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PAPER

Blockchain Technology in Education: Opportunities, Challenges, and Beyond

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ABSTRACT

Blockchain technology has gained significant attention for its decentralized, secure, transparent, and immutable characteristics. It has been adopted in various domains, including the financial and education sectors. This systematic review provides a comprehensive analysis of the opportunities, challenges, and future educational prospects of blockchain technology by examining published research from various disciplines. A bibliometric approach was adopted using R Studio. Datasets were sourced from the Scopus database, which included Scopus-indexed articles from 2018 to 2022. The keywords “blockchain” and “education” were used to retrieve relevant articles. Specific criteria were applied to filter the literature sources, ensuring that our discussions focused on the applications and challenges of blockchain technology in education. We only considered articles written in English, specifically those published in proceedings and journals. The review identified that blockchain technology has the potential to transform education by enhancing data security, facilitating efficient verification and credentialing processes, and enabling peer-to-peer transactions. However, addressing challenges such as adoption, technical expertise, data privacy, security, and standardization is crucial. Therefore, the study concludes that implementing blockchain technology in education can yield significant benefits for future generations. These benefits include reducing the gap in global education and increasing transparency and accountability in the education sector.

KEYWORDS

blockchain, educational technology, emerging technology, digital, bibliometric

1 INTRODUCTION

Digital technology is constantly evolving, and disruptive innovations are emerging at a rapid pace. Some of the most exciting developments include extended reality and the metaverse, which are poised to revolutionize how we interact with digital content [1–3]. Additionally, blockchain technology, which utilizes distributed ledger technology (DLT), is poised to enhance a wide range of industries.

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Distributed ledger technology is a decentralized database managed by multiple participants and nodes, equipped with the necessary technological infrastructure and protocols to enable simultaneous access, validation, and record updating across a networked database [4]. Blockchain evolved from DLT, although there are some differences between the two. While DLT can be used privately and can have permissioned or permissionless access, blockchain is a public and permissionless technology [5]. As a distributed database or ledger among computer network nodes (Figure 1), it enables the recording and sharing of information across a community or peer-to-peer network, with each member maintaining a copy of the information. This makes transactions more transparent and secure, thereby minimizing acts of data misappropriation, such as bribery and corruption. Blockchain participants replace third-party intermediaries as the guardians of trust by utilizing cryptography and running complex algorithms to certify the integrity of the entire system.

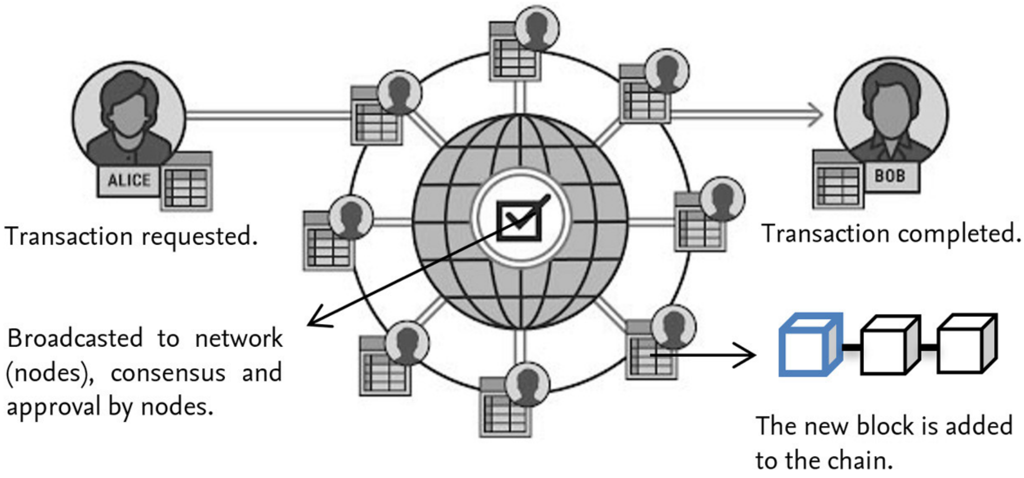


Fig. 1. Blockchain concept [6]

Mathematicians Stuart Haber and W. Scott Stornetta first outlined the origins of blockchain technology in a research paper titled "How to Timestamp a Digital Document" in 1991 [7]. Their proposal aimed to solve the problem of digital document tampering by creating a cryptographic system that verifies the date and time a document is created or modified.

In 1992, the incorporation of Merkle Trees into the design made the blockchain more efficient by allowing the collection of multiple documents into one block [8]. Nick Szabo designed "bit gold" in 1998, which was a decentralized digital currency mechanism considered to be a direct precursor to the Bitcoin architecture. In 2004, Hal Finney introduced a prototype for digital cash called Reusable Proof of Work (RPoW), which marked a significant early milestone in the history of cryptocurrencies. Blockchain technology gained widespread adoption with the release of Satoshi Nakamoto's white paper in 2008 [9], followed by the launch of the first cryptocurrency network, Bitcoin (BTC), in 2009. While Bitcoin is based on Proof of Work (PoW), many of the alternative coins that followed are based on Proof of Stake (PoS) or other types of mechanisms.

Today, blockchain technology powers various platforms such as Ethereum, Binance, Polygon, Solana, Cardano, and more (see Figure 2). It also supports decentralized finance (DeFi) applications (DApps), non-fungible tokens (NFTs), and smart contracts, facilitating secure and decentralized transactions without third-party interference [10–12].

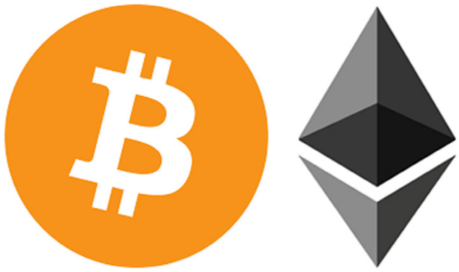


Fig. 2. Bitcoin and Ethereum icons

Blockchain technology has the potential to revolutionize educational processes, particularly in terms of data security, efficiency, and transparency [13], [14]. It may transform the traditional practices of educational credentialing and verification. However, for the technology to be successfully adopted, several issues must be addressed, such as adoption, technical expertise, data privacy and security, and standardization [15–17].

A systematic review of published research across multiple disciplines, including education, technology, and computer science, is warranted to address these pressing challenges and identify potential areas for further research and development. This study conducted a comprehensive and systematic review of the challenges and applications of blockchain technology in the education sector. The study specifically focused on trends, challenges, and opportunities. We employed bibliometric analysis as the research methodology, collecting data from the Scopus database, which includes academic journals and conference proceedings published over the past five years. The study identified the potential contributions of blockchain technology in various educational domains, such as credentialing, student records management, assessment, and academic research. Finally, the paper concludes by summarizing the key findings and discussing the implications for future research and practice in the field of blockchain technology in education. It emphasizes the need for more empirical studies to assess the substantive impact of blockchain technology on improving the quality and accessibility of education.

2 METHODOLOGY

This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a rigorous review process. We utilized both statistical methods and a bibliometric approach to obtain comprehensive results [18]. Bibliometric analysis is a popular and rigorous method for exploring and analyzing scientific data [19]. The web application Biblioshiny in R Studio combines the functionality of bibliometric packages with the user-friendly interface of the Shiny package environment. It was utilized for data gathering, analysis, and visualization. We also utilized Microsoft Excel for data management and visualization, which supported our analysis.

The review process comprised three stages: 1) data gathering, 2) data analysis, and 3) data visualization. However, guided by PRISMA, the process was more systematic and enhanced the reporting of this study. The strategies employed included determining specific research questions, keywords, criteria, and reliable sources of high-quality data; collecting data; screening and filtering data based on titles, abstracts, and discussions; analyzing data; visualizing data; and compiling reports and findings. A more detailed depiction of the review process is shown in Figure 3.

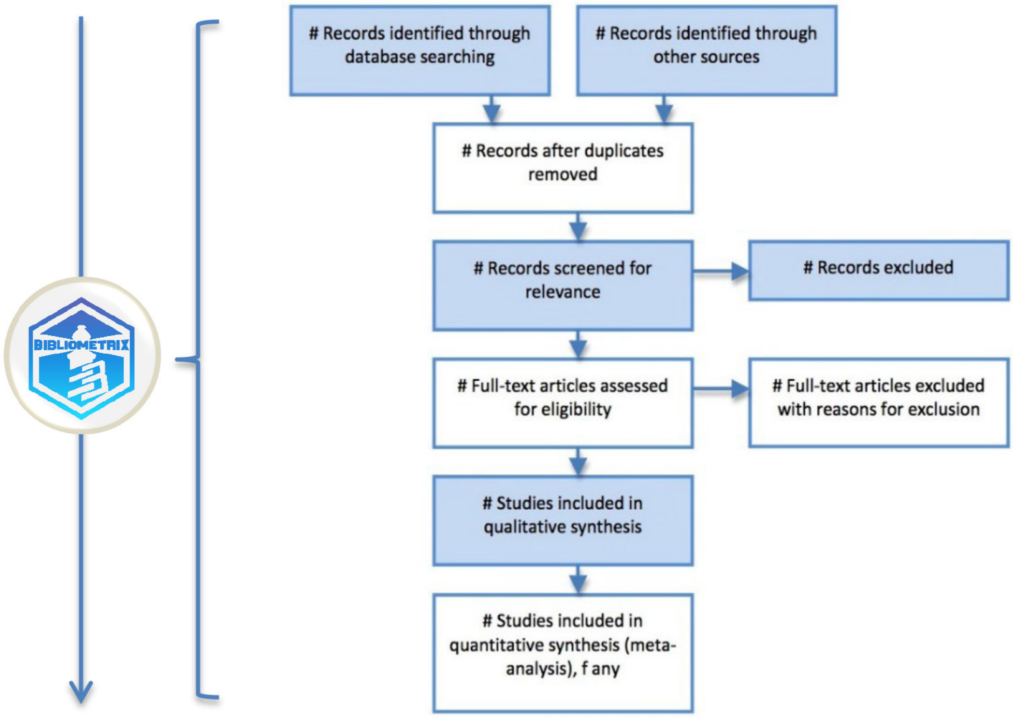


Fig. 3. PRISMA flow diagram

This paper reviews scholarly research publications related to the application and challenges of blockchain technology in the education domain from 2018 to 2022. We addressed the following research questions in this study:

1. How has research on blockchain technology in education developed between 2018 and 2022?
2. Which institutions, nations, and authors are the most prominent internationally?
3. Which journals and papers have had the most significant impact?
4. Which publications have received the most citations?
5. What are the research collaboration and authorship patterns?
6. What topics (trend analysis, keywords, pluses, and themes) are associated with this research field?
7. What are the applications and challenges of blockchain technology in education?

3 RESULTS AND DISCUSSION

3.1 RQ1: How has research on blockchain technology in education developed between 2018 and 2022?

The dataset used in this study was sourced from the Scopus database and imported into bibliometrics for filtering and extraction. As shown in Figure 4, the bibliographic metadata resulting from the dataset conversion was complete. It included important details such as author name, abstract, title, number of citations, and other relevant information necessary for finding, citing, or rating publications.

The completeness and accuracy of bibliographic metadata are essential for effective information management. This enables quick and easy access to relevant publications and facilitates accurate citation of sources, ensuring that authors and publishers receive the recognition they deserve. The standards for completeness and accuracy of bibliographic data depend on the guidelines set by the database provider or publisher, as well as the quality and consistency of the data entry process. Nevertheless, researchers must ultimately verify the accuracy of the bibliographic data before using it for research or any other purposes.

Metadata	Description	Missing Counts	Missing %	Status
AB	Abstract	0	0.00	Excellent
AU	Author	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
C1	Affiliation	20	6.15	Good
DI	DOI	43	13.23	Acceptable
DE	Keywords	64	19.69	Acceptable
RP	Corresponding Author	119	36.62	Poor
ID	Keywords Plus	138	42.46	Poor
CR	Cited References	325	100.00	Completely missing
NR	Number of Cited References	325	100.00	Completely missing
WC	Science Categories	325	100.00	Completely missing

Fig. 4. The completeness of bibliographic metadata

The bibliometric algorithm rated the following metadata elements: AB, AU, DT, SO, LA, PY, TI, and TC as "Excellent," C1 as "Good," and DI and DE as "acceptable." However, we found RP, ID, CR, NR, and WC to be either "poor" or "completely missing." As a result, we decided to exclude these elements from the subsequent analysis. The initial dataset consisted of 325 documents from 198 sources, including articles, books, book chapters, notes, and proceedings, with 813 authors (see Figure 5).

```
Documents    325  of  325
Sources      198  of  198
Authors      813  of  813
```

Fig. 5. Total documents, sources, and authors

Next, the total number of documents was filtered based on several criteria: 1) English language documents; 2) open access availability; 3) journals and conference proceedings papers only; and 4) publication date between 2018 and 2022.

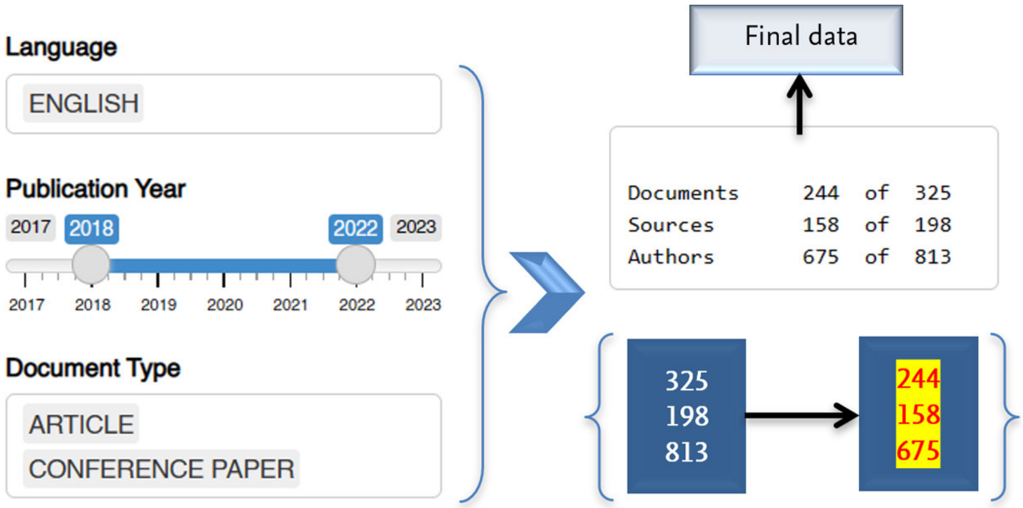


Fig. 6. Data filtering by inclusion and exclusion criteria

Based on the results of the data filtering, we can summarize the following information: 1) main information; 2) document contents; 3) authors; 4) author collaboration; and 5) document types. In the first section, we categorize the primary information based on the time period, sources, number of documents, annual growth rate, average age of documents, average citations per document, and references. Table 1 presents the summary statistics of the bibliometric metadata, considering 244 documents published between 2018 and 2022 that were used in this analysis. These documents emerged from journals, conferences, or proceedings, as described in Figure 6.

In addition, we included 675 authors, 38 single-authored papers, and 652 distinct keywords associated with the authors in the dataset. Furthermore, the data entries we collected only had a time attribute of publication year, and we conducted our trend analysis on a yearly basis. The published records comprised 675 authors and 244 documents, with the number of publications increasing from 12 in 2018 to 76 in 2022 (Table 1).

Table 1. Data results by main information

Description	Results
Timespan	2018:2022
Sources (journals, proceedings)	158
Documents	244
Annual growth rate %	58.64
Document average age	2.34
Average citations per doc	8.193
References	1
Keywords plus (ID)	1196
Author's keywords (DE)	652
Authors	675
Authors of single-authored docs	38

(Continued)

Table 1. Data results by main information *(Continued)*

Description	Results
Single-authored docs	38
Co-authors per doc	3.23
International co-authorships %	18.85
Article	96
Conference paper (proceedings)	148

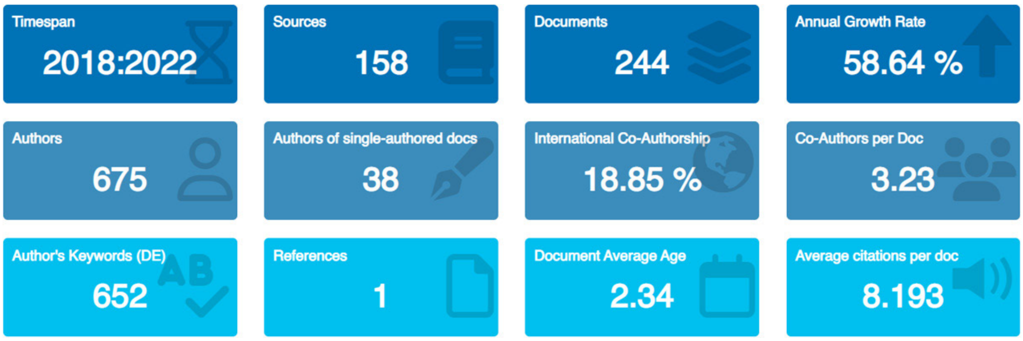


Fig. 7. Main information

Figure 7 shows that the annual growth rate of publications on blockchain technology in education experienced a significant increase from 2018 to 2022, with a yearly growth rate of approximately 58.64%. Evidently, over the past few years, researchers have continuously increased their focus on blockchain and its relationship to education. In 2018, there were 12 articles on the topic, which doubled in 2019 and reached its peak in 2022 with 76 articles. Figure 8 depicts the steady growth and evolution of research trends on this new technology.

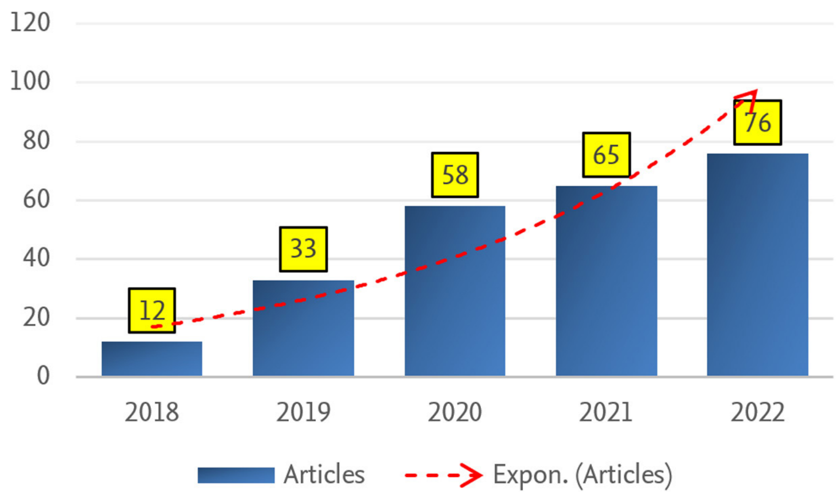
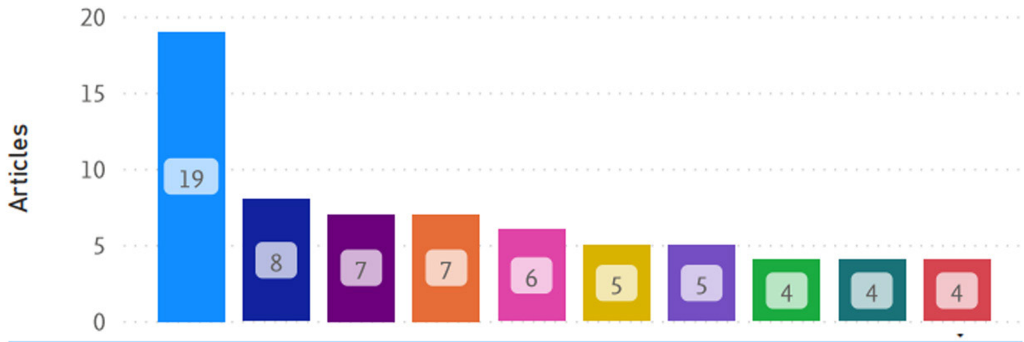


Fig. 8. Annual scientific production

In the analysis presented in Figure 9, researchers found that the most commonly used publication outlet for research on blockchain in education was the *ACM International Conference Proceedings Series*, with 19 articles. Following closely were the *Journal of Physics: Conference Series* (8 articles), *Communications in Computer and Information Science* (7 articles), *Lecture Notes in Computer Science* (7 articles), and *Sustainability (Switzerland)* (6 articles).



ACM International Conference Proceeding Series	19
Journal of Physics: Conference Series	8
Communications in Computer and Information Science	7
Lecture Notes in Computer Science	7
Sustainability (Switzerland)	6
Advances in Intelligent Systems and Computing	5
Lecture Notes in Networks and Systems	5
Computational Intelligence and Neuroscience	4
International Journal of Emerging Technologies in Learning	4
Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering	4

Fig. 9. Most relevant sources

3.2 RQ2: Which institutions, nations, and authors are the most prominent internationally?

Our analysis reveals the most prominent institutions and scholars researching blockchain from 2018 to 2022. Figure 10 shows the top 10 authors, with Aini Q. ranking first. Other prolific scholars in the top 10 authors are listed below, revealing the number of articles and their publication history over the years.

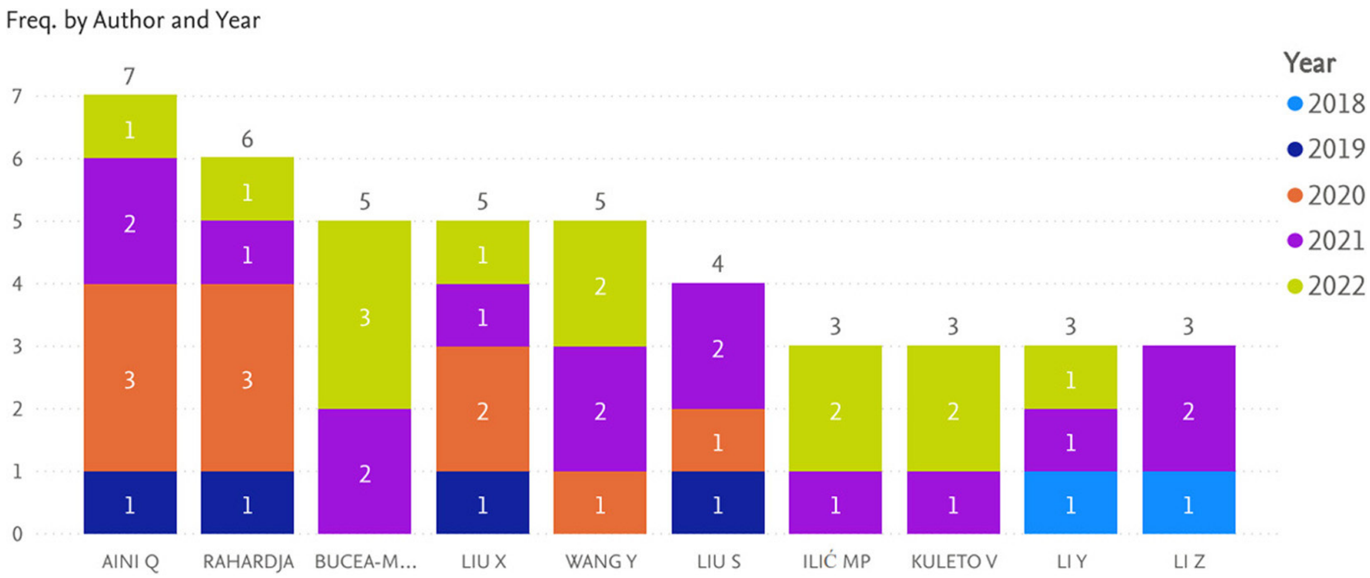


Fig. 10. Authors' production over time

Lotka's Law, also known as Lotka's Law of Scientific Productivity, is a pattern that describes the productivity of authors in a specific field of study. It is true that only a few authors will produce the most published work, while many will contribute only a minimal amount. Specifically, the law states that the number of authors who have published "n" papers is approximately equal to 1 divided by the square of n times the total number of authors in the field [20–22]. We can observe this pattern in Figure 11.

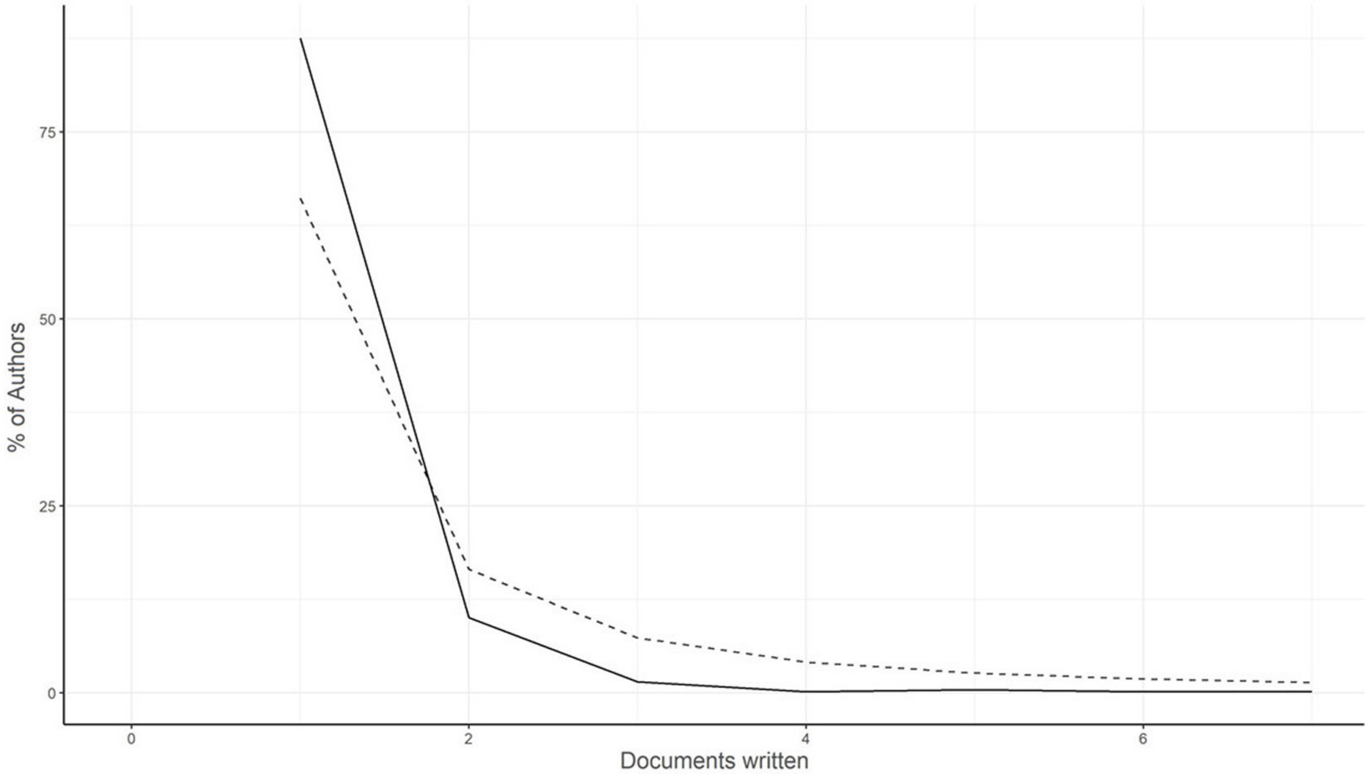


Fig. 11. Author productivity through Lotka's Law

Lotka's Law is an effective metric for researchers and information professionals, as it helps them understand the distribution of productivity in a specific field. This law can be helpful for these professionals in identifying the most prolific and influential authors, as well as evaluating the impact of research institutions and funding agencies.

In bibliometrics, the term "corresponding author's country" refers to the nation where the author, who is responsible for the communication and correspondence related to the research paper, is based. This information is typically found in the published article's metadata and is commonly used in bibliometric analyses to determine the paper's country of origin. Using the country of the corresponding author as a proxy for the study's country of origin is essential in bibliometric analyses that seek to investigate the scientific output and impact of various nations or regions. It also allows the identification of collaborations between researchers from other countries. However, it is important to note that many researchers collaborate with colleagues from other countries on research projects. As a result, the corresponding author's country may not necessarily reflect the country or countries where the research was actually conducted.

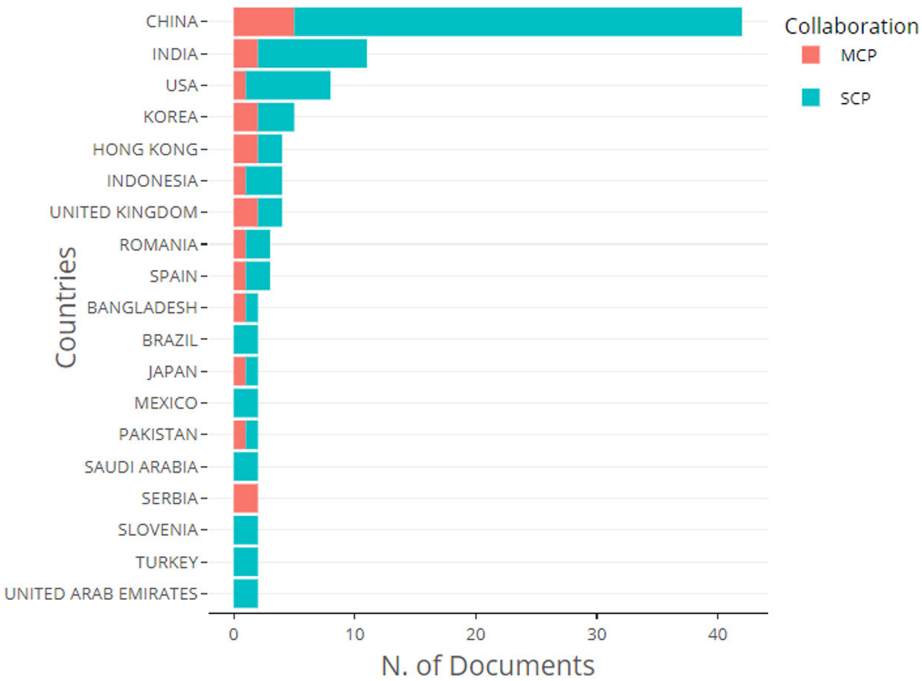


Fig. 12. Corresponding author's countries

Similarly, the country of the corresponding author may not necessarily correspond to the author's nationality or citizenship. In Figure 12, we can see that China is ranked first with 42 articles, out of which 37 were SCP (Scientific Communication Papers) and 5 were MCP (Medical Case Papers). SCP and MCP are two different models for understanding collaboration in research. SCP stands for "Single Country Partnership" and refers to collaborations between researchers from different institutions within the same country. SCP collaborations are often used as a proxy for domestic collaborations and can provide insights into the strength and productivity of the research community within a specific country. MCP stands for "Multiple Country Partnership" and refers to collaborations between researchers from different institutions in various countries. MCP collaborations are often used to examine the extent of international collaborations and can provide insights into the globalization of research. India has 11 articles, followed by the USA with 8, South Korea with 5, and Hong Kong and Indonesia with 4 each.

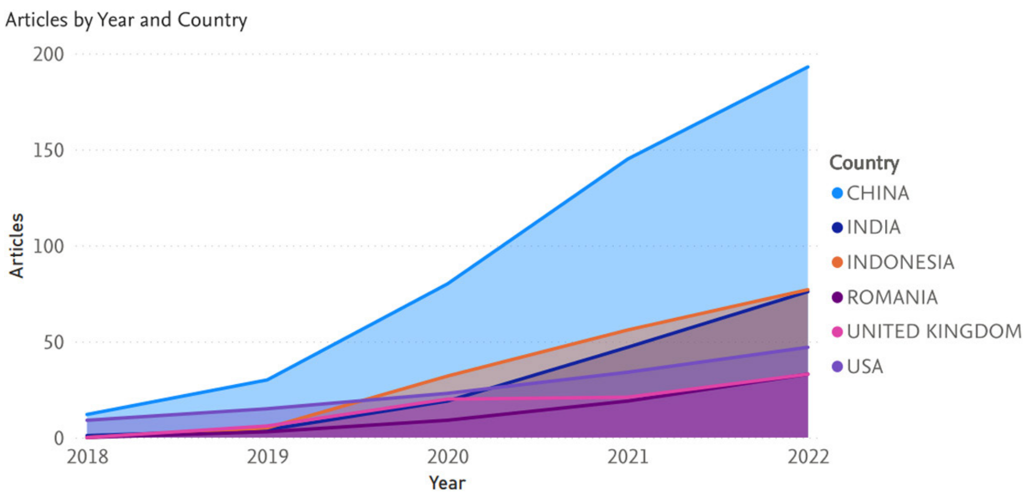


Fig. 13. Countries' production over time

We analyzed the number of publications attributed to each country for each year from 2018 to 2022. China had the highest publication output across all years, significantly increasing from 12 in 2018 to 193 in 2022. India had a lower output than China but steadily rose from 1 in 2018 to 76 in 2022. The USA had a relatively stable publication output, with a slight increase from 9 in 2018 to 47 in 2022. Indonesia and Romania had fewer works than other countries, but both showed an increasing trend over the years. In 2018, Indonesia had no publications, but in 2022, it had 77. Similarly, Romania had no publications in 2018, but in 2022, it had 33. The United Kingdom steadily increased its number of publications from 6 in 2019 to 33 in 2022, although its output was lower than that of China, India, and the USA (see Figure 13).

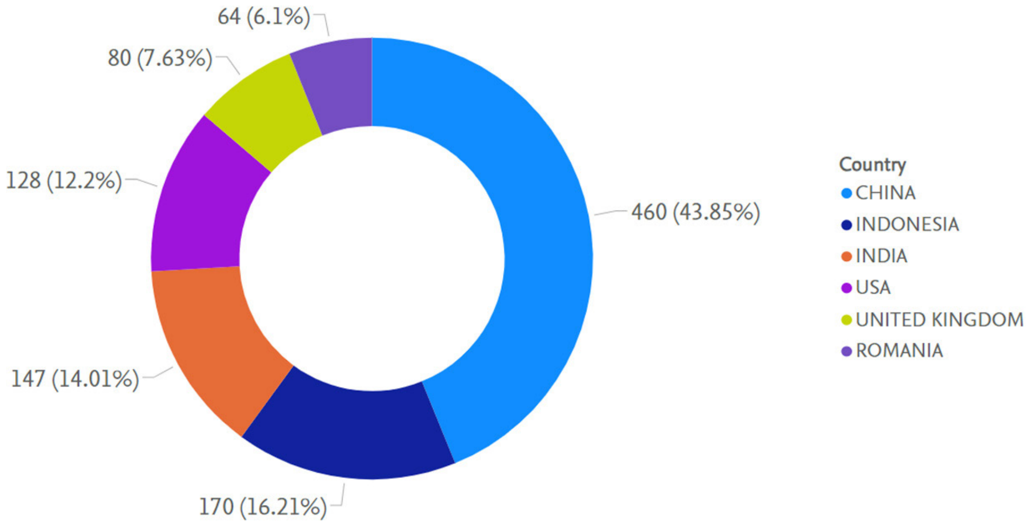


Fig. 14. Countries' production over time (cont.)

The total publication output for China from 2018 to 2022 is 460, for India it is 147, for the USA it is 128, for Indonesia it is 170, for Romania it is 64, and for the United Kingdom it is 80. From this data (see Figure 14), China is the leading country in research output over these five years, followed closely by India and the USA. Indonesia and Romania have lower publication outputs, but both countries demonstrate an increasing trend in research output. The United Kingdom shows a moderate, yet steady, increase in publications. Overall, the bibliometric data suggests that China, India, and the USA are the major contributors to research in this field.

3.3 RQ3: Which journals and papers have had the most significant impact?

We can assess the local influence of a source by using different bibliometric indicators, such as the proportion of publications published in the source, its citation impact, or the number of publications in comparison to other sources. As illustrated in Table 2, we measure the local effects of sources based on their total citations. This table presents academic data for ten journals and conference proceedings in the field of information technology and education. We can utilize bibliometric indices, such as the h-index, g-index, and m-index, to assess the impact and productivity of scholarly publications based on the number of citations they have received. Furthermore, the total number of citations (TC) and the number of publications (NP) provide a comprehensive overview of the impact and output of each journal. The “PYstart” column displays the year of the first publication of each journal.

Table 2. Sources’ local impact by total citations

Journals and Conference Proceedings	h_ind	g_ind	m_index	TC	PYstart
International Journal of Information Management	1	1	0.25	321	2020
IEEE Access	1	1	0.167	293	2018
Journal of Computing in Higher Education	1	1	0.25	98	2020
International Journal of Emerging Technologies in Learning	3	4	0.5	71	2018
Journal of Marketing Education	1	1	0.167	69	2018
Proceedings of the 19th Annual Sig Conference on Information Technology Education	1	1	0.167	64	2018
Journal of Higher Education Policy and Management	1	1	0.2	53	2019
Knowledge Management and E-Learning	1	1	0.167	42	2018
Communications in Computer and Information Science	2	6	0.4	41	2019
International Conference on Big Data and Smart City	1	1	0.2	39	2019

Overall, Table 2 highlights the diverse effects of each source. The *International Journal of Information Management*, *IEEE Access*, and the *Journal of Computing in Higher Education* have achieved an h-index and g-index of 1, indicating that their most cited article has received at least one citation. The *International Journal of Information Management* has the highest total citations (TC) with 321, followed by *IEEE Access* with 293, and the *Journal of Computing in Higher Education* with 98. Notably, all three journals were launched in recent years: the *International Journal of Information Management* in 2020, *IEEE Access* in 2018, and the *Journal of Computing in Higher Education* in 2020.

The *International Journal of Emerging Technologies in Learning* has the highest h-index and g-index of 3 and 4, respectively, indicating a higher impact than the other journals in the table. Additionally, it has the highest m-index of 0.5, indicating a higher proportion of highly cited papers. Despite this, the journal has the lowest total citation count of 71, and the NP is also relatively low at 4. It began publishing in 2018. The journals: *Journal of Marketing Education*, *SIGITE 2018: Proceedings of the 19th Annual SIG Conference on Information Technology Education*, *Journal of Higher Education Policy and Management*, *Knowledge Management and E-Learning*, and the *2019 4th MEC International Conference on Big Data and Smart City, ICBDSC 2019*, all have an h-index and g-index of 1. They have a total citation range of 39 to 69, and the number of publications ranges from 1 to 7.

These journals were first published between 2018 and 2019. *Communications in Computer and Information Science* has an h-index of 2, a g-index of 6, and an m-index of 0.4, indicating a moderate level of impact and productivity. This journal has a total citation count of 41 and the highest NP, with seven. We observed that it started publishing in 2019.

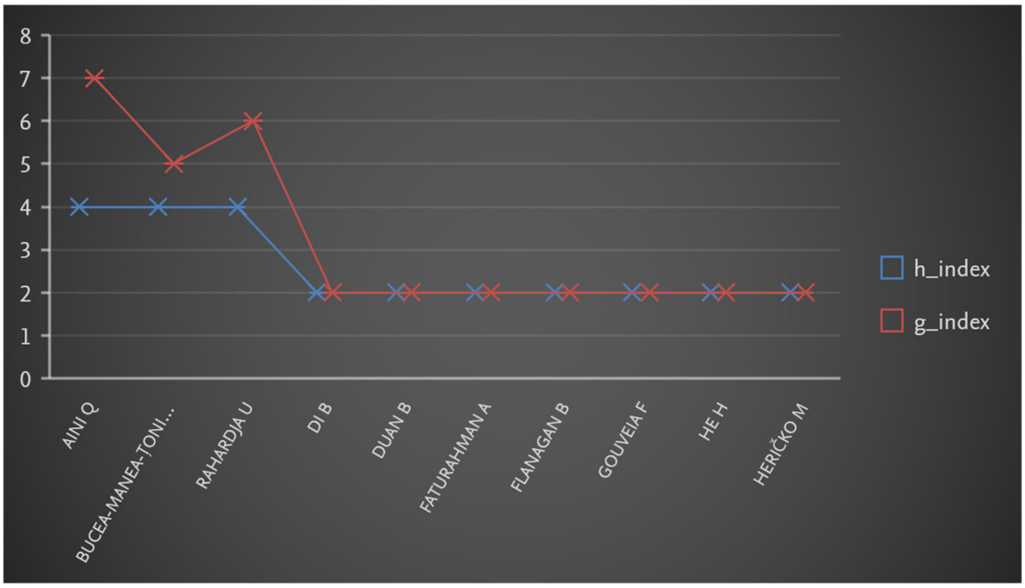


Fig. 15. Authors' local impact measured by h_index and g_index

Identifying influential local sources helps us understand the research landscape and support regional research. Figure 15 shows "Authors' local impact," which measures an author's recognition within their local academic community based on their publication count and citations from researchers in the same region.

Based on the data, AINI Q, RAHARDJA U, and BUCEA-MANEA-ȚONIŞ R each have an h-index of 4, indicating that they have individually published at least four papers that have received a minimum of four citations. However, AINI Q has the highest g-index of 7, indicating that their publications have had a higher level of impact, with several highly cited papers. Regarding TC, HERIČKO M has the highest number at 326, suggesting that their work has had a significant influence on their field. However, it is important to note that citation counts can differ depending on the field or topic of study and should not be viewed as the sole measure of an author's impact.

3.4 RQ4: What are the research collaboration and authorship patterns?

In Figure 16, we present information on the number of citations related to scientific articles from different countries. The data shows that the United Kingdom has a total count of 380 articles, with an average of 95.00 citations per article. Slovenia closely follows with 326 articles and an average of 163.00 citations per article. China has 123 articles with an average of 2.90 citations per article, while the USA has 108 articles with an average of 13.50 citations. Spain has 104 articles with an average of 34.70 citations, while Pakistan has 53 articles with an average of 26.50 citations. Japan has 44 articles with an average of 22.00 citations, while Brazil has 40 articles with an average of 20.00 citations. Serbia has 19 articles with an average of 9.50 citations, while Malta has 18 articles with an average of 18.00 citations.

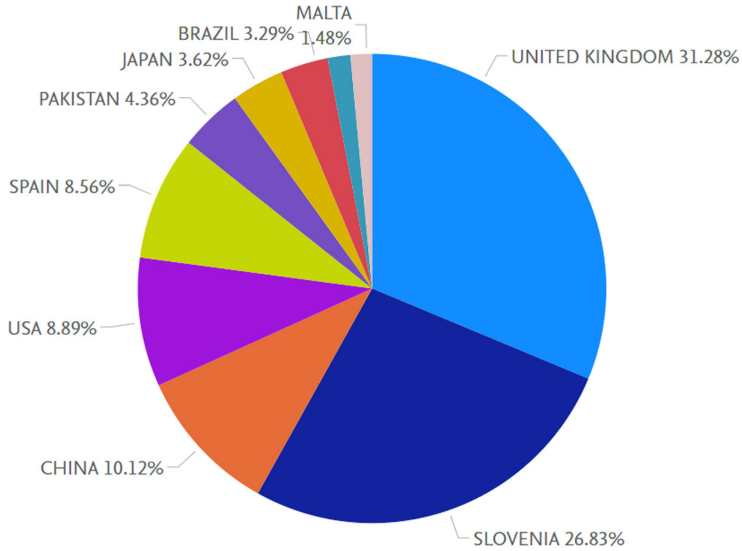


Fig. 16. Most cited countries by average article citations

Figure 17 presents data on the total number of citations received by papers from various academic journals and their average yearly citations. This dataset includes ten papers, with "DWIVEDI YK, 2020, INT J INF MANAGE" having the highest total citations (321) and average citations per year (80.25). "On the other hand, "YUMNA H, 2019, LECT NOTES COMPUT SCI" has the lowest total citations (37) and average citations per year (7.40)." The paper "DWIVEDI YK, 2020, INT J INF MANAGE" stands out as the most impactful, with a large number of total citations and a high citation rate. Notably, the two papers with the highest number of citations and average citations per year were "DWIVEDI YK, 2020, INT J INF MANAGE" and "TURKANOVIĆ M, 2018, IEEE ACCESS," with 80.25 and 48.83, respectively. This indicates that these papers have had a sustained and significant impact. By contrast, papers like "YUMNA H, 2019, LECT NOTES COMPUT SCI" have received fewer citations and are cited less frequently. A paper's citation rate can be influenced by several factors, including the topic, quality, and relevance of the paper to the research community. Overall, the data indicates that "DWIVEDI YK, 2020, INT J INF MANAGE" and "TURKANOVIĆ M, 2018, IEEE ACCESS" have had a lasting impact, while the remaining papers in the dataset have had a lower impact.

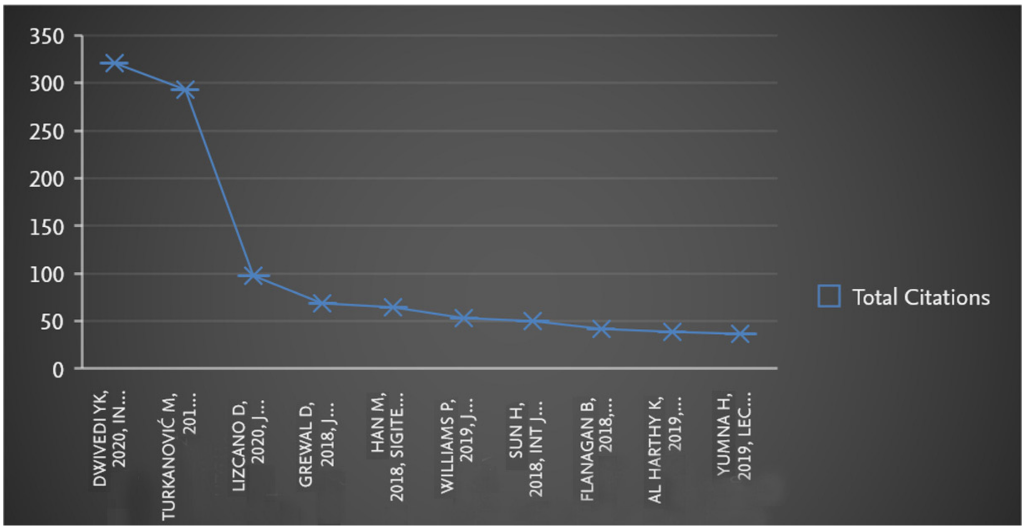


Fig. 17. Most cited documents

3.5 RQ5: What are the research collaboration and authorship patterns?

The data reveals the number of articles produced by various affiliations from different countries, including Indonesia, China, Slovenia, South Korea, and Romania. The University of Raharja, located in Indonesia, produced the highest number of articles, with 13 publications. Following closely were Beijing Normal University, Bina Nusantara University, East China Normal University, the University of Maribor, Zhengzhou Normal University, Jeju National University, the Chinese University of Hong Kong, the University Business Academy in Novi Sad, and the University Politehnica of Bucharest, each generating between six and nine articles (see Figure 18).

It is important to note that the data only provides information on the number of articles produced without indicating their quality or impact. Consequently, further analysis is needed to assess the relevance and impact of these publications. Additionally, the data only covers a specific period and may not accurately represent the long-term research output of these affiliations (see Figure 19).

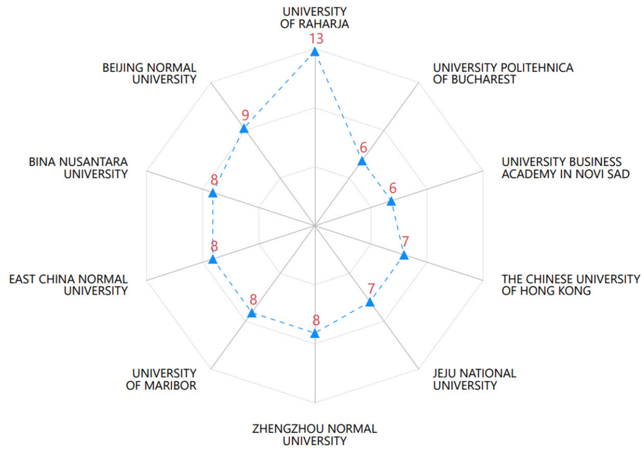


Fig. 18. Most relevant affiliations

Fig. 19. Collaboration network

3.6 RQ6: What topics (trend analysis, keywords, pluses, and themes) are associated with this research field?

The term "blockchain" appears most frequently in the data, with 161 occurrences, followed by a similar term, "blockchain," with 65 occurrences, likely referring to the same or related concepts. These findings suggest that the data may be related to technology and digital tools used in cryptocurrency and other digital transactions. Additionally, the terms "engineering education," "e-learning," "students," "higher education," "education computing," "information management," "digital storage," and "high education" are present with frequencies of 46, 44, 40, 26, 22, 19, 18, and 16, respectively. These terms indicate a potential focus on the use of technology in educational settings, student experiences, university settings, and educational administration and organization (see Figures 20 and 21). However, without additional information, it is unclear how relevant the less familiar terms are.

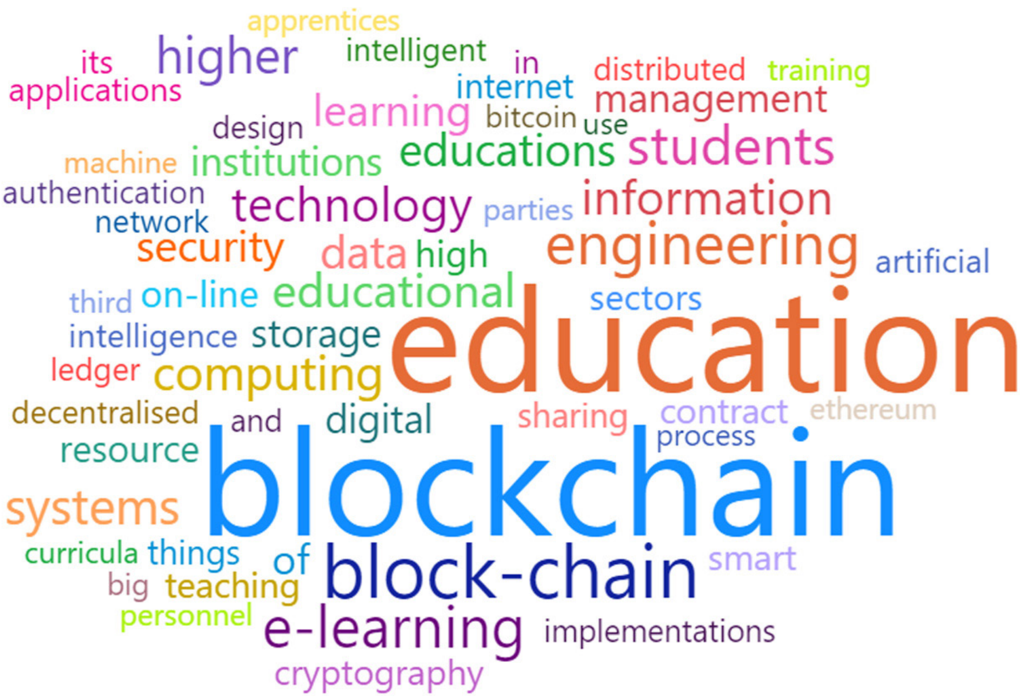


Fig. 20. Word cloud showing the most frequent terms

The data shows the frequency of occurrence of various terms across different years, with "blockchain" and "block-chain" appearing consistently throughout all years. There is a notable increase in frequency from 2018 to 2022. In 2018, "blockchain" appeared six times; however, in 2022, it appeared 161 times, indicating a significant increase in interest in this field. Furthermore, the frequency of "engineering education" and "e-learning" increased from 2018 to 2022, indicating a growing interest in utilizing blockchain technology in digital and engineering education (see Figure 21).

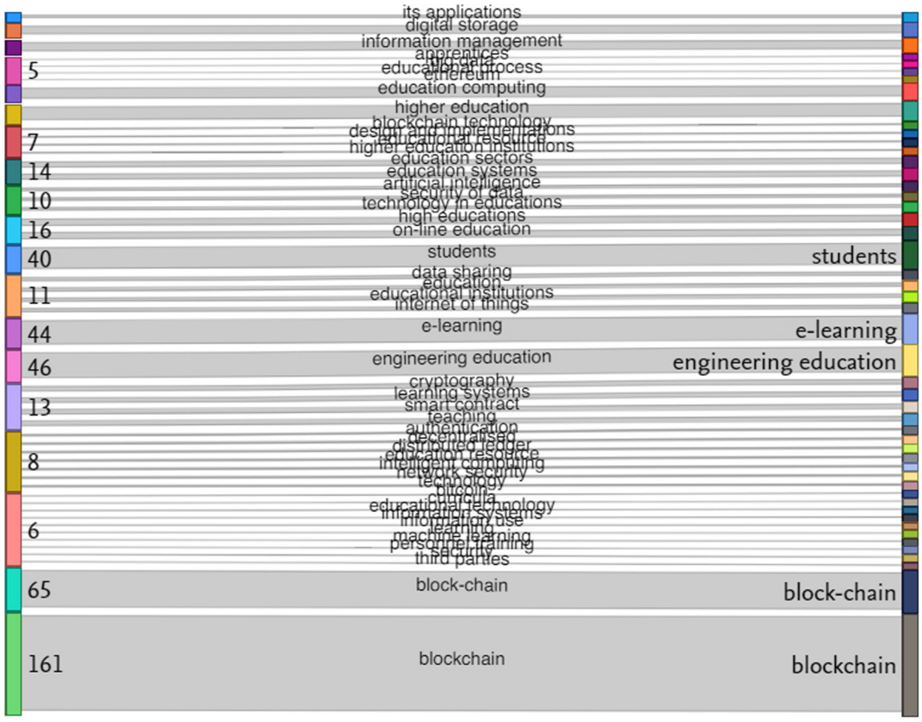


Fig. 21. Most frequent terms in percentage

Additionally, the number of "students" has increased over the years, which likely indicates a growing emphasis on learner experiences and outcomes associated with the use of technology in education. The terms "higher education," "education computing," and "information management" have maintained a relatively consistent frequency over the years, with a slight increase in 2020 and 2021. On the other hand, the terms "digital storage" and "higher education" appear less frequently and maintain a relatively stable frequency over the years. The data suggests a growing interest in blockchain technology and its application in education, as well as a general rise in the use of technology in educational settings over time.

3.7 What are the applications and challenges of blockchain technology in education?

Blockchain technology has the potential to revolutionize the education sector by enabling secure and efficient sharing of educational data, improving the management of academic records, and providing a decentralized platform for educational transactions (see Figure 21). This potential aligns with the arguments of various scholars, such as Fernandes and Werner [23] and Ala [24], among others. Scholars believe that educational institutions can ensure the secure and efficient storage and sharing of sensitive student data by leveraging the cryptographic security and decentralization features of blockchain technology. Blockchain technology can help prevent data breaches and other security incidents, which is particularly relevant in an era where cyberattacks on educational institutions are increasing.

The applications of blockchain technology in education include credential verification, secure data sharing, decentralized learning platforms, and micro-credentialing. Credential verification can eliminate the need for centralized attestation authorities. At the same time, secure data sharing can offer a reliable platform for students, teachers, and institutions to exchange educational data, such as transcripts and diplomas.

Decentralized learning platforms can provide a distributed, peer-to-peer network for sharing educational resources and facilitating learning [25]. Finally, educational institutions and organizations can use blockchain to create and verify micro-credentials, which can demonstrate specific skills and competencies [15], [26–28].

Blockchain technology has the potential to transform how educational data is securely and efficiently shared. It can be used to create a distributed ledger system that enables secure storage and access to data for students, educators, and administrators. Blockchain could enable us to share educational data among multiple parties without relying on a central authority. The immutability of blockchain ensures data accuracy and integrity. Once someone enters the data into the system, it cannot be changed or tampered with. This feature ensures that all parties have access to the same, up-to-date information.

Moreover, blockchain provides a secure method for storing and sharing records and transcripts. The data is encrypted and difficult to access without the correct information [29], [30]. Additionally, blockchain can create a digital identity for students, storing their educational records and achievements while providing access to transcripts, certificates, and other important documents. This benefits both students and educators by providing a secure and efficient way to access and share educational data [16], [31–33].

Blockchain technology offers a decentralized platform for educational transactions, which includes securely storing data, digitally signing documents, processing payments, and managing authentication. It could revolutionize how educational institutions handle transactions and manage data. By creating an immutable and secure ledger, blockchain facilitates payments between academic institutions, streamlining processes, reducing transaction fees, and enhancing transparency in the educational system. Moreover, blockchain ensures the secure storage of student records and sensitive data, limiting access to authorized personnel only. It also enables digital signatures, document verification, and communication between educational institutions. Furthermore, blockchain reduces the risk of fraud and errors, thereby enhancing workflow efficiency.

Additionally, blockchain can manage authentication processes, enabling students and other stakeholders to securely access their accounts and educational resources. This helps to mitigate the risk of identity theft and unauthorized data access (see Figure 22). Experts believe that blockchain technology will play a central role in supporting the future development of the metaverse. The metaverse refers to a virtual reality space where users can interact with each other and the digital environment in real time. This inevitable evolution of the internet is poised to become a reality soon [34].

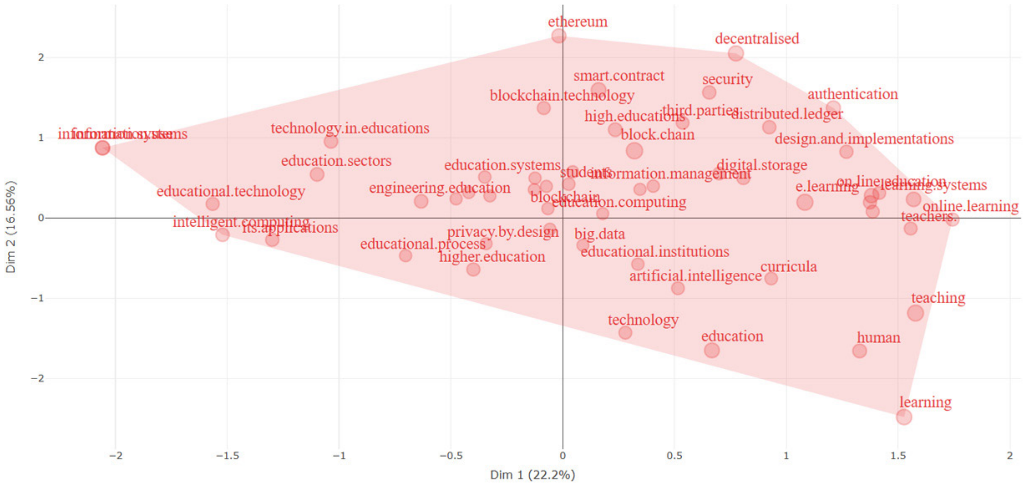


Fig. 22. Thematic maps

The implementation of blockchain technology in education also faces several obstacles. These challenges include technical issues such as scalability, interoperability, and standardization. There are also adoption challenges that arise due to the need for collaboration among various stakeholders, including educational institutions, governments, and technology providers. Privacy and security concerns are another challenge, as the transparent and immutable ledger could potentially expose personal information to unauthorized parties. Additionally, costs can be a significant barrier, especially for small institutions or those in developing countries. Finally, legal and regulatory barriers, particularly those related to data protection and privacy laws, can also pose challenges.

4 CONCLUSIONS

Our findings show that blockchain technology has the potential to revolutionize the education sector by providing secure, transparent, and tamper-proof record-keeping. It can also facilitate credential verification and streamline administrative processes. In recent years, the education sector has witnessed an increasing adoption of blockchain technology, with stakeholders developing numerous initiatives and projects globally. However, implementing blockchain technology in education also presents several challenges that require attention and resolution. To fully harness the potential of blockchain technology in education, additional research and development are required. We must address technical challenges such as scalability, interoperability, and standardization through continuous innovation and exploration. Adoption challenges require collaboration with multiple stakeholders and may involve changes in regulatory and institutional frameworks. It is essential to address the privacy and security concerns associated with blockchain technology in order to safeguard sensitive data. Indeed, moving forward, it may be critical to prioritize research and development efforts to address these challenges and fully harness the potential of blockchain technology in education. To address these challenges, we can develop technical standards and protocols that facilitate interoperability and scalability while also ensuring data privacy and security. Education policymakers, institutional leaders, and technology providers should collaborate to establish a clear roadmap for adopting and integrating blockchain technology in education. As blockchain and other disruptive technologies evolve, we anticipate the emergence of more innovative applications and use cases in the field of education. By addressing the challenges and concerns associated with blockchain technology, we can unlock its full potential and create a more efficient and secure educational ecosystem.

5 AUTHOR CONTRIBUTIONS

Agariadne Dwinggo Samala: Conceptualization, Methodology, Software, Data Curation, Formal Analysis, Visualization, Supervision, Writing—original draft, Writing—review and editing. **David Mhlanga:** Resources, Investigation, Validation, Writing—review and editing. **Ljubisa Bojic:** Formal Analysis, Resources, Validation, Writing—review and editing. **Natalie-Jane Howard:** Validation, Writing—review and editing. **Diogo Pereira Coelho:** Validation, Writing—review and editing.

6 REFERENCES

[1] A. Cannavo and F. Lamberti, "How blockchain, virtual reality, and augmented reality are converging, and why," *IEEE Consumer Electronics Magazine*, vol. 10, no. 5, pp. 6–13, 2021. https://doi.org/10.1109/MCE.2020.3025753

[2] A. D. Samala and M. Amanda, "Immersive Learning Experience Design (ILXD): Augmented reality mobile application for placing and interacting with 3D learning objects in engineering education," *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 17, no. 5, pp. 22–35, 2023. https://doi.org/10.3991/ijim.v17i05.37067

[3] A. D. Samala, F. Ranuharja, B. R. Fajri, Y. Indarta, and W. Agustiarmi, "ViCT-Virtual Campus Tour Environment with spherical panorama: A preliminary exploration," *International Journal of Interactive Mobile Technologies*, vol. 16, no. 16, pp. 205–225, 2022. https://doi.org/10.3991/ijim.v16i16.32889

[4] O. Konashevych, "Cross-blockchain protocol for public registries," *International Journal of Web Information Systems*, vol. 16, no. 5, pp. 571–610, 2020. https://doi.org/10.1108/IJWIS-07-2020-0045

[5] J. J. Hunhevicz and D. M. Hall, "Do you need a blockchain in construction? Use case categories and decision framework for DLT design options," *Advanced Engineering Informatics*, vol. 45, p. 101094, 2020. https://doi.org/10.1016/j.aei.2020.101094

[6] "Blockchain in real estate: How this disrupts the market," CB Insights. https://www.cbinsights.com/research/blockchain-real-estate-disruption/. [Accessed: Mar. 19, 2023].

[7] S. Haber and W. S. Stornetta, "How to time-stamp a digital document," *Journal of Cryptology*, vol. 3, no. 2, pp. 99–111, 1991. https://doi.org/10.1007/BF00196791

[8] H. Liu, X. Luo, H. Liu, and X. Xia, "Merkle tree: A fundamental component of blockchains," in *2021 International Conference on Electronic Information Engineering and Computer Science, EIECS 2021*, pp. 556–561, 2021. https://doi.org/10.1109/EIECS53707.2021.9588047

[9] S. Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System," 2008. [Online]. Available: www.bitcoin.org

[10] F. J. García-Corral, J. A. Cordero-García, J. de Pablo-Valenciano, and J. Uribe-Toril, "A bibliometric review of cryptocurrencies: How have they grown?" *Financial Innovation*, vol. 8, no. 1, pp. 1–31, 2022. https://doi.org/10.1186/s40854-021-00306-5

[11] H. Taherdoost, "Non-Fungible Tokens (NFT): A systematic review," *Information 2023,* vol. 14, no. 1, p. 26, 2022. https://doi.org/10.3390/info14010026

[12] I. Makarov and A. Schoar, "Cryptocurrencies and Decentralised Finance (DeFi)," 2022. [Online]. Available: www.bis.org; https://doi.org/10.3386/w30006

[13] S. Pu and J. S. L. Lam, "The benefits of blockchain for digital certificates: A multiple case study analysis," *Technol. Soc.*, vol. 72, p. 102176, 2023. https://doi.org/10.1016/j.techsoc.2022.102176

[14] N. Lutfiani, Q. Aini, U. Rahardja, L. Wijayanti, E. A. Nabila, and M. I. Ali, "Transformation of blockchain and opportunities for education 4.0," *International Journal of Education and Learning*, vol. 3, no. 3, pp. 222–231, 2021. https://doi.org/10.31763/ijele.v3i3.283

[15] J. Park, "Promises and challenges of Blockchain in education," *Smart Learning Environments*, vol. 8, no. 1, pp. 1–13, 2021. https://doi.org/10.1186/s40561-021-00179-2

[16] A. A. M. A. Ali, M. Mabrouk, and M. Zrigui, "A review: Blockchain technology applications in the field of higher education," *Journal of Hunan University Natural Sciences*, vol. 49, no. 10, pp. 88–99, 2022. https://doi.org/10.55463/issn.1674-2974.49.10.10

[17] A. Mohammad and S. Vargas, "Challenges of using blockchain in the education sector: A literature review," *Applied Sciences 2022,* vol. 12, no. 13, p. 6380, 2022. https://doi.org/10.3390/app12136380

[18] A. D. Samala *et al.*, "Metaverse technologies in education: A systematic literature review using PRISMA," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 18, no. 5, pp. 231–252, 2023. https://doi.org/10.3991/ijet.v18i05.35501

[19] A. D. Samala *et al.*, "Top 10 most-cited articles concerning blended learning for introductory algorithms and programming: A bibliometric analysis and overview," *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 17, no. 5, pp. 57–70, 2023. https://doi.org/10.3991/ijim.v17i05.36503

[20] E. G. Summers, "Bradford's law and the retrieval of reading research journal literature," *Read Res Q*, vol. 19, no. 1, p. 102, 1983. https://doi.org/10.2307/747340

[21] M. Kawamura, C. D. L. Thomas, Y. Kawaguchi, and H. Sasahara, "Lotka's law and the pattern of scientific productivity in the dental science literature," *Medical Informatics and the Internet in Medicine*, vol. 24, no. 4, pp. 309–315, 2009. https://doi.org/10.1080/146392399298320

[22] P. T. Nicholls, "Empirical validation of Lotka's law," *Inf. Process Manag.*, vol. 22, no. 5, pp. 417–419, 1986. https://doi.org/10.1016/0306-4573(86)90076-2

[23] F. A. Fernandes and C. M. L. Werner, "A scoping review of the metaverse for software engineering education: Overview, challenges and opportunities," *PRESENCE: Virtual and Augmented Reality*, pp. 1–40, 2023. https://doi.org/10.1162/pres_a_00371

[24] A. Alam, "Platform utilising blockchain technology for elearning and online education for open sharing of academic proficiency and progress records," in *Smart Data Intelligence: Proceedings of ICSMDI*, 2022, pp. 307–320. https://doi.org/10.1007/978-981-19-3311-0_26

[25] A. D. Samala, R. Marta, S. Anori, and Y. Indarta, "Online learning applications for students: Opportunities & challenges," *Educational Administration: Theory and Practice*, vol. 28, no. 3, pp. 1–12, 2022. https://doi.org/10.17762/kuey.v28i03.409

[26] V. Aulia and S. Yazid, "Review of blockchain application in education data management," in *2021 2nd International Conference on Smart Computing and Electronic Enterprise: Ubiquitous, Adaptive, and Sustainable Computing Solutions for New Normal, ICSCEE 2021*, 2021, pp. 95–101. https://doi.org/10.1109/ICSCEE50312.2021.9497997

[27] Y. Shi, H. Shahriar, D. Lo, and H. Chi, "Enhancing blockchain technology education with innovative active learning," in *Proceedings of the 2022 IEEE 2nd International Conference on Advanced Learning Technologies on Education and Research, ICALTER 2022*, 2022. https://doi.org/10.1109/ICALTER57193.2022.9965006

[28] D. Mourtzis, J. Angelopoulos, and N. Panopoulos, "Blockchain integration in the era of industrial metaverse," *Applied Sciences 2023*, vol. 13, no. 3, p. 1353, 2023. https://doi.org/10.3390/app13031353

[29] G. Chen, B. Xu, M. Lu, and N.-S. Chen, "Exploring blockchain technology and its potential applications for education," *Smart Learning Environments*, vol. 5, no. 1, pp. 1–10, 2018. https://doi.org/10.1186/s40561-017-0050-x

[30] S. Kosasi, U. Rahardja, N. Lutfiani, E. P. Harahap, and S. N. Sari, "Blockchain technology – emerging research themes opportunities in higher education," in *International Conference on Science and Technology, ICOSTECH 2022*, 2022. https://doi.org/10.1109/ICOSTECH54296.2022.9829053

[31] M. Zhao *et al.*, "Blockchain in online learning: A systematic review and bibliographic visualization," *Sustainability*, vol. 15, no. 2, p. 1470, 2023. https://doi.org/10.3390/su15021470

[32] M. Alshahrani, N. Beloff, and M. White, "Revolutionising higher education by adopting blockchain technology in the certification process," in *2020 International Conference on Innovation and Intelligence for Informatics, Computing and Technologies, 3ICT 2020*, 2020. https://doi.org/10.1109/3ICT51146.2020.9311970

[33] R. Patan, R. M. Parizi, M. Dorodchi, S. Pouriyeh, and A. Rorrer, "Blockchain education: Current state, limitations, Career Scope, Challenges, and Future Directions," *ArXiv*, 2301.07889, 2023. https://doi.org/10.48550/arxiv.2301.07889

[34] A. D. Samala *et al.*, "Global publication trends in augmented reality and virtual reality for learning: The last twenty-one years," *International Journal of Engineering Pedagogy (iJEP)*, vol. 13, no. 2, pp. 109–128, 2023. https://doi.org/10.3991/ijep.v13i2.35965

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