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Review

Blockchain Applications in Education: A Systematic Literature Review

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Abstract: Blockchain is one of the latest technologies attracting increasing attention from different actors in diverse fields, including the educational sector. The objective of this study is to offer an overview of the current state of the art related to blockchain in education that may serve as a reference for future initiatives in this field. For this, a systematic review of reference journals was carried out. Eleven databases were systematically searched and eligible papers that focused on blockchain in education that made significant contributions, and not only generic statements about the topic, were selected. As a result, 28 articles were analyzed. Lack of precision, and selection and analysis bias were then minimized by involving three researchers. The analysis of the selected papers provided invaluable insight and answered the research questions posed about the current state of the application of blockchain in education, about which of its characteristics can benefit this sector, and about the challenges that must be addressed. Blockchain may become a relevant technology in the educational field, and therefore many proofs of concept are being developed. However, there are still some relevant technological, regulatory and academic issues to be addressed to pave the way for the mainstream adoption of this technology.

Keywords: blockchain; blockchain applications; blockchain in education; decentralized education; lifelong learning; standards and interoperability; systematic literature review

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1. Introduction

Blockchain is the technology behind Bitcoin, the cryptocurrency initially described by Nakamoto [1]. A blockchain is a time-ordered set of blocks; that is, each block is cryptographically linked to the previous one forming a chain (chain of blocks). All blocks are stored in a decentralized and distributed ledger and become trustworthy digital records that are that are unmodifiable in practice, but easy to verify. There is no centralized or hierarchical structure in the blockchain network, and the information is shared by a network of peers.

Each block contains a reliable register of one or more actually executed transactions that are created and exchanged by the participants (peers) of the blockchain network, which eventually modify its state. To add new information to the chain, a consensus about its truthfulness has to be reached among the peers in the network.

The content of the transactions depends on the specific blockchain and its purpose. For example, in Bitcoin, the main information registered are exchanges of bitcoins between accounts.

Some blockchains support the use of smart contracts [2], which are similar to computer programs but are deployed on the blockchain and executed autonomously by all the active participants in the network. These smart contracts can read and write information from the blockchain and other sources using oracles (oracles are hardware or software devices that feed the smart contract with external information and/or send data to the outside world) [3], process information, store transaction outcomes, and even trigger actions in systems off-chain. All of the operations are tamper-proof and are recorded in the blockchain to add confidence.

There are three main blockchain types:

- Public: these are open to anyone who wants to be part of the peer-to-peer network (i.e., they are permissionless). Once connected, peers can download and access all of the information, generate and validate transactions and execute smart contracts. To reach a consensus about new transactions, a task must be executed by peers (typically, up to millions of participants). Public blockchains achieve maximum immutability, decentralization and transparency, but they are very inefficient, since a lot of processing power, storage and electricity are required to reach a consensus. The transaction volume and speed are very low. Bitcoin and Ethereum [4] are examples of this type.
- Private: participants may only join if they are invited (i.e., permissioned). There are rules set by the organization that controls the network. In these highly centralized blockchains, immutability and transparency of the chain are limited. The number of peers is typically low, and the network tends to be much smaller and specialized. Therefore, the system is comparatively more efficient, and higher transaction volumes and speeds can be achieved, and, consequently, lower costs and resource usage are incurred. Hyperledger [5] is an example of this type.
- Consortium: is a combination of the two previous types. Like in a private blockchain, participants may only join if they are invited, however, there is not a single organization that controls the network but instead a group of them. From a governance perspective, they maintain the decentralized nature of a public blockchain, although they are more controlled and regulated. Consequently, transaction volume, speed and resources usage are also better.

There are four stages of blockchain maturity [6]:

- Blockchain 1.0 was focused on transactions and it was mainly used on the development of crypto currencies in cash-related applications.
- Blockchain 2.0 adds privacy, smart contracts, and non-native tokens, among other features.
- Blockchain 3.0 incorporates decentralized applications (dApps), back-end code that is executed on a decentralized peer-to-peer network, expanding the uses of blockchain to different markets as health, supply chain, government, education, etc.
- Blockchain 4.0 introduces artificial intelligence (AI), supporting decentralized AI-based decision making based on blockchain reliable data without the need for direct human intervention.

According to Bashir [3], blockchain has ten features (distributed consensus, transaction verification, platforms for smart contracts, transferring value between peers, generating cryptocurrency/incentives, smart property, security provision, immutability, uniqueness, and smart contracts) that make it worthy of investigation for enhancing educational systems, as it will be explained and discussed in detail.

Objectives

The educational sector already foresaw the possibilities of blockchain technology [7]. Several initiatives involving different approaches are being developed [8,9] and there is an increasing body of literature about blockchain in education, referring to diverse applications.

This publication is intended to provide to academics and practitioners an original, updated and timely perspective about the introduction of blockchain in the field of education by systematically analyzing the most relevant publications so far. With respect to previous reviews [10,11], this article was designed with a much wider scope by extending the databases surveyed, and reviewing and updating the terms utilized to identify relevant contributions.

The final aim of this article is to provide an overview of the current state of the art that may serve as a reference and a starting point for future initiatives related to this topic.

Defining the Research Questions

Based on the purpose of this review, the following research questions were formulated:

1. What is the current state of the usage scenarios for blockchain in education?
2. What are the features of blockchain that could benefit education?
3. What are the unresolved issues of blockchain in education?

After defining the objective of this work and the research questions that guide the investigation, a search protocol was designed, which is described in the following sections.

The rest of this paper is structured as follows. Section 2 presents the systematic review procedure followed in this article. Section 3 shows the results of the review. Section 4 discusses the results and Sections 5–7 present other related works, some limitations and conclusions, respectively.

2. Methods

Systematic literature reviews are a very convenient resource to take the pulse of the state of the art of a topic and establish a good starting point to find selected scientific publications that meet certain academic requirements, and thus serve as the foundation for further research in that topic.

2.1. Protocol

According to PRISMA [12], to elaborate a complete description of the systematic literature review of blockchain in education, the PRISMA statement must be defined first. It consists of a 27-item checklist and a four-phase flow diagram (cf. Figure 1) that guide the selection of publications to be included or excluded.

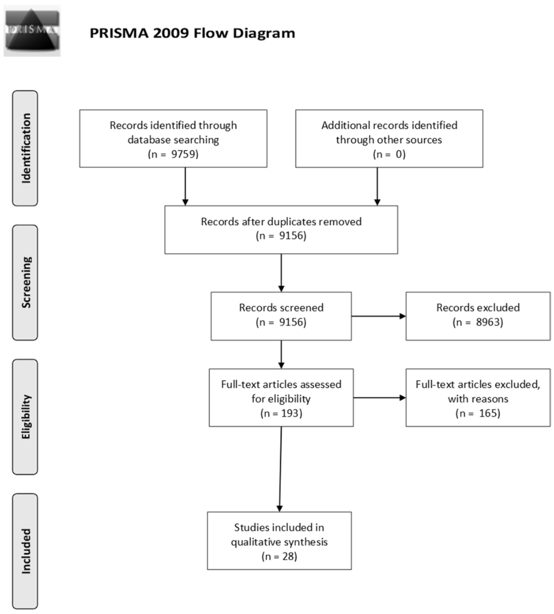

Figure 1. Flow diagram of the screening and selection procedure.

In the case of this review (cf. Tables A1 and A2), 21 out of the 27 items are satisfied, which indicates a high degree of compliance with the methodology.

2.2. Eligibility Criteria

The inclusion criteria for an article to be selected were:

- The text of the article must be in English.
- The publication's title, abstract and full content must be available online.
- Only articles published in peer-refereed journals will be considered.
- The article must be centered in blockchain and education as its main topic.

- The author or authors must contribute to the field of blockchain and education, and not only express an opinion or point of view, or present a use case (due to this criterion, the articles reporting exclusively use cases cited in the introduction were excluded from the final selection).
- Since blockchain is a relatively recent research field, searches were not limited by publication date.

2.3. Information Sources

The first step in the flow diagram is the identification phase. Electronic searches were performed on eleven scientific databases: the ACM digital library, Emerald, ERIC, IEEE Xplore, ProQuest, SAGE Journals, ScienceDirect, Scopus, Springer, Taylor and Francis online and Web of Science.

These databases contain relevant peer-reviewed academic publications, and they were chosen because they are considered as highly relevant by researchers in education and information technology.

After defining the protocol and developing the queries, the final search was conducted on 31 May 2020.

2.4. Search Terms

The keywords for the search query were selected in advance according to the procedure below:

- A general online search in the ACM digital library, IEEE Xplore, ProQuest, SAGE Journals, ScienceDirect, Scopus, Springer, Taylor and Francis online, Web of Science, Google Scholar and ResearchGate was conducted with different combinations of terms related to blockchain and education. Synonyms for each search term were then identified and used.
- All of the publications that matched this search were downloaded and registered (986 results). Those specifically related to education were identified.
- The words in the title and keywords of these documents were analyzed, and the most used specific terms were extracted.
- The final selection of terms included blockchain or "block chain", and educat*, learn*, academic, student, accredit*, certific* and credent* (* represents a wildcard). By re-querying the mentioned databases using the selected terms only, all of the relevant publications could be retrieved again, so they were chosen and confirmed as search keywords.

2.5. Data Collection Process

After selecting the query terms (as word stems in most cases), the boolean OR operator was used to join synonyms, while the boolean AND was used to link the search keywords. Eventually, the following search string was constructed:

(blockchain OR "block chain") AND (educat* OR learn* OR academic OR student OR accredit* OR certific* OR credent*)

This search term combination was used to query the databases by title, abstract and keywords whenever it was possible. All matches found were included in the initial list. The exact query for each database is included in Table A3.

The database that returned the most results to this search query was Springer (5357), followed by Scopus (1535), Web of Science (643), Taylor and Francis Online (615), IEEE Xplore (420), Emerald (364), ACM (315), Sage Journals (257), ProQuest (149), ScienceDirect (95), and Eric (9).

All of the references were successfully transferred to Refworks (Refworks https://refworks.proquest.com/, accessed on 2 April 2020), where duplicates were removed. The flow diagram of the screening and selection procedure is described in Figure 1.

After performing the search and deleting duplicates, the screening process was initiated. All of the titles and abstracts of the initial list of candidate publications were read and selected or discarded for the next phase, according to the defined criteria.

After that phase, the last stage of the PRISMA methodology was applied to the remaining documents. When a decision about inclusion or exclusion was not straightforward, the full document was thoroughly analyzed to take a final inclusion decision following the eligibility criteria. This process was carried out by three researchers, who reached consensus in all cases. This helped to keep the risk of bias under reasonable limits.

As a result, 28 articles were included in this systematic literature review for the final process of qualitative synthesis. All of these discuss relevant contributions to the field of blockchain in education.

3. Results

To sum up, (cf. Figure 1), 9759 records were retrieved from the selected eleven electronic databases, and 803 of them were excluded for duplication. Then, 8963 were removed after analyzing their titles and abstracts, and after filtering them by type of publication. The full text of the remaining 193 articles was retrieved for a comprehensive review. Finally, 28 of them met the eligibility criteria described in this article and were included in this systematic review and are summarized in Section 3.2.

3.1. Publication Year and Geographical Distribution

The distribution of the selected articles by publication year is presented in Figure 2.

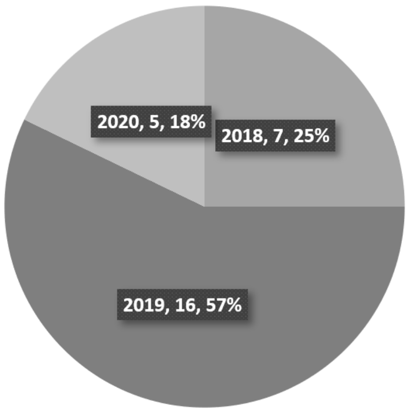

Figure 2. Selected articles by year.

The largest number of these articles (16) were published in 2019 (the high number of publications in 2019 suggests that previous reviews are outdated) (57%), and seven (25%) in 2018. In 2020, the number of publications when the search was made was five (15%). The number of documents published in journals about these topics is clearly growing, although the interest in blockchain in the field of education and the first initiatives started in 2013 [7].

Most documents (13) were published in Europe (47%) (four in United Kingdom, two in Germany and Switzerland, and one in Spain, France, Hungary, the Netherlands, and Turkey). Nine studies (32%) came from Asia (four from India, two from South Korea and one from Malaysia, Russia and, Taiwan R.O.C.). The rest (six) were published in America (21%), more specifically in the United States of America. The geographical distribution of the selected articles by journal continent is represented in Figure 3 and by country in Figure 4.

3.2. Summary of Contributions

In this section, a summary of each publication is provided, including the implemented blockchain technology when identified by the author or authors. A comparison of the main contributions and a categorization of each article is offered in Section 4.

In [13], Arndt and Guercio propose a model to store student's transcript information so that it could be transferred among universities to support learner's mobility. The solution is prototyped with two different approaches, both using blockchain technology. In the first case, Ethereum is combined with the Neo4j open-source NoSQL database. BigChainDB, a distributed database system, is utilized in the second case.

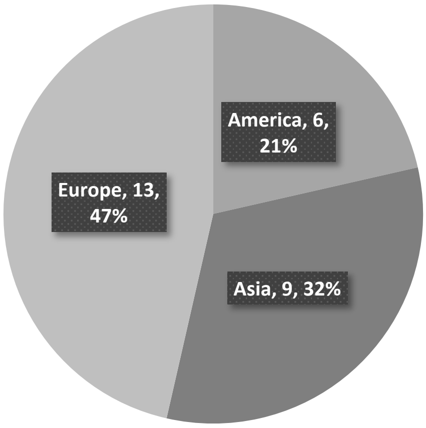

Figure 3. Number of publications by continent.

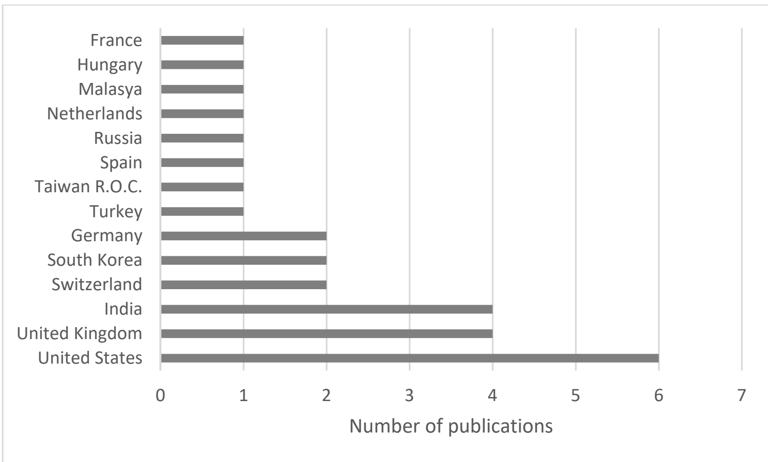

Figure 4. Number of publications by country.

The contribution by Badyal and Chowdhary [14] introduces a service to issue academic certificates that can be verified by recruiters. The implementation is based on the Hyperledger Fabric framework and the authors discuss a proof of concept of this initiative. A different approach is proposed by Bálint et al. [15], as they report the design of an automated bursary payment system for universities. Their platform is technically modeled as an extension of the Bitcoin structure, with a DLCC (Digital Learning Chain Structure) blockchain. Using smart contracts, the processes between students and universities are autonomously executed: a grade book is queried, progress is assessed, and cryptocurrency is transferred to the student's account if the requirements are met. The article also includes the results of empirical research about the students' opinions about Bitcoin and the proposed platform.

Choi et al. [16] discuss the design, prototype and characterization of a badge-awarding system to assess achievements in education using blockchain technology. The resulting platform is compatible with IMS Global Learning Consortium's Open Badges [17]. The process of earning a badge is verified by the Ethereum network and events are tamper-proof and recorded in the blockchain, so that anyone can check if a badge is valid.

The proposal by Dai et al. [18] is oriented to create a system to authenticate learning resources in massive open online courses (MOOC) for teachers and students using blockchain technology to avoid malicious data tampering and other information security problems. After learning contents are registered on the platform, learners can verify their validity before using them.

UniChain is described, prototyped and its performance analyzed in the paper by Daraghmi et al. [19], an Ethereum-system to issue and manage academic certificates that can be trustfully accessed and shared among students, universities and other third parties, while keeping students' privacy by means of time-based smart contracts. It also proposes an incentive mechanism based on the commitment of academic institutions regarding their efforts towards maintaining records and adding new ones. Another model to issue and verify academic certifications based on blockchain to reduce the incidence of certificate forgery is proposed by Ghazali and Saleh [20] but, in this case, the blockchain technology used is not specified.

A different application field is addressed by Guo et al. [21], who model a combination of a generic public and private blockchain-based platform to manage and share multimedia contents in online education. It enables the creation of lifelong trusted learning academic certificates for learners, helps protecting digital copyrights of multimedia works shared by educational entities and, therefore, promotes the establishment of a community to share globally multimedia educational resources.

An initiative to share exam questions and protect them from being leaked is proposed and analyzed by Islam et al. [22]. Question papers are encrypted with a timestamp and trustfully stored in the blockchain with a smart contract that controls when they can be accessed. The actual blockchain technology to be applied is not specified. The authors also propose an algorithm to randomly select a question paper.

Jeong and Choi [23] introduce a certificate management platform for performance assessment during recruitment based on Ethereum and Bitcoin. Their proposal stores all the certificates issued by the institution to the students. The system is compatible with the IMS Global Learning Consortium's Open Badges [17] specification. A prototype is built and described in the article.

A proposal, including a proof of concept about how to develop an Ethereum blockchain-based initiative integrated with Moodle, is discussed by Karataş [24]. Its aim is to verify digital certificates issued to the participants in a certain event.

In [25], Lam and Dongol discuss the design and prototyping of a blockchain-based e-learning platform using the HyperLedger framework to improve transparency and trust by automating academic credentials and evaluation processes. The paper also provides a stakeholder's feedback study.

Li and Han [26] propose and prototype in their paper a model that combines a consortium blockchain among academic institutions and storage servers to issue, manage and share educational records. The off-chain storage servers contain the educational information in encrypted form while the hash of this data is tamper-proof saved on the Ethereum blockchain. Smart contracts manage the process of cross-institutional sharing of educational records. Performance and possible security attacks to the model are also analyzed in the text.

A platform using the generic blockchain technology that converts student's grades into competency values that are trustfully and tamper-proof stored is described and prototyped by Li et al. [27].

Lizcano et al. [28] discuss the prototyping of a blockchain-based system for academic centers using a token (Kudos [29]). By using this platform, academic institutions can adapt their education to the needs of the labor market while the performance of their students is monitored. On the other side, students can have their certificates and qualifications updated and verified by anyone. As an additional benefit, employers obtain a mechanism to drive the training of students for specific professional profiles that they need.

An Ethereum blockchain-based model to register the professional competencies of the general population is designed by Novikov et al. [30]. For each person, an educational index (EI) is calculated and updated by a smart contract on each new professional achievement.

For the platform to work, educational institutions must register the issued diplomas or certificates. This way, a third party (e.g., a potential employer) can trustfully verify if a professional has certain competences.

Ocheja et al. [31] propose a blockchain of learning logs (BOLL); an Ethereum-based system to register all the learning achievements of students that can be shared trustfully among institutions on a single platform. It includes a permission feature to authorize who can access the information. A prototype is developed and assessed.

In [32], Palma et al. propose and prototype an Ethereum-based system, not yet used by real users, for issuing and verifying academic certificates by higher education institutions in Brazil.

Blockchain for Education [33] is introduced in [34] by Prinz et al., a Quorum-based platform [35] to generate, manage and verify reliable counterfeit-proof certificates, based on the needs of academic institutions, students and the labor market, which supports machine-readable certificates using an extension of Open Badges [17]. This solution provides an API to facilitate the integration with other platforms, such as Moodle.

Rooksby and Dimitrov [36] design and build an initial prototype of an Ethereum-based system for a university to store student's information, grades and certificates. It has its own cryptocurrency to make payments and reward the best students.

Several initiatives to issue and verify academic certificates based on blockchain are described and analyzed by Saleh et al. [37], who also compare their security requirements and propose their own model using the Hyperledger Fabric Framework.

Sun et al. [38] make a compilation of educational applications where blockchain can be implemented and propose a solution to the problems of online education based on a custom blockchain technology: full record of learning trajectory, trusted certification of learning results and decentralized sharing of education resources.

Based on the European Credit Transfer and Accumulation System (ECTS) concept, Turkanović et al. [39] design and prototype a system for higher education in which academic institutions transfer credits called EduCTX to students for the courses that they successfully accomplish. The platform is based on the ARK blockchain [40], where the peers are higher education institutions that collaborate to maintain the running of the initiative.

The article by Ubaka-Okoye et al. [41] designs an Ethereum-based framework to secure educational data from modifications. An intelligent agent autonomously monitors all of the information and protects data from malicious access-privileged users or attackers.

Edublocs, a project to register on an Ethereum-based blockchain students' activities, is introduced by Vargas and Soriano [42]. This information is utilized by teachers to assess student progress and design personalized learning itineraries.

Wahab et al. [43] model a Tangle-based platform to issue, manage and check the authenticity of academic certificates. Tangle [44] is a distributed ledger technology built on Directed Acyclic Graphs (DAG) with some special features that provides a highly scalable architecture, zero fees and achieves a quantum resistant security.

Another system based on blockchain for cooperative education is designed by Wanotayapitak et al. [45]. With their proposal, undergraduate students already in the labor market can integrate their job activity as part of their educational program. To accomplish this, they design a digital E-Portfolio where information and acquired digital competences are counterfeit-proof stored on the blockchain to be shared among communities of higher education institutions and third parties (e.g., employers).

In [46], Williams models a future of education based on blockchain where universities must collaborate to remain competitive, allowing students to have a real authentic learning curriculum [47], receive meaningful feedback, improve the learning process by applying skills and communicating with others.

3.3. Contributions and Categorization of Individual Publications

In this section, the selected publications' main contributions are compared and categorized according to their application field in Tables 1 and 2. More detailed descriptions of the articles are provided in Section 3.2.

Table 1. Contributions of the publications besides a model.

Publication	Develops a Prototype	Includes Empirical Measures or Results
Arndt and Guercio [13]	✓	
Badyal and Chowdhary [14]	✓	
Bálint et al. [15]	✓	✓
Choi et al. [16]	✓	✓
Dai et al. [18]		
Daraghmi et al. [19]	✓	✓
Ghazali and Saleh [20]		
Guo et al. [21]	✓	
Islam et al. [22]	✓	
Jeong and Choi [23]	✓	
KARATAŞ [24]	✓	
Lam and Dongol [25]	✓	✓
Li and Han [26]	✓	✓
Li et al. [27]	✓	✓
Lizcano et al. [28]	✓	✓
Novikov et al. [30]		
Ocheja et al. [31]	✓	✓
Palma et al. [32]	✓	
Prinz et al. [34]	✓	
Rooksby and Dimitrov [36]	✓	
Saleh et al. [37]		
Sun et al. [38]		
Turkanović et al. [39]	✓	
Ubaka-Okoye et al. [41]		
Vargas and Soriano [42]	✓	✓
Wahab et al. [43]		
Wanotayapitak et al. [45]		
Williams [46]		

Table 2. Publications and applications category.

Publication	Certificate Issue and Management of Academic Results	Record of Learning Trajectory	Certificate Management for Performance Assessment during Recruitment	Blockchain-Powered Competency and Education	Education Resources	Tokens Transfer	Evaluate Academic Institutions
[13]	✓						
[14]	✓		✓				
[15]						✓	
[16]	✓	✓					
[18]					✓		
[19]	✓						
[20]	✓						
[21]	✓				✓		
[22]					✓		
[23]	✓	✓	✓				
[24]	✓						
[25]	✓	✓					
[26]	✓	✓					
[27]		✓					
[28]	✓	✓	✓	✓		✓	✓
[30]	✓		✓	✓			✓
[31]	✓	✓					
[32]	✓						
[34]	✓						
[36]	✓	✓				✓	
[37]	✓						
[38]	✓	✓			✓		
[39]						✓	
[41]		✓					
[42]		✓					
[43]	✓						
[45]	✓	✓		✓			
[46]	✓			✓			

As a general approach in all of the documents reviewed, the authors include a model of the described initiative with a higher or lower level of detail, as discussed below. Nineteen papers (67%) refer a prototype. In nine cases (32%), additional information or experimental results are included.

4. Discussion

The publication trend indicates that there is an increasing interest in applying blockchain in the field of education. However, considering the importance of the topics and the relatively small number of studies that were retrieved, additional research should be conducted in this area in order to claim that it is mature enough to reach full acceptance among the practitioner's community.

The systematic review conducted of the 28 publications discussed above provided the insight required to respond to the three initial research questions.

4.1. Research Question 1: What Is the Current State of the Usage Scenarios for Blockchain in Education?

The selected publications can be categorized into seven main groups, and some of them can be classified in more than one. The criteria followed was to group the articles according to their individual applications, contributions and approaches, sorted according to the topics addressed. This classification is not always straightforward, and in some cases, relevant differences can be identified among different initiatives in the same group.

4.1.1. Certificate Issue and Management of Academic Results

In 21 out of 28 articles (75%), the focus of the publication is a system to issue, manage, share among institutions and verify academic certificates or transcripts.

Today, most of the certificates are paper-based or electronic and are difficult to preserve, find and use when required (e.g., a professional opportunity, a new educational endeavor, etc.), and authenticity is hard to check, as fake documents can be very realistic. Since there is no central organization that keeps a copy to validate each document, its originality has to be verified against the issuer institution (if still available), and this can be time- and resource-consuming, and involves several bureaucratic tasks.

To solve this, the main idea behind these contributions is to store the information on a blockchain system, to make it tamper-proof and decentralized, so that data could be retrieved even if the institution or the whole educational system is discontinued. In a nutshell, students could share their curricula trustfully signed by an institution and have their credentials verified by potential employers or other academic institutions, improving their mobility [13], and reducing diploma and credentials fraud, while maintaining the learner's privacy.

The works reviewed combine several blockchain solutions with other technologies. For example, in two cases, the resulting proposal is compatible with Open Badges [16,34].

4.1.2. Record of Learning Trajectory

Twelve articles (42%) model blockchain-based learning platforms to trustfully register student's achievements by academic organizations. Note that the information managed in this case extends the transcripts and certificates discussed in the in the previous category.

The idea behind these articles is that learners would store their learning evidence from any source (formal, non-formal or informal) on a blockchain-based system to keep the information trustful and tamper-proof, and verifiable by third parties.

Authors consider and propose different approaches about how these learning records can be used, managed and protected. For example, thanks to the platform modeled by Ocheja et al. [31], each student can have their learning records stored and transferred from one institution to another in a safe form. Choi et al. [16] model a system where learners obtain badges according to their achievements.

4.1.3. Certificate Management for Performance Assessment during Recruitment

Four documents (14%) introduce applications that are specifically related to performance assessment during the recruitment process based on academic information.

Badyal and Chowdhary [14] propose a service that facilitates the verification of students' data by recruiters. This academic information is signed by academic institutions, and is trustfully stored on a blockchain-based platform.

Similarly, Jeong and Choi [23] design and prototype a system for performance assessment during recruitment.

Among other features, the initiative described by Lizcano et al. [28] allows employers to drive learners' education according to the market needs and register the results, so that it would not be necessary to double check the knowledge and competences of job candidates.

Novikov et al. [30] model a system to register professional competencies and developmental paths, simplifying the process of employing graduates and professionals.

4.1.4. Blockchain-Powered Competency and Education

Grades and certificates are not the only option to demonstrate the knowledge of a learner, as learning outcomes can be converted into competence values, which, in turn, should be trustfully processed, tamper-proof stored and easily verifiable.

In this category, four blockchain-based initiatives (14%) were identified. For example, Lizcano et al. [28], Novikov et al. [30] and Wanotayapitak et al. [45] model solutions to register competences. In the first proposal, they are taken from an official quality agency in Spain (ANECA), while the second one focuses mainly on professional competencies of the general population. The third work addresses the creation of e-portfolios to assess cooperative education.

4.1.5. Education Resources

Four articles (14%) present initiatives to combine blockchain with educational resources according to different approaches, so that they can be safely shared and protected from unauthorized access, copied, modified or even deleted.

Dai et al. [18] discuss a platform to authenticate and check the integrity of learning resources in MOOCs for teachers and learners, while Guo et al. [21] focus on digital rights management of multimedia resources in an online educational scenario.

Islam et al. [22] propose and analyze a framework to share exam questions that can be safely kept from being accessed until a certain date and time.

4.1.6. Tokens Transfer

Four articles (14%) discuss the use of tokens for fees, credits and currency transfer, according to different approaches.

Bálint et al. [15] envision a bursary payment system for higher education institutions to automatically transfer cryptocurrency to the student when certain academic requirements are met. A similar design is proposed by Rooksby and Dimitrov [36], where the best students are rewarded with tokens.

Lizcano et al. [28] transfer Kudos tokens [29] as a reputation or nominal prestige currency, as a reward when students achieve specific requirements or met some conditions.

In combination with other innovations, the best students are also rewarded with Kelvin coins in the platform designed by Rooksby and Dimitrov [36], a university-specific cryptocurrency.

Turkanović et al. [39] use the EduCTX tokens as credits for learning units similar to the European Credit Transfer and Accumulation System's units (ECTS), which academic institutions transfer to the students for the courses they complete.

4.1.7. Evaluating Academic Institutions

According to two articles (7%), academic institutions may also be independently evaluated using a blockchain-based solution.

Lizcano et al. [28] present a platform that allows educational institutions to be assessed and ranked according to the academic results of their learners. A similar approach is modeled by Novikov et al. [30], where professional skills are registered and the academic institutions are rated according to the results of their alumni.

4.2. Research Question 2: What Are the Features of Blockchain That Could Benefit Education?

According to Bashir [3], blockchain has ten features that are discussed in this section under the prism of the reviewed publications to analyze how they can benefit education (cf. Table 3).

Despite the fact that blockchain has many interesting characteristics, it is not always the best solution for all scenarios. Wust and Gervais [48] offer a systematic methodology to determine the most appropriate technical solution (blockchain based or not) to solve a specific application problem.

4.2.1. Distributed Consensus

This feature allows a blockchain-based system, made up of tens or even thousands of participants, to agree upon a single version of the information stored throughout the network, without the need for a central authority.

In the field of education, grades, competences, portfolios, certificates and in general, students' information is presently stored in each academic institution, and it is partially shared with official educational bodies. It is difficult to make accessible these records among other stakeholders or third parts. The distributed consensus could allow organizations to collaborate and store in a single platform the same information, and, as a consequence, make it easily available to others.

Table 3. Publications and features of blockchain.

Publication	Distributed Consensus	Transaction Verification	Platforms for Smart Contracts	Transferring Value between Peers	Generating Cryptocurrency/Incentives	Smart Property	Security Provision	Immutability	Uniqueness	Smart Contracts
[13]	✓	✓	✓			✓	✓	✓		✓
[14]	✓	✓	✓			✓	✓	✓		✓
[15]	✓	✓	✓	✓		✓	✓	✓	✓	✓
[16]	✓	✓	✓			✓	✓	✓		✓
[18]	✓	✓	✓			✓	✓	✓		✓
[19]	✓	✓	✓		✓	✓	✓	✓		✓
[20]	✓	✓	✓			✓	✓	✓		✓
[21]	✓	✓	✓			✓	✓	✓		✓
[22]	✓	✓	✓			✓	✓	✓		✓
[23]	✓	✓	✓			✓	✓	✓		✓
[24]	✓	✓	✓			✓	✓	✓		✓
[25]	✓	✓	✓			✓	✓	✓		✓
[26]	✓	✓	✓			✓	✓	✓		✓
[27]	✓	✓	✓			✓	✓	✓		✓
[28]	✓	✓	✓	✓		✓	✓	✓	✓	✓
[30]	✓	✓	✓			✓	✓	✓		✓
[31]	✓	✓	✓			✓	✓	✓		✓
[32]	✓	✓	✓			✓	✓	✓		✓
[34]	✓	✓	✓			✓	✓	✓		✓
[36]	✓	✓	✓	✓		✓	✓	✓	✓	✓
[37]	✓	✓	✓			✓	✓	✓		✓
[38]	✓	✓	✓			✓	✓	✓		✓
[39]	✓	✓	✓	✓		✓	✓	✓		✓
[41]	✓	✓	✓			✓	✓	✓		✓
[42]	✓	✓	✓			✓	✓	✓		✓
[43]	✓	✓	✓			✓	✓	✓		✓
[45]	✓	✓				✓	✓	✓		
[46]	✓	✓	✓			✓	✓	✓		✓

This feature is utilized in all of the articles reviewed, according to different approaches to registering information. For example, Li and Han [26] specifically design and build a framework to issue, manage and share educational records among educational organizations using blockchain and off-chain storage servers that reduce transaction costs and improves efficiency. Initiatives like this facilitate learners' mobility [13] and minimize the possibility of mistakes, while also helping to solve the cold-start challenge in learning analytics systems [31] and the loss of records [32].

4.2.2. Transaction Verification

In blockchain, all proposed transactions are verified according to agreed rules by the active participants of the network before being included in a block. As a consequence, the warehoused data can be considered trustful.

In the educational field, organizations issue, manage and revoke information that should be trustful, tamper-proof stored, and verifiable to avoid forgery; thus, this blockchain feature is a key component to achieving this. As a consequence, all proposals reviewed take into account this characteristic at some level.

For example, Ocheja et al. [31] develop a single platform to record all of the academic achievements of students and make them trustfully available to several educational entities.

4.2.3. Platforms for Smart Contracts

Not all blockchains support smart contracts. However, when this feature is available, it supports the possibility of running tasks on behalf of the users by executing certain processes in a truthful way, by means of storing all related transactions in a tamper-proof and accountable way.

As evidence about this feature being relevant to education, all the reviewed publications utilize smart contracts executed on different platforms to automate processes and launch tasks (cf. Table 4). The platforms of choice are ARK blockchain [40], Bitcoin, Ethereum, Hyperledger Fabric, Quorum [35], and Tangle [44].

Table 4. Platforms used in the publications.

Platform	Publication
ARK blockchain [40]	[39]
Bitcoin [1]	[15]
Ethereum	[16,19,24,26,28,30–32,36,41,42]
Ethereum and also BigChainDB [49]	[13]
Ethereum and Bitcoin	[23]
Hyperledger Fabric	[14,25,37]
Quorum [35]	[34]
Tangle [44]	[43]

Other publications do not specify the smart contract platform used.

4.2.4. Transferring Value among Peers

Blockchain facilitates the reliable transfer of value among participants using tokens, which have different properties (or may not even exist) depending on the type of blockchain used.

Tokens in the education field are introduced with different purposes. For example, they can be used as a reward or financial bonus for students' academic achievements [15,36], as reputation or nominal prestige [28], or as learning units EduCTX [39].

4.2.5. Generating Cryptocurrency/Incentives

Some blockchain networks may create new tokens or incentives to motivate peers to validate transactions and keep the environment secure. The initiatives reviewed are applications developed using existing blockchain technologies, so they do not design their own protocols or consensus mechanisms, and because of that this feature is not very relevant in these initiatives.

Nonetheless, an exception is UniChain [19], a solution to manage electronic academic records and maintain students' privacy while guaranteeing compatibility with existing databases, to offer efficient, secure and interoperable access to records by academic institutions, learners and third parties. Each institution can have one or more participants in the network, which are responsible for blockchain maintenance. The proposal includes an incentive mechanism integrated with the Proof of Authority consensus protocol [50] for creating, validating, and appending new blocks. It does not satisfy all of the requirements of a cryptocurrency, but it does incentivize peers to contribute to the framework.

4.2.6. Smart Property

This feature allows the linking digital or physical properties to the blockchain in a permanent, trustful and tamper-proof way, so that they cannot be owned by anyone else until they are transferred. The owner of the asset is the only one who has control over it, and it is not possible to double-spend or double-own it.

In the educational field, according to this review, the most frequent "property" managed are certificates and grades that are issued or revoked by an institution, which, in turn, are "assigned" to learners, alumni or professionals, as discussed in Section 4.1. Related to this type of information, there are different approaches in the surveyed works. For example, data can be tamper-proof stored [13], shared with recruiters [14], used to acknowledge the assistance to an event [24], analyzed to award badges on certain achievements [16,23], or applied to register competences [30], among others. Academic institutions may also be unbiasedly ranked according to educational criteria [28,30].

Other smart properties are related to educational resources, so they can be verified for authentication [18] or access [22], or used to manage the digital rights of multimedia content [21].

The smart properties assigned to learners, professionals or institutions depend on the actual application scenario. However, a relevant difference with other usage fields is that academic records are normally the property of their owners. They may be shared, but they cannot be transferred among final recipients, since they reflect personal skills, acquired knowledge or reputation.

Nevertheless, there are exceptions where tokens may be explicitly transferred, as they are used as cryptocurrencies [15,28,36].

4.2.7. Security Provision

Blockchain, due to its design and technology, assures security characteristics as integrity, availability, authentication and nonrepudiation for the stored transactions. Nevertheless, in many scenarios, information must be available to all members to provide transparency and verifiability, so confidentiality and privacy cannot be provided. To solve this, some blockchains are specifically designed with mechanisms to provide these.

The blockchain's peer-to-peer nature helps to reduce the security risks in education, since information (i.e., certificates, grades and competences discussed in Sections 4.1.1–4.1.4) is tamper-proof stored, authenticated and protected against repudiation because it is signed by the issuers, and it is highly available due to its peer-to-peer distribution, which supports the creation of trustful information even in unsecure environments.

These blockchain characteristics are also used in combination with other technologies to authenticate and check the integrity of learning resources in MOOCs for teachers and learners [18], manage the access and use of multimedia resources [21] or exam questions [22].

Privacy and confidentiality are features that are not easy to achieve in public blockchains, because all of the information is public and is needed to verify transactions. To solve this, hash codes of the information are stored in the blockchain instead of the actual content of the records, which are stored off-chain and encrypted. The system is controlled by smart contracts [19,26].

An alternate solution consists of a private or consortium-based blockchain platform to restrict access to academic data to authorized participants, to protect recipients' privacy and confidentiality [14,25,37]. Prinz et al. [34] develop their initiative over Quorum, which supports private transactions between network members.

Wahab et al. [43] propose a model using Tangle, a distributed ledger that achieves a quantum resistant security, that adds promising features to secure academic information.

Note that the accountability of blockchain is a key point to trustfully register token's transfers, as discussed in Sections 4.2.4, 4.2.6 and 4.2.9.

4.2.8. Immutability

Transactions stored in a blockchain are almost impossible to modify, since, depending on the type of platform and the number of network participants, the computational effort required is very high. As a consequence, they are considered to be immutable in practice.

In the educational field, it is a key feature to have tamper-proof, available, authenticated and protected against repudiation data on certificates, grades, competences, etc. The immutability characteristic warrants that data will remain unchanged forever and, if something is modified by someone, the alteration(s) will also be immutably accounted.

For example, Ubaka-Okoye et al. [41] propose an intelligent agent that monitors autonomously educational information and protects it from unauthorized modifications.

4.2.9. Uniqueness

Every transaction stored in a blockchain is unique and traceable. This feature prevents the possibility of double spending or double owning of a token or asset.

As discussed in Section 4.2.6, academic information reflects personal, professional or institutional skills, reputation or knowledge, and these properties cannot be spent or transferred, so uniqueness for these applications is not relevant.

On the contrary, in the educational sector, uniqueness is necessary for token-related initiatives when they are equivalent to currency or economic incentives [15,28,36].

4.2.10. Smart Contracts

As previously discussed, some blockchain platforms allow the execution of smart contracts that automatically and autonomously read, process and store data in the blockchain and other sources or destinations by means of oracles, according to their previously defined programming.

The reviewed initiatives are aware of this feature, as discussed in Section 4.2.3. As a general approach, provisions are made to use smart contracts with different approaches and technologies (cf. Sections 4.1.1–4.1.7).

4.3. Research Question 3: What Are the Unresolved Issues of Blockchain in Education?

Although blockchain has many relevant features that can benefit the educational field, as discussed in the previous sections, there are still several drawbacks and challenges that need to be addressed and questions to be responded to under the prism of the reviewed articles.

Some problems correspond to generic limitations of blockchain technologies that affect the educational sector, while others are specific to their application in education. Both types are summarized in the next paragraphs.

Blockchain, as discussed in most articles, is a still immature but rapidly evolving set of technologies, and its adoption in the educational field is still in an early stage of development [18]. There is a need for more research to better understand, characterize, evaluate its usefulness and tackle open issues, for example to create academic certificates [19].

As a relative new set of constantly-evolving technologies, in many cases a complete application programmers' interface (API) is not available to integrate new proposals or legacy systems [13], and at this time there are concerns about the sustainability of the chosen blockchain platforms [42], since there are hundreds of them with different business models and commitment from their developers.

Blockchain and its properties and benefits are, indeed, not easy to understand for the general public [25] and therefore there is a lack of trust in the platform [15]. This is also because blockchain is highly hyped and not always the best solution to all projects, where other technologies are more appropriate [13].

Nevertheless, as described in Section 4.1, there are many initiatives, some of them prototyped and even used in real scenarios as a proof of concept. It would be very helpful if the expertise and results of these pilots were shared among institutions [39,46] and if there were more collaboration among all actors involved to foster the general adoption of blockchain technologies.

Education has a global dimension and involves many stakeholders who must consider the existence of others, although they could be organizationally independent. Blockchain brings to this field many applications that require a new open interconnection model [36] that is not always easy to integrate in the academic organizations and their proprietary systems, and that can play against their own interests or strategies.

Security is a key blockchain feature. However, there are still security framework issues [41] regardless of the hard work of the community to make it stable and safe. Platforms like Bitcoin and Ethereum are the target of constant external attacks [42] that try to exploit current and future vulnerabilities. Storing educational information in blockchain is a risk due to the possibility of bugs in the application or in the platform, or even because the participants do not protect properly their private keys [31].

Privacy in blockchain is not easy to achieve and consequently is a problem in some use cases in the academic field that handle sensitive information. Public blockchains are not a proper solution to store this data, even when encrypted [26], and therefore private or consortium blockchains are preferred [37]. Notwithstanding, some regulations in different countries protect personal information. As an important limitation in Europe, the European General Data Protection Regulation (GDPR - General Data Protection Regulation is regulation EU 2016/679 of the European parliament and of the council on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC.) does not allow for any personal information to be registered in an undeletable storage, such as a blockchain [13], and data must be anonymized. This topic is widely discussed and must be solved before applying blockchain in the educational field to register people's data. From the GDPR's point of view, hashing personal data, as used in different initiatives, cannot be considered an anonymization technique [51]. In other countries, for example Brazil, public education allows private data to be publicly available, while in private education it must be protected [32].

The immutability feature of blockchain technology can also be problematic, as it prevents any chance of deleting educational data even for legitimate reasons both for academic institutions, learners or third parties. These can be modified by authorized entities, but the original information will be recorded forever in the blockchain, and this collides with GDPR's right to be forgotten.

In general, the legal aspects of blockchain in education are still to be addressed, and there are regulatory and governance barriers [25]. A standard regulation across the many different education systems and jurisdictions in the world would be necessary to expand the applications of blockchain in this field. For example, the owner of the data when shared in a P2P network must be defined [36].

Scalability and performance are also unresolved topics when the number of transactions increase, and blockchain technologies are not perceived to be ready for general adoption, which is also the case in the educational field [25]. However, the relevance of this issue depends on the actual application and the flow of information and participants. Blockchains are slow with typically high transaction times [46] and have a limited storage capacity [26] compared with other systems, which could be a real limitation for some academic scenarios.

The consensus protocols, especially those utilized in public blockchains, waste a lot of energy and resources (i.e., bandwidth, storage, computing, etc.) to keep the information reliable [43] and more research is required to address these issues. For many institutions or countries, the widespread use of blockchain in education may involve high costs. Again, this depends on the specific usage, the selected type of blockchain and how its features are valued (e.g., availability, immutability, etc.). For example, the use of Tangle with no transaction fees [43] or government-controlled blockchains with highly efficient nodes to centralize information and lower the cost of operations [30] are proposed. Ocheja et al. [31] discuss who should pay the costs of generating lifelong learning records, namely students or learners, and therefore it should not be excessive. Note that, in the case that a public blockchain is used, the fluctuance in the tokens' value must be considered [46]. On the contrary, in private and consortium blockchains these fees are lower [32], and there is no price variations due to market conditions, but the whole network must be deployed and maintained.

Additional challenges must be addressed according to the reviewed documents. Blockchain can store and assure the validity of the content of transactions, but not the authenticity of the learning. The quality of information and interactions still depend heavily on humans, that is, teachers and learners [25]. Education comprises many processes beyond evaluation and certification, and there are many assessment scenarios in the real world (e.g., exams, but also presentations, interviews, real time controls, group projects, class participation, etc.) that are difficult to model with blockchain and smart contracts [25]. More research about the combination of education with blockchain is needed to model and solve these challenges.

5. Other Related Work

In addition to the articles finally included in this review, there are other relevant publications that may complete the vision on the current state of the topic [8–11,52]. These studies were excluded from the final analysis because they do not make concrete contributions to the field, as they correspond to literature reviews or collections of use cases.

For example, Yumna et al. [11] report a literature review where only keywords "blockchain", "education", and "review" were considered in papers collected in Google Scholar by March 2018. The authors discuss the use of blockchain in education, and focus on some use cases related to certificate registration and interoperability for diversified learning accreditation. Three articles satisfying the criteria of this review were identified in that work [34,36,39]. Alammary et al. [10] discuss another literature review based on the query (blockchain + education) OR (blockchain + learning) OR (blockchain + teaching) in nine databases by April 2019. Four papers satisfying the criteria of our review were identified in that work [28,32,39,46] and another one [8] is referenced below.

Chen et al. [8] enumerate several use cases of blockchain by certain institutions, and discuss additional potential applications beyond the registration and sharing of academic certificates and learning outcomes.

Finally, Hameed et al. [9] analyze some applications of blockchain and education, and Jirgensons and Kapenieks [52] collect and study different initiatives of blockchain in the educational field.

6. Limitations

There are three limitations that should be considered about this systematic review. The first one is the limited number of online databases queried. Many more could have been consulted, and there is always a risk of not including an article published in other sources. Blockchain is a relatively recent set of technologies and the number of publications is growing. However, the most relevant databases related to the topic were selected.

The second limitation is the keywords and the queries applied to the databases. Nevertheless, the search terms were selected with alternatives according to a defined procedure adequate to the educational field before starting the research, and were combined using Boolean operators. The suitability of the terms was double-checked before starting the queries in Section 2.4.

The third limitation is the risk of bias in the selection of the publications. To avoid it, a fixed set of criteria were defined and followed to include or exclude documents. The number of publications about blockchain and education has been increasing in recent years, and the most rigorous ones are those published in peer-refereed journals, and this was one of the most restrictive filters. All the included works that were screened and the final selection was thoroughly analyzed by the authors, who achieved an agreement when there was a doubt whether they should be incorporated in the review or not.

7. Conclusions

In this systematic review, 28 publications are analyzed and, from their perspective, the current state of blockchain applications in education is discussed, together with the potential benefits that they can bring to this sector, and the multiple questions that must be addressed for its mainstream introduction.

Blockchain can contribute greatly to the education field and, in fact, it is showing its potential through the different initiatives that were researched and published in recent years. Its characteristics open up a new range of possibilities to reinforce the security, trust and efficient use of academic information, securely facilitate its issuance, exchange, exploitation and verification, and develop new use cases.

As can be seen in this work, the research and the number of blockchain projects aimed at the world of education continues to grow, despite the fact that both the underlying technology and the applications are not still mature, but they are evolving quickly. Issues must be addressed both from the technological point of view (e.g., security, privacy, performance, scalability, etc.), normative and regulatory (e.g., laws, harmonization with the GDPR, standards that allow the interconnection of academic institutions, for example, etc.) and academic perspectives in order to adequately model processes using smart contracts.

By now, there are no widely adopted blockchain projects in education but only models, pilots and proofs of concept. Nevertheless, progress is continuous, and initiatives generate more and more interest, as they demonstrate that blockchain is becoming a key technology in future educational scenarios.

Other surveys were conducted in the past, but with a very limited number of reviewed publications. The increasing number of new works published recently makes this work relevant to the community.

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Appendix A

This appendix includes three tables. The first and the second one list the PRISMA checklist for the abstract and the PRISMA checklist. The third one introduces the actual queries performed on each of the databases considered in this survey.

Since each database uses its own syntax in the advanced search tool, slightly different query strings were utilized. For example, ScienceDirect does not allow the use of wildcards (*), or in Springer does not support queries including certain fields only.

Table A1. PRIMA Checklist for Abstract.

Section/Topic	Num.	Checklist Item	Reported on Page
	TITLE		
Title	1	Identify the report as a systematic review, meta-analysis, or both.	
	BACKGROUND		
2. Objectives ☑	2	The research question including components such as participants, interventions, comparators, and outcomes.	1
	METHODS		
3. Eligibility criteria ☑	3	Study and report characteristics used as criteria for inclusion.	1
4. Information sources	4	Key databases searched and search dates.	
5. Risk of bias	5	Methods of assessing risk of bias	1
	RESULTS		
6. Included studies ☑	6	Number and type of included studies and participants and relevant characteristics of studies.	1
7. Synthesis of results ☑	7	Results for main outcomes (benefits and harms), preferably indicating the number of studies and participants for each. If meta-analysis was done, include summary measures and confidence intervals.	1
8. Description of the effect	8	Direction of the effect (i.e., which group is favored) and size of the effect in terms meaningful to clinicians and patients.	
	DISCUSSION		
9. Strengths and Limitations of evidence ☑	6	Brief summary of strengths and limitations of evidence (e.g., inconsistency, imprecision, indirectness, or risk of bias, other supporting or conflicting evidence).	1
10. Interpretation		General interpretation of the results and important implications	1
	OTHER		
11. Funding	6	Primary source of funding for the review.	
12. Registration	7	Registration number and registry name.	

From: Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med.* **2009**, *6*, e1000097, doi:10.1371/journal.pmed1000097.

Table A2. PRIMA Checklist.

Section/Topic	Num.	Checklist Item	Reported on Page
		TITLE	
Title ☑	1	Identify the report as a systematic review, meta-analysis, or both.	1
		ABSTRACT	
Structured summary ☑	2	Provide a structured summary including, as applicable: background; objectives; data sources; study eligibility criteria, participants, and interventions; study appraisal and synthesis methods; results; limitations; conclusions and implications of key findings; systematic review registration number.	1
		INTRODUCTION	
Rationale ☑	3	Describe the rationale for the review in the context of what is already known.	1
Objectives ☑	4	Provide an explicit statement of questions being addressed with reference to participants, interventions, comparisons, outcomes, and study design (PICOS).	2–3
		METHODS	
Protocol and registration ☑	5	Indicate if a review protocol exists, if and where it can be accessed (e.g., Web address), and, if available, provide registration information including registration number.	3
Eligibility criteria ☑	6	Specify study characteristics (e.g., PICOS, length of follow-up) and report characteristics (e.g., years considered, language, publication status) used as criteria for eligibility, giving rationale.	3
Information sources ☑	7	Describe all information sources (e.g., databases with dates of coverage, contact with study authors to identify additional studies) in the search and date last searched.	3–4
Search ☑	8	Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated.	4–5, 23–25
Study selection ☑	9	State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis).	5
Data collection process ☑	10	Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators.	5
Data items ☑	11	List and define all variables for which data were sought (e.g., PICOS, funding sources) and any assumptions and simplifications made.	5
Risk of bias in individual studies ☑	12	Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis.	5
Summary measures	13	State the principal summary measures (e.g., risk ratio, difference in means).	
Synthesis of results	14	Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., I2) for each meta-analysis.	
Risk of bias across studies	15	Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies).	
Additional analyses	16	Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified.	
		RESULTS	
Study selection ☑	17	Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally with a flow diagram.	4–5
Study characteristics ☑	18	For each study, present characteristics for which data were extracted (e.g., study size, PICOS, follow-up period) and provide the citations.	5–11
Risk of bias within studies ☑	19	Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12).	5–11
Results of individual studies ☑	20	For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot.	5–11
Synthesis of results ☑	21	Present the main results of the review. If meta-analyses are done, include for each, confidence intervals and measures of consistency	5–11
Risk of bias across studies	22	Present results of any assessment of risk of bias across studies (see Item 15).	
Additional analysis	23	Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]).	
		DISCUSSION	
Summary of evidence ☑	24	Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., healthcare providers, users, and policy makers).	11–19
Limitations ☑	25	Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias).	11–19
Conclusions ☑	26	Provide a general interpretation of the results in the context of other evidence, and implications for future research.	20–21
		FUNDING	
Funding ☑	27	Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review.	20

From: Moher, D.; Liberati, A.; Tetzlaff, J.; Altman, D.G.; The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Med.* **2009**, *6*, e1000097, doi:10.1371/journal.pmed1000097.

Table A3. Search query for each database. * represents a wildcard in the query.

Database (Sorted by Name)	Search Query
ACM digital library	Title:((blockchain OR "block chain")) OR Abstract:((blockchain OR "block chain")) OR Keyword:((blockchain OR "block chain"))) AND (Title:((educat * OR learn * OR academic OR student OR accredit * OR certific * OR credent *)) OR Abstract:((educat * OR learn * OR academic OR student OR accredit * OR certific * OR credent*)) OR Keyword:((educat * OR learn * OR academic OR student OR accredit * OR certific * OR credent *))
Emerald	(blockchain OR "block chain") AND (educat * OR learn * OR academic OR student * OR accredit * OR certificate OR credent *)
ERIC	(blockchain OR "block chain") AND (educat * OR learn * OR academic OR student * OR accredit * OR certificate OR credent *)
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ProQuest	((TI((blockchain OR "block chain")) OR AB((blockchain OR "block chain")) OR IF((blockchain OR "block chain")) OR SU((blockchain OR "block chain")))) AND (TI (educat * OR learn * OR academic OR student OR accredit * OR certific* OR credent *) OR AB(educat * OR learn * OR academic OR student OR accredit * OR certific * OR credent *) OR IF(educat * OR learn* OR academic OR student OR accredit * OR certific* OR credent *) OR SU(educat* OR learn* OR academic OR student OR accredit * OR certific * OR credent *))
SAGE Journals	(blockchain OR "block chain") AND (educat * OR learn * OR academic OR student * OR accredit * OR certificate OR credent *)
ScienceDirect	(blockchain OR "block chain") AND ("education" OR "learning" OR academic OR student OR accreditation OR certificate OR credential)
Scopus	TITLE-ABS-KEY ((blockchain OR "block chain") AND (educat * OR learn * OR academic OR student* OR accredit * OR certificate OR credent *))
Springer	(blockchain OR "block chain") AND (educat * OR learn * OR academic OR student * OR accredit * OR certificate OR credent *)
Taylor and Francis online	[[All: blockchain] OR [All: "block chain"]] AND [[All: educat *] OR [All: learn *] OR [All: academic] OR [All: student *] OR [All: accredit *] OR [All: certificate] OR [All: credent *]]
Web of Science	TS = (blockchain OR "block chain") AND TS = (educat * OR learn * OR academic OR student OR accredit * OR certific * OR credent *)

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