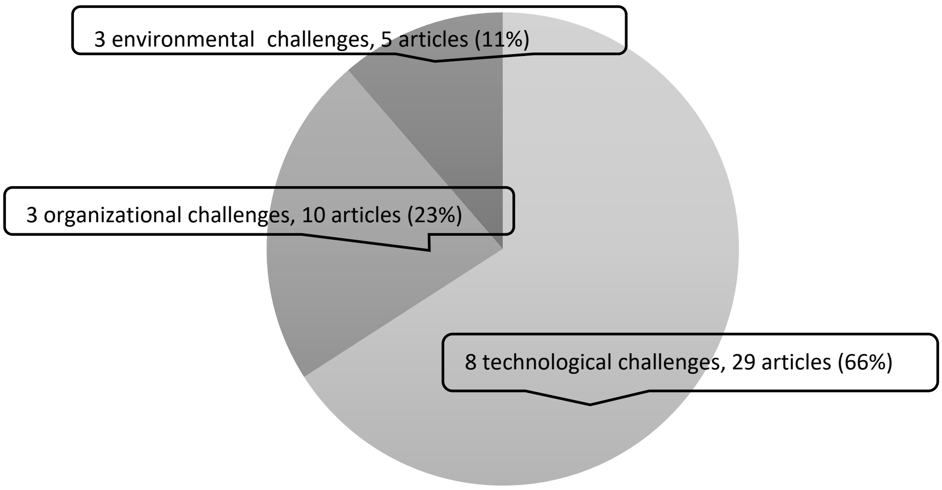

Figure 4. The number of challenges and articles in each context in the TOE framework.

This is due to the technological novelty and immaturity of blockchain technology. However, this reflects a research gap, in terms of organizational and environmental challenges, that will have a negative impact and will increase resistance to the acceptance of this technology in the education sector. For example, the lack of commitment by senior management leads to a barrier to blockchain adoption because the coherence of sustainable educational blockchain system processes could be affected. In addition, this will have an impact on resource management and spending decisions, which could affect the support needed for the adoption of blockchain technology. Therefore, more research is needed from an organizational and environmental perspective.

Immaturity is one of the most important challenges for blockchain adoption in higher education. This review showed that fourteen of the reviewed articles reported that blockchain still suffers from certain immaturity problems, from different angles such as the poor usability of blockchain-based applications and solutions. Despite the importance of this aspect, usability was not the focus of the selected article, and other issues such as security and privacy received more attention. Therefore, the usability of blockchain should be improved through new user-friendly interfaces that better meet the needs of users, while students, academics, and administrative staff should receive training on how to use the technology.

Another challenge reported by the selected articles is the limited interoperability and standardization. The absence of uniformity among blockchain protocols compromises the consistency of fundamental processes, such as security, and makes mass acceptance almost impossible. Therefore, establishing common standards for different blockchain protocols could assist enterprises to collaborate on application development, validate proofs-of-concept, and share blockchain solutions, as well as integrate with legacy systems. In addition, the lack of standards affects the security of the blockchain as there is no central expert, authority, or organization that can make a decision. Furthermore, the regulatory educational authorities play a key role in managing different aspects, such as degree attestation and verification standards, the secrecy and integrity of candidate certificates credentials, the quality and reliability of the system, security, data protection, and the exchange of records between academic institutions and regulatory educational authorities.

Blockchain is a secure technology, but it still suffers from security attacks. Nine of the reviewed articles highlighted different types of security attacks on the blockchain that could affect educational applications. However, these attacks should be studied in their entirety. More explicitly, researchers should classify the attacks and carry out more assessments and simulations of possible attacks. This will improve the integrity and provide a secure basis for future blockchain technology adoption.

In addition, this review showed that although researchers have focused on privacy-preserving solutions, few articles have considered the importance of compliance with data protection laws, such as CCPA and GDPR. Furthermore, besides using the appropriate privacy-preserving solutions, educational institutions can enhance their opportunities for implementing blockchain systems that comply with data protection laws. They can, for example, limit or even eliminate the saving of personal data on the blockchain, try to assess whether a blockchain is truly required to meet a specific academic, business, or social purpose, or adopt permissioned blockchains with more stringent usage regulations.

The sustainability of education is one of the challenges that has not received much attention in the selected articles; only two articles have discussed this issue. The adoption of blockchain technology in education without aligning it with a clear philosophy of education sustainability could disrupt the goal of education by creating a new form of social inequality and injustice. Blockchain technology should therefore bring many benefits, but the adoption of a clear philosophy of sustainable education is necessary, in which the main objective is beyond the limits of bureaucratic efficiency, scientific evidence, and social control. On the other hand, more articles have also focused on another important aspect of sustainability, which is climate change and a greater carbon footprint; some articles even considered this challenge to be the most difficult obstacle in the way of adopting blockchain technology. It is, therefore, necessary to further research these two aspects of sustainability.

Two articles discussed the impact of market readiness and the awareness of stakeholders on the adoption of blockchain technology in the education sector. This review revealed that there is a lack of awareness, training, and understanding among stakeholders in the education sector about the advantages and the use of blockchain. There is a gap in how and where the blockchain can be used, as well as its real impact and benefits, which requires meaningful training for stakeholders. Understanding business models, technological properties, and the governance of blockchain technology is not only necessary to realize the technology's effectiveness but also for its use. In addition, this review has shown that a lack of awareness and involvement of senior management may hamper an organization's willingness to use blockchain technology.

The use of blockchain in the education sector can entail significant costs for educational institutions. However, this depends on the intended application characteristics, complexity, the blockchain type used, the blockchain platform, how its features are valued (e.g., immutability, availability, etc.), and other technology stacks. For example, building a decentralized application on a public blockchain such as Ethereum will be much less expensive than creating an enterprise blockchain on a private platform. By creating a blockchain application from scratch, the cost will increase by adding infrastructure improvement costs, smart contracts, transaction fees, cryptography, consensus algorithms, and other expenses.

Despite the important role of skilled professionals in the successful implementation of blockchain technology in the education sector, one of the 36 articles pointed to the lack of adequate skills as a challenge. However, the lack of knowledge and skills required to manage data in a blockchain network could be one of the reasons for the lack of confidence in this technology. As a result, several educational institutions remain cautious about the adoption of blockchain technology, and further research in this area is, therefore, needed.

5. Challenges and Limitations

The literature search was carried out on the following databases (ScienceDirect Web of Science, Springer, IEEE Xplore, and MDPI). Although these databases cover several areas and cover many individual databases, such as ScienceDirect, MDPI, and Web of Science, this decision may have influenced the number of relevant articles obtained. The use of other databases might have increased the number of articles analyzed and could have contributed to an improvement of the overall analysis. In addition, the authors chose to limit the number of irrelevant articles (articles published many years ago, articles that were too general, or articles that did not focus on the research question). In addition, only articles in English were included. These options may have ruled out relevant articles, such as articles written in languages other than English.

These restrictions may have had a significant impact on the number of records obtained and may have had some effect on the retrieval of relevant papers. As a result, the number of papers reviewed and the eligibility of various studies constrained our search. They may also have influenced our data extraction and analysis. However, these constraints had no significant impact on the discussion and conclusions

This review allowed us to answer the predefined research question: "What are the challenges of using blockchain technology in the higher education sector?" This review focused on the challenges of using blockchain technology in the education sector, rather than delving deeply into the various mechanisms and solutions to address them, which paved the way for further reviews to discuss and classify the latest techniques and mechanisms used to address the identified challenges.

6. Conclusions

The role of blockchain technology in the higher education sector is promising and has expanded in recent years. The key contribution of this review is to provide a clear picture that summarizes what has already been written about the challenges of using blockchain technology in the higher-education sector. The review identified the most important and relevant studies in the field, providing details on the topics that have prompted more academic attention and detailing the blockchain adoption challenges. The methodology chosen to answer the research questions was a literature review.

Concerning the study question, "What are the challenges of using blockchain in the education sector?", the challenges are classified, based on the TOE framework, into the following three perspectives: technological, organizational, and environmental. The technological challenges are as follows: poor usability, a lack of scalability, limited interoperability, and standardization (classified under the immaturity of blockchain challenge), the complexity of integration, security issues, privacy, immutability, and lack of flexibility, and data unavailability. In the organizational context, there is a lack of adequate skills, financial barriers, and a lack of management commitment and support. In the environmental context, there are also legal issues and lack of regulatory compliance, market and ecosystem readiness, and sustainability concern.

This review showed that technological challenges received more attention from the reviewed articles than in the other two contexts. This reflects a research gap in terms of the organizational and environmental challenges that will have a negative impact and will increase resistance to the acceptance of this technology in the education sector. Therefore, more research is needed from an organizational and environmental perspective.

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