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TOPICAL REVIEW

Blockchain in Education: A Systematic Review and Practical Case Studies

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ABSTRACT The advent of blockchain technology over the last decade has led to the development of multiple use-cases of decentralization in various fields including education. This paper presents a unique bibliometric and qualitative analysis of the blockchain in education with novel contributions on temporal development, emerging themes and practical case studies on adoption and integration with existing educational technologies. We focus on identifying the major actors in the space, demographic participation and adoption, current hot topics, grey areas, and potential areas for innovation. Our analysis shows that while the blockchain has been around for about 13 years, blockchain in education only became prominent 5 years ago. This research also reveals that most of the efforts have been focused on reporting and verifying academic certificates and transcripts: only very few research focused on reporting and connecting in-depth academic records such as learning behaviour logs, learning contents and assessment data. This calls for concern as current education blockchain systems do not consider interoperability at the blockchain level and the heterogeneous nature in which institutes create and consume academic data. Finally, we present discussions on the implications of our findings, potential solutions and aspects of education blockchain research that can help to improve educational outcomes for various stakeholders.

INDEX TERMS Academic records, analysis, application programming interface (API), artificial intelligence (AI), bibliometric, blockchain of learning logs (BOLL), education, experience API (xAPI), information and communication technology (ICT), latent dirichlet allocation (LDA), learning management system (LMS), learning record store (LRS), learning tools interoperability (LTI), quick response (QR), sharable content object reference model (SCORM), smart ecosystem for learning and inclusion (SELI).

I. INTRODUCTION

Blockchain technology presents a decentralized paradigm where two parties can transact without relying on a mediating third-party. To facilitate transactions between two parties that do not trust each other, the blockchain maintains a ledger that is available to both parties and the authenticity of the ledger is guaranteed through a consensus algorithm. While there are many consensus algorithms as reported in [1], the main functions of a consensus algorithm are: to ensure that ledger entries are consistent, verify an actor can write or modify them and prevent its compromise. These features among others have made blockchain technology very attractive to many fields such as finance [2], supply chain [3], internet of things [4], [5], healthcare [6] and education [7].

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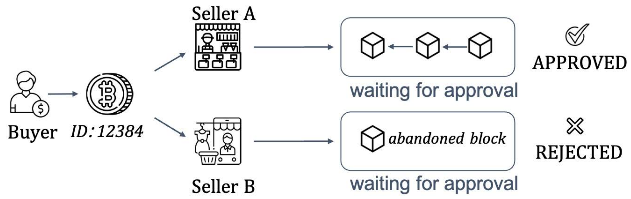

FIGURE 1. Preventing double-spending on the blockchain.

One of the strong arguments for blockchain in finance is how it solves and prevents the double-spending problem [8]. In Fig. 1, we demonstrate how the blockchain prevents a buyer from spending the same coin when transacting with two different sellers A and B. When the buyer spends the same coin, both sellers receive it and try to add the block containing that transaction to the ledger. However, the consensus mechanism ensures that only one instance of this coin is spent on the network by retaining the longest chain of blocks after approval at seller A. Thus, the block which contains double-spending of the same coin as seen from seller B is abandoned and the transaction is invalidated. The double-spending problem usually makes the role of the third party in financial transactions more visible and gives further credibility to how the blockchain takes on this responsibility. However, it is difficult to picture the double-spending problem in other fields that use blockchain technology such as education. In recent times, technological innovations have played a key role in redefining education [9]. From e-learning systems to data-driven methods, various schools have sought ways to use technology to solve problems such as content delivery and reach, recommendation, early intervention, assessments, credentials issuing, and verification.

Different institutes often adopt different technologies to manage academic records and issue credentials. This heterogeneity of systems across schools makes it difficult for students to import their learning data from one school to another in a tamper-proof and protected environment. Also, instant verification of academic credentials becomes more complicated as each credential must be validated against a set of rules defined by each school through the specific interfaces provided by such schools or the consortium they belong to. Consequently, it becomes desirable to solve these problems: how can schools easily connect and exchange information with little or no change to internal technology setup while maintaining trust and tamper-proof records management? This is one scenario where the blockchain fits as a solution in education. Other aspects of education that blockchain brings some innovation to include academic research, reputation, e-portfolio, and intellectual property [10], [11], connecting lifelong learning and learning analytics platforms [7], [12], [13], credits, credentials, and certificates [14], [15]. These reasons have led to the development of various technologies, frameworks and proposals on how the blockchain can be used in education. Specifically, this work focuses on providing answers to the following research questions:

RQ1. What is the growth and thematic evolution of research on blockchain in education?

RQ2. What are the rules and methods of implementing blockchain in education?

RQ3. What are the learning tools and technical changes associated with the adoption of blockchain in education?

The goal of this paper is to conduct a systematic review, collect and analyze peer-reviewed research article metadata and abstracts indexed in Scopus and Web of Science databases and in which blockchain is used to improve education services. Different from previous work, this paper also presents practical case studies on how the blockchain technology has been adopted to improve learning success by using the technology to engender inclusivity, drive digital storytelling, enable personalization, connect lifelong learning data and foster privacy control by data owners. The lack of existing literature on a systematic study of how the emerging blockchain technology is being used in education, what key changes are required, possible impacts and challenges make this work a key necessity. Particularly, this paper makes the following novel contributions:

- Present an overview of the temporal development and growth of the field of blockchain technology and its application in education.
- Critical evaluation of the current progress and limitations of blockchain in education.
- Practical studies on how blockchain can be used with existing educational technologies and/or as a standalone new educational technology.
- Reveal prevailing challenges that have hindered the overall use and impact of blockchain in education.

This study is presented in the following order and as shown in Figure 2: Section II presents some related work, their limitations and our unique contributions. Section III details the methodology adopted in this research including the justification for the chosen method of a systematic review and the processes for data collection and analysis. The results from the data analysis, discussions on various sub-themes and practical case studies are presented in Section IV. Finally, we present discussions on key implications of the findings from this work in Section V and recommend potential directions for future work.

II. RELATED WORK

Many excellent literature reviews on blockchain in education such as [10], [11], [16], [17], [18], [19] have revealed the various body of work that are solving some key problems in education through the blockchain. [10] presented a report on the concept of blockchain and how it can be applied in the education sector. However, their report focused mainly on the use of the blockchain to report academic certificates and accreditation information and was conducted when most works on blockchain in education were proposals without concrete implementations. Similarly, [16], [18] conducted an exploratory review on the use of blockchain in education, reported a few emerging works and discussed potential

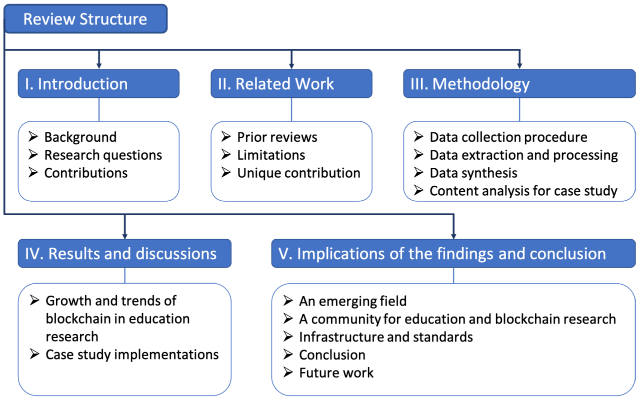

FIGURE 2. Review structure.

use cases. In this paper, we conduct a specific review on how these potential use cases have been implemented and adopted in education. [17] conducted a systematic review on blockchain-based educational applications. While this work is closely similar to our focus, [17] limited their focus to identifying education blockchain applications, their benefits and challenges: failing to reveal thematic areas driving the adoption of blockchain in education, how such technologies are integrated with existing learning tools and implications for the field of education technology research.

This paper presents a different viewpoint: a quantitative, and qualitative bibliometric analysis of the research on blockchain in education with practical case studies that can guide future adoption. The result from this analysis provides useful information on milestone articles, key authors, differences across countries, bibliometric trends, hot topics and emerging areas. The qualitative analysis is done by reviewing 47 selected articles which addressed specific aspects of education blockchain research (milestone articles) and have continued to inspire other efforts. The results show a common trend of blockchain in education being more focused on credentials. It also reveals that despite the lopsided focus on reporting and verifying academic credentials, standardization is still a problem and it is rarely discussed in most studies on blockchain in education.

III. METHODOLOGY

To answer RQ1, we adopted the scientific method of bibliometric analysis [20] which has been acknowledged as a useful tool for understanding a research field's temporal evolution across disciplines without subjective bias [21], [22]. This technique has been applied by scholars across different domains including finance [23], [24], [25], supply chain [26], big data [27], [28], and education [29], [30] to analyse a research area, identify thematic boundaries, lead authors and possible directions for future research. Consequently, our study uses the bibliometric technique to understand how various research on the application of blockchain in education have evolved. The bibliometric analysis is conducted using bibliographic coupling, co-occurrence relations, thematic evolution, and network (author, countries and network) analysis.

To answer RQ2 and RQ3, it is necessary to carefully and correctly select candidate papers that can provide answers to technologies, changes and methods required when integrating blockchain with existing learning tools. The task of indexing unstructured data or documents such as research papers with varying formats is non-trivial given a large number of papers. Thus we employed the topic modeling approach of document indexing by Latent Dirichlet Allocation (LDA) [31] which has been found useful and effective in previous work [32], [33]. To decide terms for topic modeling, we curated a list of key terms that are expected to be found in papers that would provide answers to RQ2 and RQ3 which include: *"technology. implementation. system. application. tool. app. server. software. program. smart contract. rules. permission. privacy. access. security. validate. verify. credentials. certificates. transcripts. diploma"*. It is important to also mention that the chances of missing relevant papers that do not use these exact terms are very low as LDA provides a suitable algorithm to detect the occurrence of key terms [34].

The data collection for this study was conducted from two main databases, namely, the Scopus and Web of Science which includes papers from top venues such as IEEE conferences and journals, and ACM conferences and journals. To reduce the risk of missing relevant studies, we also used the backward and forward snowballing technique for each paper selected from these two databases. The backward snowballing was carried out by examining the reference list of the primary selections while the forward snowballing was conducted by reviewing other papers that cited the primary list. The choice of these two databases is based on their reputation as scholars consider them world-leading and competing databases based on their science citation index [35], [36]. Also, most bibliometric studies used Web of Science and Scopus databases as their common data sources [37] and both Web of Science and Scopus provide a well-structured journal classification system suitable for collecting bibliometric data. More so, recent data scientists are developing bibliometric analysis tools that can conveniently accept data downloaded from the Web of Science and Scopus databases [20], [38].

A. DATA COLLECTION PROCEDURE

The primary article search was carried out by using selected keywords. These keywords were jointly selected by the authors, with criteria that were based on the frequently used authors' keywords found in most of the related articles. For example, the list of keywords such as "blockchain" combined with "education", or "lifelong learning" or "life-long learning" or "digital certificate" or "academic record" or "e-learning" were used. Table 2 presents details on how these keywords were combined with the use of the operators (AND/OR). The table also shows the result of the number of data entries returned. Notably, the search was focused on the metadata of the articles: the title, abstract, and authors' keywords.

TABLE 1. Search keywords and outputs from the databases.

Database	Search string	Result
Scopus	(TITLE (("blockchain" AND "education") OR ("blockchain" AND e-learning) OR ("blockchain" AND lifelong learning) OR ("blockchain" AND lifelong-learning) OR ("blockchain" AND digital certificate) OR ("blockchain" AND academic record)) OR ABS (("blockchain" AND "education") OR ("blockchain" AND e-learning) OR ("blockchain" AND lifelong learning) OR ("blockchain" AND lifelong-learning) OR ("blockchain" AND digital certificate) OR ("blockchain" AND academic record)))	461
WoS	TITLE: (("blockchain" AND "education") OR ("blockchain" AND e-learning) OR ("blockchain" AND lifelong learning) OR ("blockchain" AND lifelong-learning) OR ("blockchain" AND digital certificate) OR ("blockchain" AND academic record))	44
Scopus + WoS	RStudio functions to combine the data. 37 duplicates removed.	Total data 468

TABLE 2. Main information about the dataset used in the bibliometric analysis.

Documents	468
Period	2017:2021
Data sources (Journals, Books, etc)	279
Keywords Plus (ID)	1,753
Author's Keywords (DE)	959
Average years from publication	1.51
Average citations per documents	3.73
Average citations per year per doc	1.16
Journal Article	134
Book chapters	16
Book review	4
Conference proceedings paper	224
Conference review	68
Editorial	3
Review	19
Authors	1,104
Author Appearances	1,348
Authors of single-authored documents	47
Authors of multi-authored documents	1,057
Single-authored documents	117
Main documents per author	0.42
Main authors per document	2.36
Main co-authors per documents	2.88
Authors collaboration index	3.01

B. DATA EXTRACTION AND PROCESSING

The search was conducted in early June 2021. After collecting the data from these two databases, the authors used two main software RStudio and Biblioshiny developed by Aria and Cuccurullo [20]. The RStudio software is an open-source solution for data science analysis while Biblioshiny is a web tool that can be launched from the RStudio to provide a web interface for data visualization. Upon merging the data from the two sources, 37 duplicates were found and removed. Therefore, the total number of data utilized in this study, which emanated from the two data sources became 468. While this number of data may seem to be moderately low, it depicts the nature of the field, which is still emerging. However, the data is sufficient to provide insights into how blockchain in education has progressed and where it is heading in terms of adoption and technology deployment within the field.

C. DATA SYNTHESIS

A total of 468 data entries published between 2017 and June 12, 2021, were used in this analysis. These documents emerged from sources such as journals, books, conference proceedings, and book chapters as described in Table 2. In addition, the dataset consists of 1,104 authors, 117 single-authored papers, and 959 authors' distinct keywords. Also, the data entries collected only had a time attribute of publication year and our trend analysis have been conducted in yearly time spans.

D. CONTENT ANALYSIS FOR CASE STUDY

To provide answers to RQ2 and RQ3 which addresses education blockchain infrastructure, technologies and methods, we conducted a content analysis on all the 468 records. First, we excluded 5 entries with missing abstracts and performed topic modelling with the abstract data using LDA as used in some previous studies [39], [40]. To obtain the optimal number of topics to classify the abstract data, we calculated the topic coherence score [41] for various models while changing the number of topics: starting at 2 topics to 50 topics in steps of 6. We then plotted the topic coherence score of each model against the number of topics. The optimal number of topics would be that of the model which had the highest coherence score just before the line flattened out. In our analysis and plot shown in Fig. 3, the optimal number of topics is 14 with a coherence score of 74%. We then created these keywords that represent concepts that can answer RQ2 and RQ3: *"technology. implementation. system. application. tool. app. server. software. program. smart contract. rules. permission. privacy. access. security. validate. verify. credentials. certificates. transcripts. diploma"*.

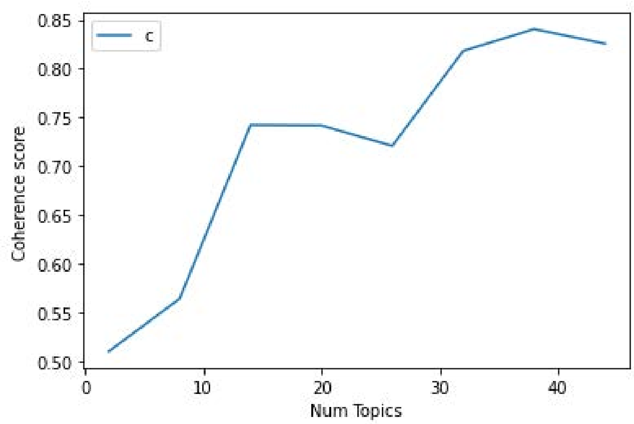

FIGURE 3. Coherence score vs number of topics.

The LDA model was then used to determine the topic that best fit the terms in RQ2, RQ3 and their associated abstracts.

212 papers matched similar topics as RQ2 and RQ3 but to eliminate papers with weak topic scores, we set a topic match threshold of 0.4 and above. Only 79 documents matched this condition. Finally, we excluded review papers and papers that were published in venues with an H-index of less than 15 (except 5 papers from emerging publications on blockchain in education). A total of 44 papers were selected for a full paper read. These papers were queried to answer questions such as: Does a working solution exists? What learning tools are being used with the blockchain? What changes are being made to these tools to accommodate the blockchain? Are additional tools required to enable blockchain systems? what limitations exist with such modifications and tools? How does the work enable the connection and exchange of data across schools? what key technologies are used for such exchange on the blockchain? Are changes required to existing infrastructure and to what extent? What rules on the blockchain govern such communication and exchange of data?

Thus, LDA was useful in discovering papers on similar topics related to RQ2 and RQ3, selecting only papers whose topic match score is above a set threshold ($\geq$40%). Our content analysis involved a full paper read of these selected works. This led to the discovery of two blockchain implementations that can answer RQ2 and RQ3. We present these case studies and how they address RQ2 and RQ3 in Section IV-B.

IV. RESULTS AND DISCUSSION

This section is dedicated to the findings that address the research questions considered in this study. We begin by presenting the quantitative bibliometric aspect of the result followed by the content analysis.

A. GROWTH AND TRENDS OF BLOCKCHAIN IN EDUCATION RESEARCH

This section provides answers to RQ1 which examines the growth and trends of research on blockchain in education including an analysis of thematic evolution, publication sources, keywords, authors and countries.

1) THEMATIC EVOLUTION

Our findings show that between 2016 and 2018, there was no significant growth in terms of the integration of blockchain with educational technologies. As shown in Fig. 4, the two main terms - ''blockchain based'' and ''educational technology'' were independently established fields. While this period witnessed a scholarly discussion about the conceptualization of integrating blockchain in education, online education had already created a niche.

On the other hand, the evolution of blockchain in education between 2019 and 2021 revealed a slightly significant growth as Fig. 5 shows an overlap between the two fields ''blockchain-based data'' and ''blockchain education''. In addition, it was shown that during this period, one of the core use of blockchain in education was for certification and certificate distribution. By 2020, the use of blockchain in education seemed to have grown such that the term ''smart application'' emerged. One could argue that blockchain technology is one of the smart applications, state-of-the-art education systems powered through secure authentication.

Another noticeable evolution of blockchain in education between 2019 and 2021 is the appearance of sub-themes such as ''future blockchain'', ''commercial'', and ''cloud developing'', in the niche component of the thematic graph as shown in Fig. 4. While earlier years showed ''online'' as the only established niche theme, recent years showed more themes with cloud development as one of the technologies driving the integration of blockchain in education. Although blockchain in education is still maturing, it can be deduced that emerging themes such as ''quality service'', ''authentication secure'', and ''chain model'' can contribute to building the trust required for educational administrators and other stakeholders to fully embrace the integration of blockchain technology.

TABLE 3. Most relevant publication sources.

Publication Sources	No. of Documents
Advances in Intelligent Systems and Computing	36
ACM International Conference Proceeding Series	32
Lecture Notes in Computer Science (+Sub-Series)	13
Communications in Computer and Information Science	12
Journal of Physics: Conference Series	9
Journal of Advanced Research in Dynamical and Cont.	7
Sustainability (Switzerland)	7
Procedia Computer Science	6
Elearning and Software for Education Conference	5
Lecture Notes in Business Information Processing	5
Lecture Notes in Electrical Engineering	5
Lecture Notes in Networks and Systems	5
Smart Innovation Systems and Technologies	5
Applied Sciences (Switzerland)	4
Ceur Workshop Proceedings	4
International Journal of Advanced Trends in Comput.	4
International Journal of Emerging Technologies in...	4
Lecture Notes of the Institute For Computer Science	4
Lecture Notes on Data Engineering and Communication	4
2020 2nd International Conference of Cybernetics	3

2) PUBLICATION SOURCES ANALYSIS

The analysis of publication sources is shown in Table 3, which revealed that ''Advances in Intelligent Systems and Computing'' tops the list of 20 most widely used publication outlets for research on blockchain in education with a total of 36 articles that were already published by mid-2021.

The Advances in Intelligent Systems and Computing journal which is dedicated to publishing articles that are focused on foundational ''theory, design methods, and applications of intelligent systems'' may have gained relevance for publishing blockchain in education articles since blockchain integration in education requires technical design method. Next among widely used publication sources is the ''ACM International Conference Proceeding Series'' with a total of 32 articles already published in mid-2021. This publication outlet publishes proceedings from several conferences focused on computer science and engineering field. Further,

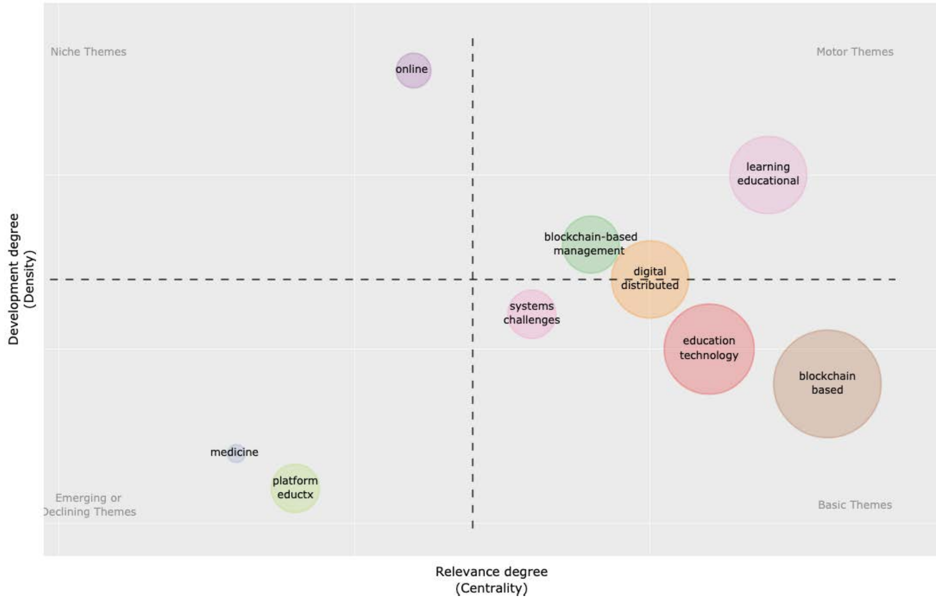

FIGURE 4. Thematic evolution 2016 - 2018.

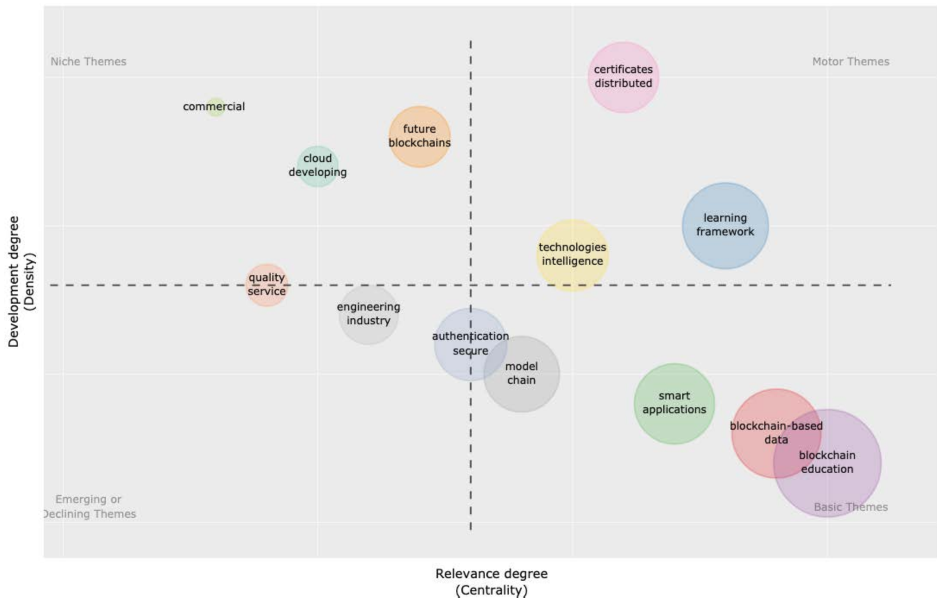

FIGURE 5. Thematic evolution 2019 - 2021.

it was revealed that Lecture Notes in Computer Science, Communications in Computer and Information Science, and Journal of Physics: Conferences Series were among the top 20 sources with publication counts of 13, 12, and 9, respectively. One important thing to note here is that the publication sources are not core education research publication venues. From the analysis, one observed that most of the sources are publishing articles within the scope of computer science and information system while the only publication source with the flavour of education is the ''E-learning and Software for Education Conference''. While the reason for this finding remains unclear, it can form a research topic for scholarly discussion.

3) KEYWORD ANALYSIS

The foundational keywords for this quantitative study remain the dominant ones. For example, keywords such as ''blockchain'' occurred 222 times in the data set, whereas ''engineering education'', ''students'', and ''higher education'' appeared 50, 40, and 33 times, respectively as shown in Table 4. Aside from keywords that are related to platforms driving blockchain in education - ''e-learning'', ''education'',

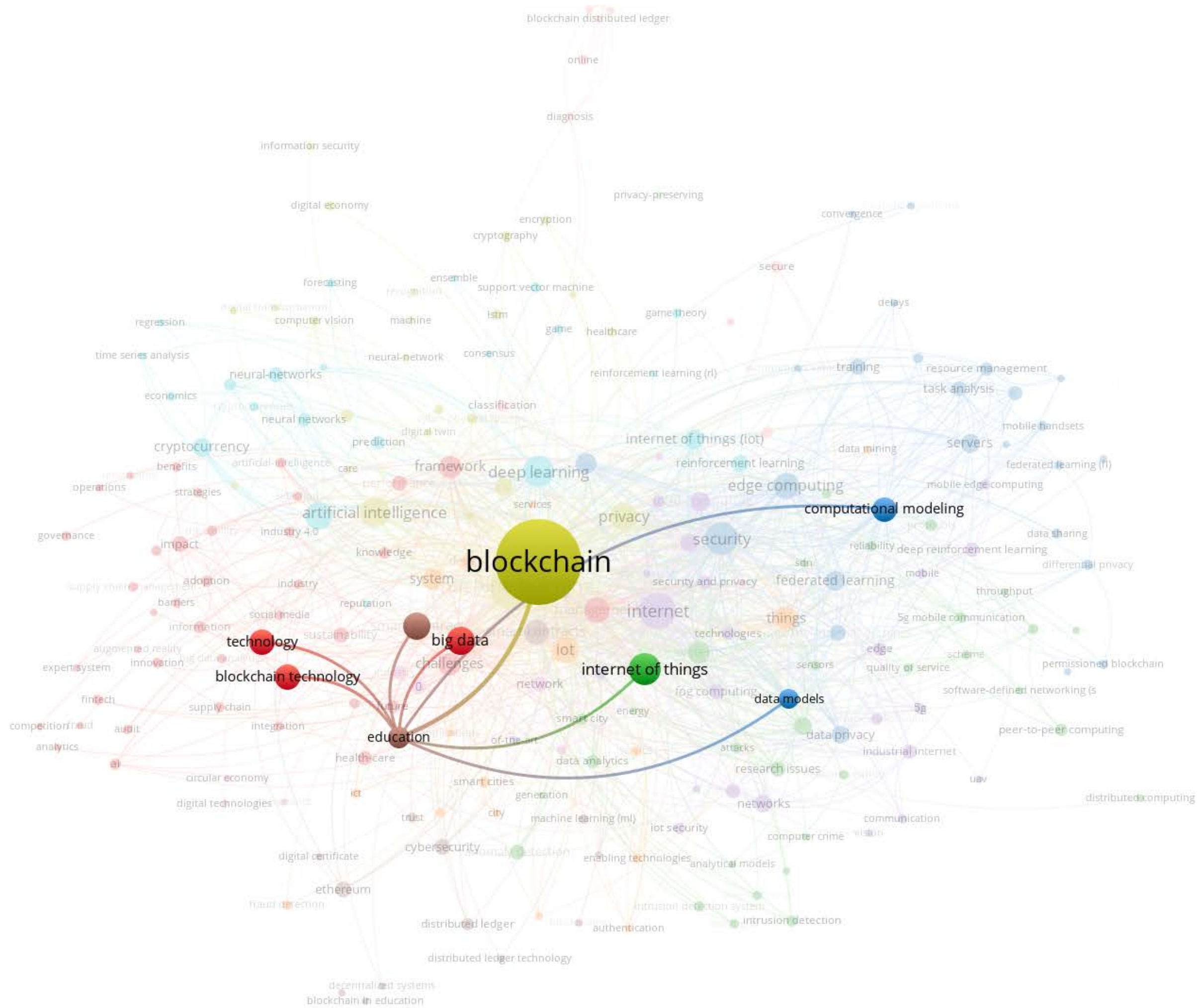

FIGURE 6. Keywords network analysis.

''information management'', and ''internet of things'' leading with 25 occurrences each, other core terms that delineate the relevance of blockchain in education were found. For example, terms such as digital certificate (n=24), artificial intelligence (n=22), educational computing (n=20), digital storage (n=18), and authentication (n=17) were among the top 20 keywords found in articles on blockchain in education. In addition, the keyword analysis presented in Fig. 6 revealed that blockchain in education is closely linked to big data, data models, and computational modeling, which are key elements of blockchain implementation.

Fig. 7 revealed several clusters that depict the characteristics of the application of blockchain technology. For example, we can see the connection between blockchain and decentralization, certificate contract, verification, trust, validity, accountability, ubiquitous, etc. In addition, Fig. 8 provides more detailed information on the authors' keywords analysis between 2019 to 2021. Blockchain being at the center of the keywords is connected to business, finance, administration, and multimedia. However, more keywords linked to education can be seen in the period under consideration compared to the previous years. For example, keywords such as students diploma, certificate, grading, and courses only

TABLE 4. Keywords analysis - most relevant words.

Words	No. of Occurrences
blockchain	222
engineering education	50
students	40
higher education	33
e-learning	25
education	25
information management	25
internet of things	25
digital certificates	24
artificial intelligence	22
education computing	20
digital storage	18
authentication	17
information systems	17
information use	16
network security	16
learning systems	15
big data	14
health care	13
supply chain management	13

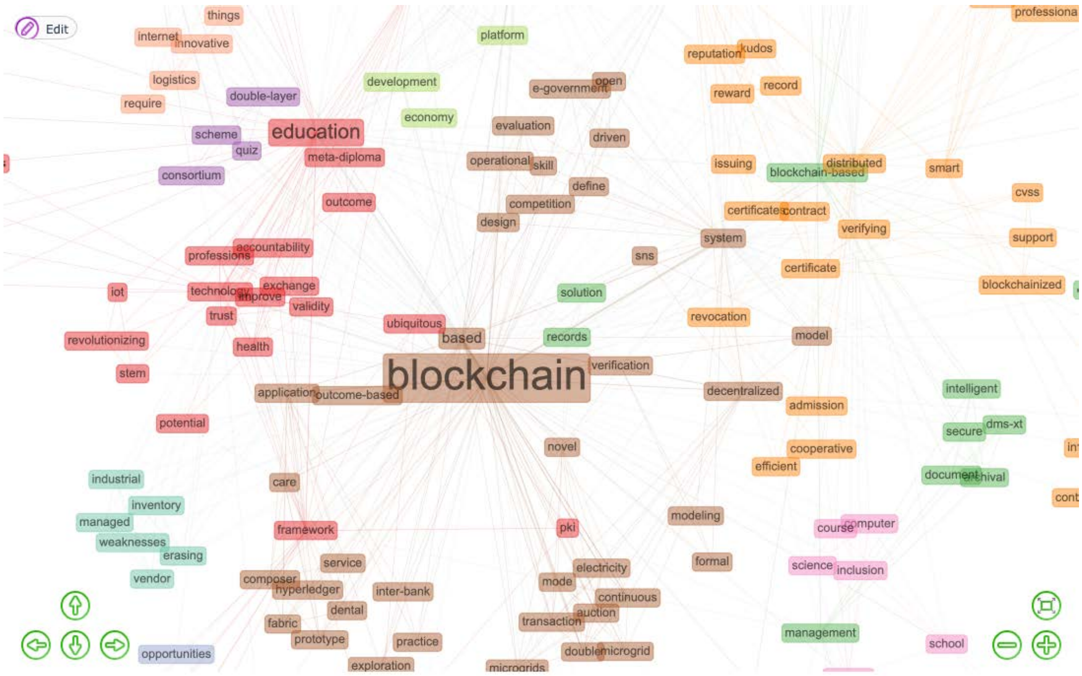

FIGURE 7. Keyword network analysis 2016 - 2018.

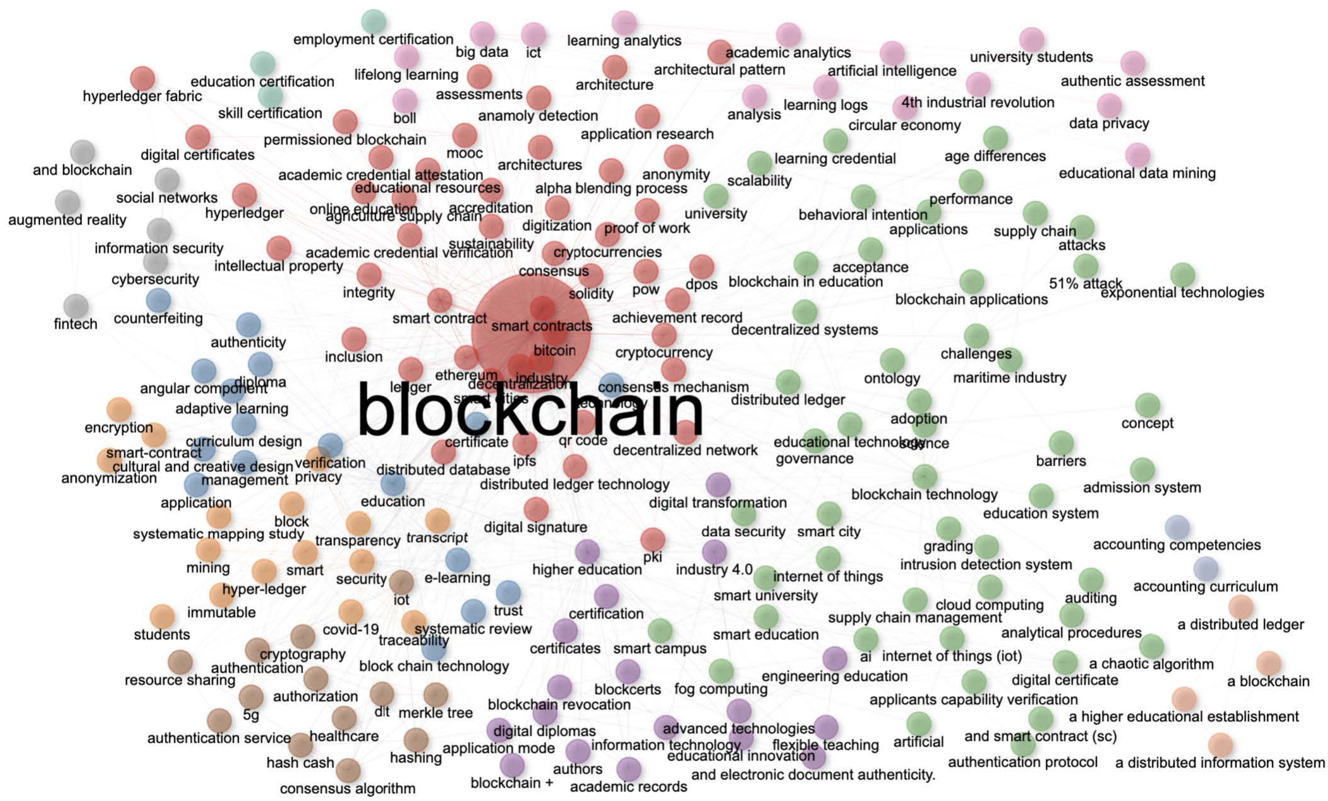

FIGURE 8. Keyword network analysis 2019 - 2021.

emerged recently. This finding depicts that blockchain adoption in education is gaining ground in recent times, but, its application in other domains such as finance and commerce is still dominant.

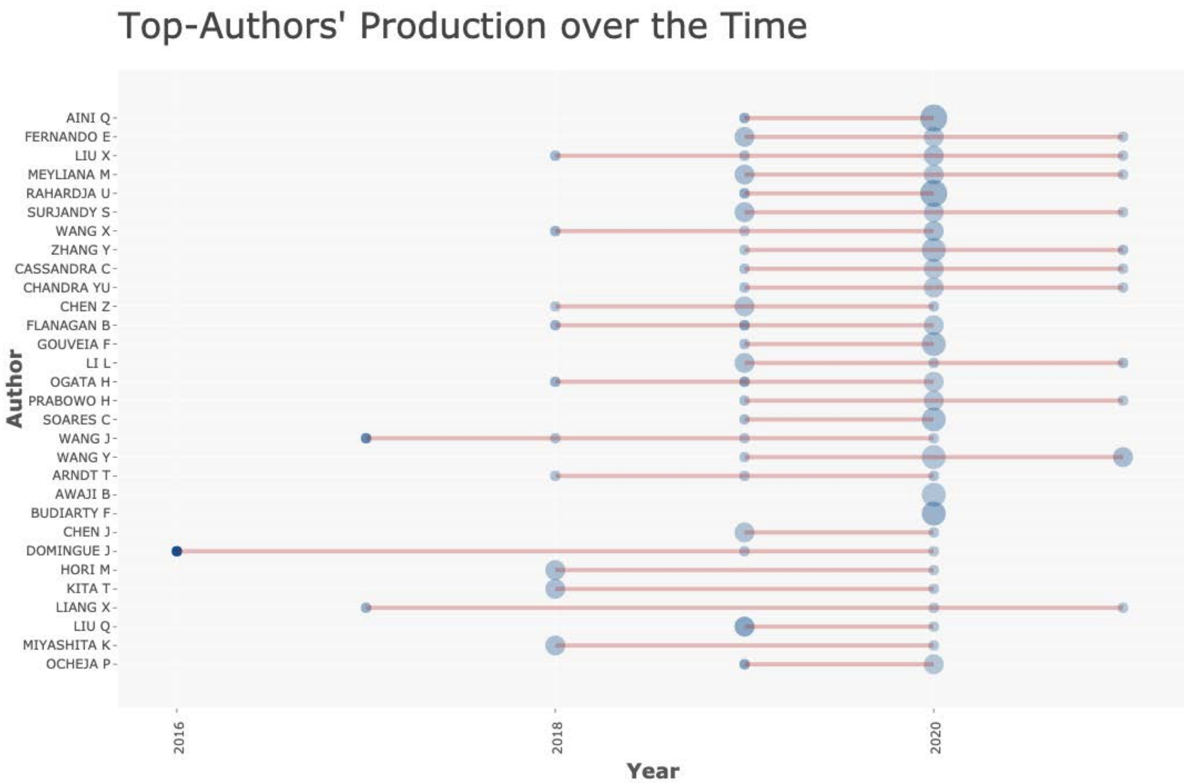

FIGURE 9. Author's citation.

4) AUTHOR ANALYSIS

The authors' analysis aims to investigate scholars promoting blockchain in education by publishing scientific articles. The analysis between 2016 to 2021 in Fig. 9 revealed the top 20 authors with the most citations with Aini Q. ranking first. Aini's first paper on blockchain in education entitled ''Design framework on tertiary education system in Indonesia using blockchain technology'' was published at a conference proceeding in 2019. Afterwards, this author published several papers in 2020 and some were hopefully prepared for publication in 2021 when the data was collected. The author with a long history of contribution is Domingue J. whose first publication appeared in 2016 followed by 2019 and 2020, respectively. Other prolific scholars found in the top 20 authors are listed in Fig. 9, showcasing the number of articles and their history of publication per year.

Regarding authors' collaboration network, Fig. 10 shows the visualization of collaborative networks existing between authors. The result revealed two kinds of networks: (1) a network of collaborators where each author within the network establishes equal link and weight, and (2) a network where an author dominates and influences other collaborators. An example of the first case is the network between Fernando E., Prabowo H., Surjandy S., Cassandra C., and Chandra Y. Similarly, Ogata H., Flanagan B., Oyelere S., and Ocheja P. also exhibited the kind of network with equal weight. On the other hand, both Wang J. and Wang Y. exhibited a collaboration network of type (2) and influenced other researchers in their network as shown in Fig. 10. This shows that scholars try to address certain educational problems by bringing together different expertise in blockchain and education, however, the collaboration effort is still minimal.

5) COUNTRY ANALYSIS

This study further investigated contributions made by countries and institutions in advancing blockchain in education. While Fig. 11 shows top 30 countries advancing research on blockchain in education based on the number of articles published, Fig. 12 presents the top 20 countries' impact based on their citation counts. It can be seen that China is leading in terms of article production whereas the USA ranks first in the citation count implying that articles from the USA put together have more impact than those from China. Also, it is interesting to see that Slovenia whose number of publications is very small and came 28th out of the 30 top countries gained huge citations (n=155), and came 3rd among the top 20 countries after Spain based on citation analysis as shown in Fig. 12. It is worthy of note that only Slovenia and India have published articles with multiple countries publication (MCP) status. In addition, the result also shows that countries such as Mexico, New Zealand, Pakistan, and Singapore that could not feature among the top 20 countries in terms of the number of articles, received citations that qualified them

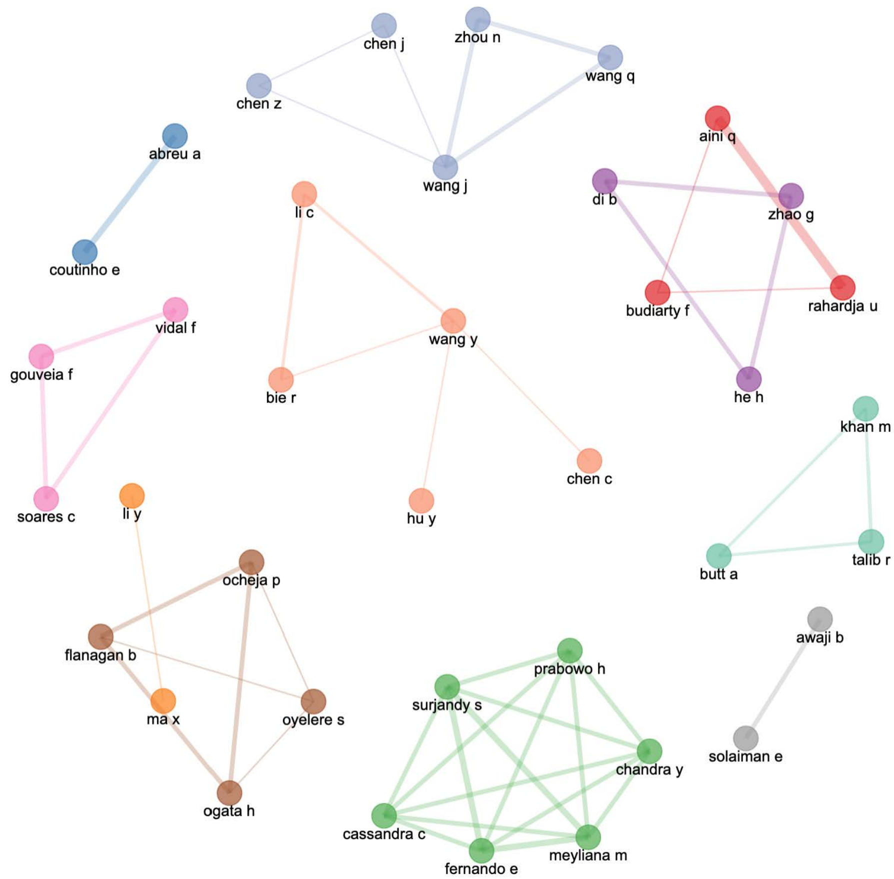

FIGURE 10. Author's collaboration network.

to belong to the 20 most cited countries on blockchain in education.

The result of the most relevant affiliations presented in Table 5 shows that the University of Raharja in Indonesia tops the list. This university is widely known for its recent study on seeking how to transform the educational landscape with blockchain technology championed by scholars such as Qurotul Aini and other colleagues. Other affiliations visible in the analysis include Beijing Normal University in China, Kyoto University in Japan, Bina Nusantara University in Indonesia, and Kennesaw State University in the USA. From Europe, the University of Barcelona in Spain is one of the learning affiliations.

TABLE 5. Most relevant affiliations.

Countries	No. of Documents
University of Raharja	16
Beijing Normal University	7
Kyoto University	7
Bina Nusantara University	6
Kennesaw State University	6
University of Barcelona	5
Covenant University	4
Jeju National University	4
Bryansk State Tech Univ. of Eng.	3
Buda University	3
Chongqing University	3
Cleveland State University	3
Federal Univ. of Santa Catarina	3
Government College University	3
Khalifa Univ. Sci. and Tech.	3
Nanyang Tech. Univ.	3
Near East University	3
Newcastle University	3
Not Reported	3
Palestine Tech. Univ. Kadoori	3

B. CASE STUDY IMPLEMENTATIONS

The results from our content analysis carried out by a full paper read revealed that very few papers could provide answers to some of the research questions. For example, out of the 44 papers selected to answer RQ2 and RQ3, only 5 papers had a working solution, only 1 paper integrated with an existing LMS, and one other paper proposed a new LMS along with its blockchain implementation. Our analysis also showed that most of the research efforts on blockchain in education have been focused on certificates and did not necessarily require integration with existing learning tools as the systems were built independently. Consequently, we conducted a case study analysis on 2 papers to provide concrete answers to the questions posed in RQ2 and RQ3. These two

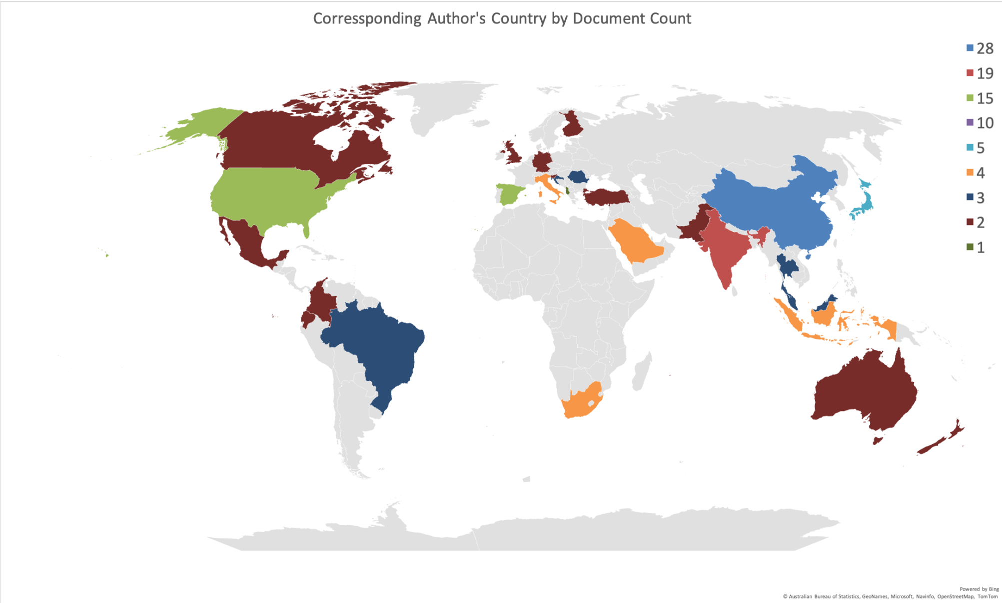

FIGURE 11. Most relevant countries.

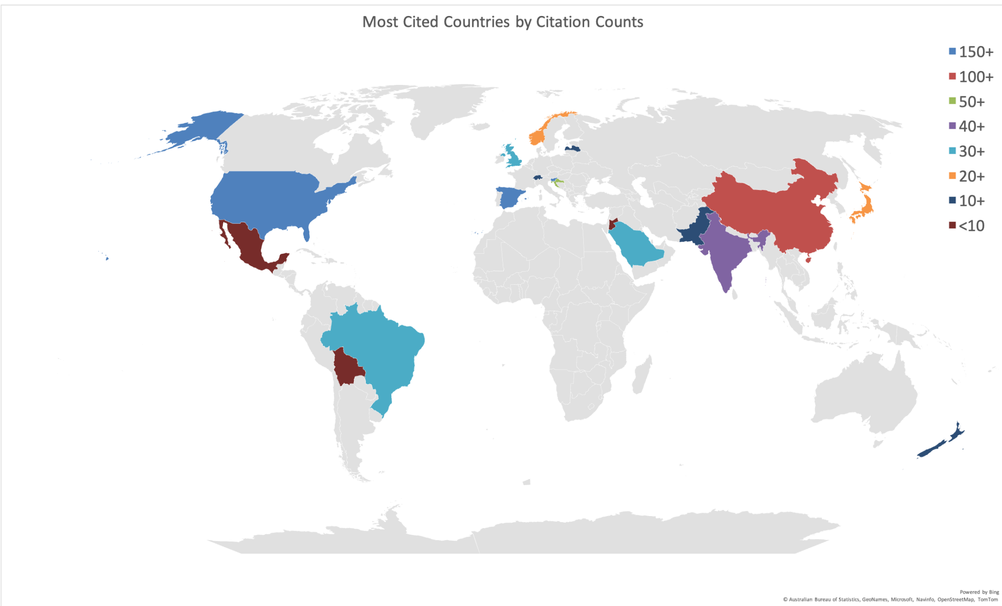

FIGURE 12. Most cited countries.

papers proposed the systems: Smart Ecosystem for Learning and Inclusion (SELI) platform [42], [43] and the Blockchain of Learning Logs (BOLL) platform [7], [44]. What follows is a discussion of these two works and how they address RQ2 and RQ3.

1) INTRODUCTION OF THE CASE STUDIES

Project 1: The SELI platform provides the teachers and learners with an environment that supports the different needs for successful learning based on an inclusive and constructivist model of education. SELI platform supports the teacher to create online courses with the authoring tool and manage the courses in the learning management system, which complies with conventional instructional design principles [42], [43]. For example, the teacher applies a three-step process based on pedagogical principles to create a course using the authoring tool. The tool provides the teacher the flexibility to decide and include varieties of pedagogical content that are suitable for a specific learning context and received a personalized report of the student's progress [45].

The SELI platform adopts emerging technologies such as blockchain (for skills and credential management) and pedagogical techniques such as digital storytelling, flipped learning and educational games to ensure individualized learning and instruction.

Project 2: The Blockchain of Learning Logs (BOLL) project is focused on developing connected lifelong learning logs on the blockchain [7], [13], [46], [47]. In the initial specification, Ocheja *et al.* [13] proposed the BOLL framework as a blockchain platform for connecting the learning logs of students when they change school. The primary objective of the framework is to solve the cold-start problem and improve learning analytics for students who face numerous challenges when adapting to a new learning environment. The BOLL system has different kinds of data such as the schools a student has previously enrolled in, the courses taken and grades obtained, granular data and logs of student interactions on various learning tools, derived insights from data, and learning contents including books, slides, quizzes and their solutions. Students can use the BOLL system to decide who can access this information.

2) LEARNING TECHNOLOGIES BEING DEPLOYED WITH THE BLOCKCHAIN

The architecture of the SELI platform is based on three supporting infrastructure: blockchain, microsites and analytics. The SELI platform was designed and implemented from the scratch, it comprises of a new learning management system (LMS), and an authoring tool (AT). LMS as a web application was implemented for the automatic creation, management, administration, documentation, tracking, reporting, and delivery of learning activities, tasks and courses. Learners can have the ability to view, listen, and interact with the learning contents. The AT comprises features that support the teacher to implement the courses by planning the proper content and activities with special requirements for inclusion. It assists teachers to create accessible didactic materials and allows sharing, instruction, guidance, and feedback, according to standardized web content and authoring tool accessibility guidelines [48], [49]. The platform also has a learning analytics supporting infrastructure comprised of a descriptive analytics dashboard that enables students and teachers to gain an understanding of learning progress.

To answer RQ3, the BOLL project connects with tools such as the Moodle LMS, A digital ebook reader called BookRoll, Learning Locker (a learning record store), a learning analytics dashboard and the BOLL system. The Moodle LMS serves as the main entry point. When a student enrols in a course for the first time on the LMS, a new account is created for them on the blockchain. For each student account created on the blockchain, the blockchain address of the student, their student ID at the current school (Moodle ID) and their current school's blockchain address are written to a smart contract for future reference. When a student change school, they can re-use their previously created account at their new school and link their student ID at the new school and the new school's blockchain address in the same smart contract registry. For example, If Alex has enrolled in two different schools on the BOLL network, the following entries in Fig. 13 will be created in the smart contract. While the student ID may change across schools, their blockchain address (Decentralized ID - DID) remains the same. The communication interface between the LMS and the blockchain (BOLL system) is implemented using Learning Tools Interoperability (LTI) Application Programming Interface (API) and Secure Box within the BOLL system [7].

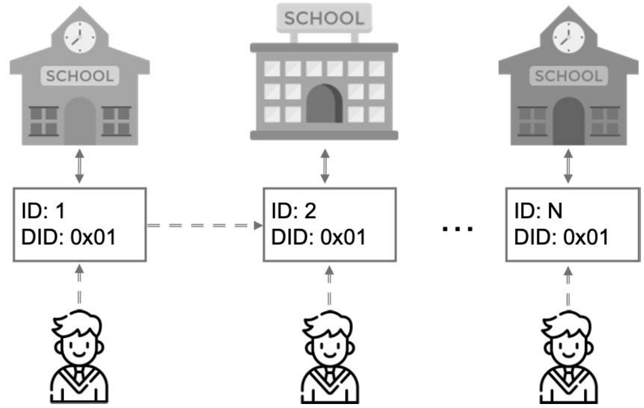

FIGURE 13. Example identity handling on BOLL.

3) RULES SPECIFIED AND USED TO VALIDATE AND REPORT ACADEMIC CREDENTIALS

The decentralized, distributed characteristics of blockchain, and the opportunity to run smart contracts give it an edge to be implemented in the SELI project. The Blockchain component in the SELI platform aims to connect all microsites in a blockchain structure so that all transactional aspects are intended to be dealt with in a distributed manner, such as authentication, course accreditation, and micro-certification of students. SELI already has a blockchain network of four nodes, located in Ecuador, Finland, Turkey and Uruguay. This network will allow that after the completion of a course, the certificates are generated and stored as smart contracts and non-monetary transactions in SELI's private Ethereum blockchain network. The SELI platform also promotes the use of blockchain by supporting open communities and storytelling services (SELI Digital Storytelling) as a tool for social interaction. The SELI Digital Storytelling service is already implemented and is under evaluation among teachers from the different countries of the project [50]. SELI blockchain implementation offers badges for skill and learning achievements. A student may receive a badge of Digital Storytelling Creator in the sustainable development course. The same student may also receive a badge of Digital Storytelling Creator in the Information and Communication Technology (ICT) for Education course. The system resolves that the student has 2 badges of Digital Storytelling Creator and in their profile, both badges indicate details of the courses identified with different hashes and this is reachable with Quick Response (QR) codes.

With respect to RQ2, the rules for validating and reporting academic credentials and lifelong learning logs on the BOLL system are encoded in the smart contracts deployed on the network. These rules include:

1) Check that a school is rightly approved on the consortium blockchain to mine transactions (Proof of Authority (PoA) consensus algorithm)
2) Check that a school is rightly approved to write or read records of their students and other students who have permitted them.
3) Ensure that lifelong learning logs written to the blockchain are resulting from learning interactions within a learning tool (direct read from a Learning Record Store (LRS) to the blockchain).
4) Verify that a student or their school has authorized any data copying operation by verifying the signatures appended to data copy requests.
5) Ensure students' data are rightly catalogued in their own smart contract by maintaining a lookup table on the blockchain.

4) ENABLING INTEROPERABILITY, CONNECTING AND EXCHANGING INFORMATION WITHOUT CHANGE TO THE UNDERLYING TECHNOLOGY

The SELI platform supports interoperability by allowing partner institutes to set up an instance of the platform on-site and connect to the global network. The approach to interoperability here is basic and institutes practically use the same SELI system but different instances.

The BOLL project answers RQ3 by providing an implementation where schools can interface their existing learning tools with the BOLL network by using LTI and an experience API (xAPI) compliant record store such as Learning Locker. To do this, the BOLL system has a Secure Box component that can be pre-configured to stream data from the LRS as they are being emitted from learner actions on learning systems, process and encode them into blockchain specific format before writing to the blockchain. The BOLL system also provide endpoints that any party on the BOLL network can query to retrieve the full records of all data stored on the blockchain. These endpoints are protected from unauthorized access by requiring a signed message from the record owner or their institute. Thus, in the BOLL project, schools can connect and exchange information without making many changes to their current technology stack. Interoperability in the BOLL project is fostered by its requirement that learning logs that are written to the blockchain use a learning data specification format such as xAPI, Caliper, Sharable Content Object Reference Model (SCORM), etc. In the pilot implementation, the project demonstrated the use of logs in xAPI format [7]. Also, the use of LTI API for authentication and account creation procedures makes it interoperable with other learning tools.

V. IMPLICATIONS OF THE FINDINGS AND CONCLUSION

In this section, we discuss the implications of the findings from this work and how we can advance the research on blockchain in education.

A. AN EMERGING FIELD

The use of blockchain in education continues to gain popularity since its first occurrence five years ago. The analysis from this research showed how the qualities of the blockchain have been used to solve various challenges in education including certificate issuing and verification [51], [52], credits validation and transfer [53], [54], [55], and connecting lifelong learning [7], [56], [57]. While these efforts are notable, the results from the thematic evolution analysis showed that most of these use-cases have relied mainly on the transaction aspects of the blockchain. For example, certificate issuing and verification mainly checks for an exact match between hashes stored within a blockchain transaction. We propose that other attributes such as links between transactions (as seen in [58]), negotiation and consensus mechanisms, rewards and penalties, and other behaviours of peers on a decentralized network be harnessed as well. For example, it is possible to use smart contracts as negotiation tools between learners and teachers to ensure non-tampering and transparency of learning goals and objectives. The SELI project is a good example of one of the few works that provided such functionality.

B. A COMMUNITY FOR EDUCATION BLOCKCHAIN RESEARCH

From the bibliometric analysis of authors and publication details, we observed that most works on blockchain in education have been published in venues whose core focus is not education research. One of the possible reasons for this could be the fact that most papers often had more technical aspects than empirical results relevant to teaching and learning. Thus, it becomes imperative for researchers in education to provide more empirical studies on the relevance and usefulness of education blockchain systems. Another probable cause of fewer publications in education centred journals is that the discussions on blockchain in education are yet to gain adequate attention in various research gatherings. The authors' analysis also showed very few collaborations across networks. For instance, while most education conferences and journals may have special tracks or sub-conferences for discussions on Artificial Intelligence (AI) in education, we rarely see such special attention being given to blockchain in education. Forming interest groups and talk series on blockchain in education will play a crucial role in advancing the community to grow and contribute more research to the field. There is also a need to encourage the sustainability of projects on blockchain in education throughout their lifetime and ensure that the results of such projects are openly available to different stakeholders. For example, the scientific and technical results of the SELI project are open-source. Furthermore, forward-looking initiatives such as CHAISE [59] promised to generate an open, inclusive blockchain-based skills administrative system, which will deliver appropriate education and training, and address skill mobility and mismatches across different sectors.

C. INFRASTRUCTURE AND STANDARDS

Despite the blockchain being a decentralized technology, one observation about most papers on blockchain in education is that each work proposes or deploys its own blockchain network separate from others. We agree that it takes a great deal of effort and collaboration to have multiple researchers and institutes come together to adopt a single system. But, is this not the primary reason why a decentralized network is preferred over centralized systems? Here, we make a case that education blockchain research needs to begin conversations on how to standardize blockchains within the field ranging from core settings to smart contracts definitions and deployment. There is an ongoing effort by the International Standards Organization (ISO) Technical Committee (TC) ISO/TC 307 on the standardisation of ''blockchain and distributed ledger technologies''. The ISO/TC 307 is focused on addressing issues such as reference architecture, taxonomy and ontology, use cases, security and privacy, identity and smart contracts [10]. Similar initiatives that handle education-specific concerns are desirable for education blockchains. For example, the ISO/IEC JTC 1/SC 36 on information technology for learning, education and training – Learning analytics interoperability could also guide interoperability of blockchain in education.

One quick gain with the availability of such standards is interoperability: multiple parties can easily co-exist on the same network, interact and exchange information with less challenge of difference in standards as seen in other education systems like the LRS. The BOLL project is one of the few research moving in this direction. In its implementation, the BOLL system delegates the job of data standards compliance to the LRS and only provides extendable base smart contracts for various kinds of log data. Also, studies have shown that blockchain technology can connect and interlink different learning experiences through different learning platforms and modalities [57]. However, there is no common agreement among stakeholders to implement a fully decentralized blockchain in education.

D. CONCLUSION

In this research, we conducted a bibliometric and qualitative analysis of education blockchain research. Our bibliometric analysis revealed the current state of the field including the growth of research publications and citations, contributions from authors and various research communities, co-occurrence patterns and thematic evolution. This paper further showed that collaborations across networks and a community focused on blockchain in education research are still lacking. Our qualitative inquiry through content analysis showed that only a handful of papers provided a working solution or even integrated with a core learning system. Also, we found out that the use of blockchain to issue and verify academic certificates has gained more attention over the years compared to other use cases of blockchain in education. We presented two case studies: the BOLL and SELI projects that used the blockchain to address other education-specific needs different from certificates as well as the requirements for adopting blockchain in education. One of the breakthrough points of this work is the potential to use the distributed ledger technology to offer an easier transfer of academic records, traceability of learning data, inclusion, privacy and information security for learners. The emerging research themes discovered in the thematic evolution analysis allude to these types of applications. This further suggests the possibility for wider adoption of blockchain in education as more concerns of education stakeholders such as scalability, latency and throughput are addressed.

E. FUTURE WORK

While the research on blockchain in education is still emerging, it is important to lay proper foundations that can guide the field in the right direction. Hence, we recommend that future work on blockchain in education should address key issues such as the interoperability of education blockchains and learning systems in general through proper standardization. Also, it is important to continuously consider other possible areas in education that can be improved by using blockchain technology. Future systematic reviews can present how blockchain in education is used to support students' learning goals. Also, as the field is continuously evolving, periodic systematic reviews will be beneficial.

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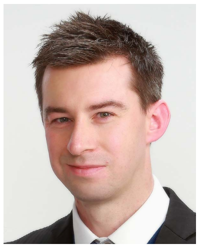

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