

Blockchain and Sustainable Higher Education in Developing Countries: A Review

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Abstract— One of the most significant technological discoveries and creative developments in today's professional world is Blockchain (BC) technology. It is a relatively new method that is gaining popularity in various fields like information management, supply chain, governance and education. It started as the basis for cryptocurrencies and later evolved to smart contracts where contracts are automatically executed without any third party. Blockchain links record of transactions between many mutually distrusting parties through a chain of encrypted hashes known as Distributed Ledger Technology. Sustainable Development Goal 4.0 ensures equitable quality education and promotes lifelong learning opportunities for all. While there is no consensus among scholars as to what constitutes a sustainable institution and how to measure sustainable development for higher education institutions, countries with different priorities are developing varying preferences in their sustainability practices. Blockchain technology shows significant potentials for learners and teachers in terms of its broad applications for the design and implementation of learning and assessment activities. Thereby conducting formative evaluation and tracking the entire learning processes. Some of the merits of adopting Blockchain in Education across reviewed literatures include; Securing students' and/or institution data, transparency, efficiency, cost effectiveness, trust and ease of evaluation. It was also observed that while there are many advantages, there are also challenges of adopting this emerging technology. Some of these challenges identified include; Scalability, acceptability, privacy and usability. Furthermore, the results showed that the use of Blockchain in education is becoming a central research focus since 2021. The review was built on 53 primary papers extracted from major scientific databases highlights that while progress has been made in the adoption of Blockchain in education among developed nations, developing countries are yet to delve properly into this technology. Also, key gaps remain in terms of research collaboration, inter linkages and synergies between these targets across the globe. This review is aimed at improving our understanding of the potentials of Blockchain for a sustainable higher institution and providing guide for further research opportunities.

Keywords: *Blockchain, Smart contracts, Consensus Algorithms, SDG 4.0.*

I. INTRODUCTION

Education is the utmost component for the sustainable growth of any nation or civilization [1]. The growth in technology coupled with advances in cyber physical systems has led to massive digitization of most higher education processes across the globe. The Internet and other Web-based applications have improved communication, increased collaboration, better resource sharing and promoted active learning. Today most students, educators, researchers are leveraging on online learning platforms to enhance their knowledge.

The behavioural changes which emerge in the younger generations inescapably led to the reshaping of learning itself. Consequently, teaching methodologies are being updated to keep up with the evolution of learning especially to train future professionals for both labour and professional career markets. Sustainable Development Goal 4.0 ensures inclusive and equitable quality education and promote lifelong learning opportunities for all. Sustainable Education (SE) on the other hand is a significant concept that promotes employability and involves continuous, inclusive, and equitable learning. The pandemic recently experienced has affected over 1.6 billion learners globally [2]. Moreover, 86% of children in low-income countries are effectively out of school due to school closures, compared with only 20% in high-income countries [2].

Blockchain is regarded as the next-generation technology, also labeled as the Internet of Trust [1], in fact we can refer to it as internet of everything . It is a decentralized Peer-2-Peer database or open network of several equal nodes linked together with no any central authority first proposed by the pseudonymous Satoshi Nakamoto [3]. Blockchain links record of transactions between many mutually distrusting parties through a chain of encrypted hashes known as a Distributed Ledger Technology (DLT). While cryptocurrencies (Bitcoin) continues to rule today's world, the other applications of Blockchain technology will rule the next decades [3]. The technology is growing at a rate of 80% Compound Annual Growth Rate (CAGR) and is expected to hold 10% of the world's Growth Domestic Product (GDP) by 2025

(<https://www.marketsandmarkets.com, Market-Reports & Blockchain-technology-market-90, 100890. html. 2023>)

This review therefore seeks to investigate the research works that have been done with regards to the higher education institutes on the bases of Blockchain across the globe. Furthermore, it pinpointed the challenges Higher Education Institutions (HEI) may face while adopting Blockchain especially in developing countries.

This review focused on Blockchain’s application in Education by examining those articles collected from 2016 to 2022 from several research databases. We demonstrated trends in the state-of-the-art Blockchain solutions with regards to HEI. Therefore, our approach will aid practitioners in building sound Educational Blockchains and also give future directions for researchers. Also, researchers and experts in the educational sector, especially in the developing nations will obtain useful information on challenges, policies and prospects to be considered while adopting Blockchain. The main contributions of this study are as follows:

- 41 articles on Blockchain for Education were reviewed
- key issues concerning sustainable development presented
- Challenges Mitigating SDG for the developing nations reviewed
- The integration of Blockchain and other emerging technologies for sustainable HEIs was presented
- The challenges of adopting Blockchain mentioned
- Recommendations and future directions presented.

The remainder of the paper is organized as follows: Section 2; Brief background to the study of Blockchain technology and its later evolvments. Section 3; the methodology that was adopted in this study. section 4; A Bibliometric trend of the Blockchain research in HEIs Section 5; presents the current adoption of Blockchain projects in the higher education field. Section 6; Blockchain and other emerging technologies. Section 7; Challenges and prospective future research directions. Section 8; Conclusion and research limitation.

This section provides an in-depth about Blockchain technology and its characteristic features. Further, it provide highlights to the evolvment of BC and consensus algorithms in the BC ecosystem.

I. Blockchain Technology

Immutability and decentralization are the basic concepts behind the Blockchain technology. Blockchain is a distributed (decentralized) database that stores transactions between participating entities in a secure, transparent and immutable way for a trustless environment [4]. The trust in such environments is being handled by a validation of each block in the mining process. Each block in the Blockchain is linked to its previous block through the hash value of the parent block, except for the first block which is known as the genesis block. New blocks (members) can be dedicated to a Blockchain only upon their successful completion of the competition imposed by the type of consensus algorithm of that particular BC. In general, every block in the BC is made up of the following components.

- Block version: It indicates protocols to be followed for block validation

- A previous hash tag, which is the hash tag of the parent block.
- A timestamp that records the timing of the BC.
- A Merkle Root, which is a data structure that stores all the hashes of all the transactions in the block.
- A Nonce, starting from 0 and increasing for every hash calculation.
- A Transaction (s) (Tx), that represents the action executed at a given timestamp.A4_format”

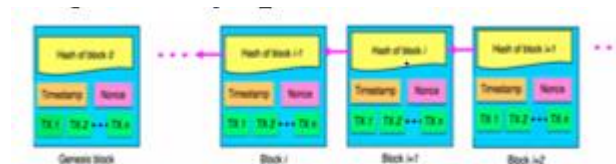


Figure 1.0: structure of a Blockchain (D. Khan et al., 2021)

II. Characteristics of Blockchain

The Blockchain technology exhibits several features useful for tackling fundamental issues of sustainable higher education for developing countries especially with regards to total inclusiveness and equitable learning, thereby assuring educational trustworthiness, efficiency and security. The characteristic features of BC include

1) Decentralization

Unlike in a centralized system where a trusted authority is required to validate every occurring transaction in the network, decentralized systems do not have any trusted governing authority or single entity to control the network. All the nodes in the network collectively manage the network, i.e., decentralized governance. The transaction in Blockchain can therefore be accomplished between 2 peers (P2P) without the approval of a central agency.

2) Immutability

This is one of the basic features of Blockchain technology. It refers to the idea that once data is recorded on a Blockchain, it cannot be modified or deleted. This concept is achieved through a combination of cryptographic techniques and made possible also due to the decentralized nature of Blockchain networks. The immutability of Blockchain has helped in achieving trust and security, thereby making it remains tamper-proof and reliable. However, it's worth noting that while Blockchain data is immutable, the interpretation and handling of data can vary depending on the software and applications built on top of the Blockchain

3) Transparency

This refers to the open nature of the Blockchain. The entire data, content and transaction history of the Blockchain are accessible at all times. Participants in the network can independently verify transactions and data without relying on a central authority. This transparent nature of Blockchain reduces the need for trust in third parties and intermediaries. Thereby deterring fraudulent or malicious activities.

Others include security, consensus, integrity, efficiency, anonymity, consensus, security and anonymity

III. Types of Blockchain

Fundamentally, there are four types of Blockchain namely;

1. *Public Blockchain*: in this type of chain, everyone has access to the BC and thus can participate in the consensus process. Examples include Bitcoin, Dash, Ethereum.

2. *Private Blockchain*: Although BC is a decentralized network, the private BC has a centralized network that is completely controlled by a single organization.

3. *Consortium Blockchain*: this is a partly centralized Blockchain where only some selected nodes participate in the consensus processes.

4. *Hybrid Blockchain*: this combines both private and public Blockchain in its architecture. Therefore, the system exhibits the features of both private and public Blockchain.

IV. Smart Contract

The term “smart contract” was originally coined to refer to the automation of legal contracts designed in the form of event–condition–action (ECA) computer programs. They are digits built on an “if-this-then-that (IFTTT)” statement for self-execution [5]. Smart contracts eliminate the need for all intermediaries by setting the contract details available to the users. One unique characteristic of smart contracts is that they are secured from all forms of deletion and tampering since its being managed in the Blockchain [6]

V. Consensus Algorithms

The “Byzantine Generals” problem is an ideal process of the consensus in Blockchain technology. During the Byzantines, some command generals circled the city with two options; either to attack or to retreat. The rule then was that all the generals would have to agree to attack, else it is a failure. Therefore, an agreement of either attacking or retreating must be reached. This is the exact situation of the BC consensus. More technically, consensus technique ensures that every node agree on the verified state of a ledger. It ensures the approval or verification of transactions on the BC network thereby avoiding double-spending [7]. Consensus algorithms can either be proof-based or voting-based. While the Proof-based are for public, the voting-based are for private Blockchain. The different types of such consensus algorithms are presented in Table 1.0.

VI. Digital Signature

Digital Signatures are cryptographic techniques deployed on a Blockchain. These techniques makes it possible for mutually distrusting parties to transact successfully. Every block in the Blockchain is assigned a public and private key. The owner of the Block keeps the private key securely without sharing it with anyone. The private key can be seen as a password for signing into the Blockchain. While the private key is kept secret, the public key is broadcasted to every node in the Blockchain, thus it is used in accessing signed transactions across the entire network.

Consensus Algorithm	Platform	Language
PoW	Bitcoin, Ethereum, Litecoin and Dogecoin	C++
PoS	Peercoin, Gridcoin and NXT	Java
PBFT	Hyperledger Fabric	Pythons, Java, JavaScript
Ripple Consensus	Financial transactions	Python
PoET	HyperLedger Sawtooth framework	Pythons, Java, C++, JavaScript, Go, Rust
PoA		
PoB	media-networks	Pythons, C++, JavaScript, Shell

VII. Blockchain Platforms

The acceptability of BC technology over the past decade has led to the development of several infrastructural frameworks. These frameworks are designed for the application of large number of manifest problems initially from cryptocurrencies, internet of Things (IoT), and recently the emergence of smart contracts. These frameworks are discussed and demonstrated graphically in figure 2.0. Ethereum it is a public Blockchain platform first proposed by Vitalik Buterin in 2013. It is an open source platform that supports the modified version of Bitcoin’s consensus [8]. It’s the most widely used platform for developing Peer to Peer distributed applications (Dapps). Other frameworks are the Hyperledger Fabric, Ethereum, Corda, etc. Corda is designed specifically for two main reasons, legal contracts and data sharing between mutually trusting parties.

The EOS is another platform for both private and public sectors designed for addressing different business needs like speeds, processing security, and role-based security [9].

VIII. Phases in the generation of the blockchain

There were three phases in the evolvement of Blockchain 1.0, Blockchain 2.0, and Blockchain 3.0 [55]

- Blockchain 1.0: it’s the origin of the Blockchain Technology basically for digital currencies such as Bitcoin.
- Blockchain 2.0: leveraged on the introduction of Smart Contracts and Ethereum.
- Blockchain 3.0: for decentralized enterprise applications such as education, healthcare, and government.
- Blockchain 4.0 is the emerging class of BC. It’s an integration of Blockchain and Artificial Intelligence (AI) to build systems capable of making decision making.



Figure 2.0: graphical view of the BC frameworks.

II. SUSTAINABLE DEVELOPMENT GOAL

SDG was an idea dated back from 2015 by the international community. Seventeen standard goals were considered as the gold standard for guiding and evaluating the growth and development of a state. These 17 SDGs were promising and covered almost every aspect of life. Some of these SDGs include 1; No Poverty, 2; Zero Hunger, 3; Good health and wellbeing, 4, Quality Education, 5; Gender Equality and 17; Partnership for goal [10]. Subsequently after the take-off of the SDGs in 2015, researchers have been motivated to undertake studies on the challenges for the implementation and adoption of these SDGs. For instance, [11] presented a mapping of the challenges of the indicators for sustainable development goals. [10] also suggested ways by which such institutions can incorporate certain activities to achieve the set objectives of the SDGs. [12] proposes science-based approaches to the adoption and evaluation of these SDGs.

A. SDG 4.0

The Sustainable Development Goal (SDG) 4, which is “ensuring inclusive and equitable quality education and promoting lifelong learning opportunities for all”, is a critical goal that is needed to be achieved for improved quality of life and the developmental advancement of any nation. Understanding the factors that inhibit the attainment of SDG 4.0 as well as the interaction of these factors could yield useful insights into the general problems of the implementation of the SDGs in general and more importantly could also provide the basis for informed corrective actions that could propel a defaulting country to higher levels in sustainable development. A major implication for our current study is that SDG 4.0 though nested in Education cannot be pursued effectively without the cooperation of other ministries, actors and stakeholders. Another interesting implication is the recognition of mutual interactions and influences with SDG 4.0 for instance influencing and interacting with other SDGs such as SDGs 5, 6, 7 and 8. Sustainable education will be based on ethics, values, and the capacity of

students and professors to adapt to the continuously changing and multi-faceted world. It means discovering what students should learn, the ways of teaching, how they can appropriate broader competences, and how education needs to change to achieve the goals [2].

B. SDG 4.0 Targets

SDG 4.0 is built upon 10 targeted goals expected to be achieved by 2030. Target 4.1; ensuring that all girls and boys without discrimination complete free (publicly-funded), equitable and quality primary and secondary education. Target 4.2, all girls and boys have access to quality early childhood development, care and pre-primary education so that they be ready for primary education. Target 4.3, ensure equal access to affordable and quality technical, vocational and tertiary education, including university. Target 4.4, substantially increase the number of youth and adults with relevant skills (technical and vocational skills) for employment, good jobs and entrepreneurship. Target 4.5 eliminating gender disparities in education and ensuring equal access to all levels of education and vocational training for the vulnerable. Target 4.6, ensure that all youth and a substantial proportion of adults, achieve literacy and numeracy. Target 4.7, ensure that all learners obtain the knowledge and skills needed to promote sustainable development, like sustainable lifestyles, human rights, promotion of a culture of peace and nonviolence, global citizenship and appreciation of cultural diversity. Target 4.a Build and upgrade education facilities that are safe, non-violent, inclusive and effective for all. Target 4.b, substantially increase worldwide the number of scholarships available to developing countries in particular and others, for enrolment in higher education, including vocational training and ICT, engineering and scientific programs, in developed countries and other developing countries. Target 4.c, substantially increase the supply of qualified teachers, through international cooperation for teacher training.

C. Other SDGs Referencing Education

In other to achieve an effective and efficient running of the SDG 4.0, it's fundamental to access other SDG that have direct relationship with SDG 4.0.0. There are five other SDGs that have direct relationship to SDG 4.0,

- 1) Health and well-being (SDG 3.0 Target 3.7), accordingly by 2030, ensuring universal access to sexual and reproductive healthcare services, including family planning, decent information and education.
- 2) Gender Equality (SDG 5.0 Target 5.6), laws and regulations that guarantee women aged 15-49 years access to sexual and reproductive health care, information and education.
- 3) Decent work and Sustainable Growth (SDG8.0 Target 8.6), substantially decrease the number of youth not employed, in education or any form of training.
- 4) Responsible Consumption and production (SDG 12 Target 12.8), ensure that people everywhere have the relevant

information and awareness for sustainable development and lifestyles in harmony with nature.

5) Climate Change mitigation (SDG 13.0 Target 13.3), improve education, awareness raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning. (<https://www.sdg4education2030.org/the-goal>)

D. Challenges Mitigating SDG 4.0

Today, the general consensus in the attainment of SDG 4.0 through its 7 targets with three enablers is gaining global attraction. This emerging consensus also highlights the need for conducting critical reviews of factors that may hinder the pursuit and attainment of the SDG 4.0 goals and targets in its totality. Evidence has shown that most developing countries are failing in their pursuit for SDG 4.0 [13]. Understanding the factors that inhibit the accomplishment of a successful SDG 4.0 and the interactions between such factors could produce valuable insights into its successes. Taking Nigeria for instance, because it is the most populous nation in Africa and that it has defined education as a medium par excellence for fast-tracking its national development. [13] adopted the fishbone and problem tree analyses to point out that poor funding, low enrolment in schools and poor educational infrastructure/facilities are the key hindrances to planning, funding and implementation capacities necessary for the delivery of SDG 4.

III. RESEARCH METHODOLOGY

This section discusses the step by step procedures involved in conducting this research. First, the identification of research question, then designing of the research procedures, screening of relevant articles from selected database repository, relevant keywords were chosen from abstracts, a systematic review and mapping of ideas were finally conducted. This is represented graphically in figure 4.0

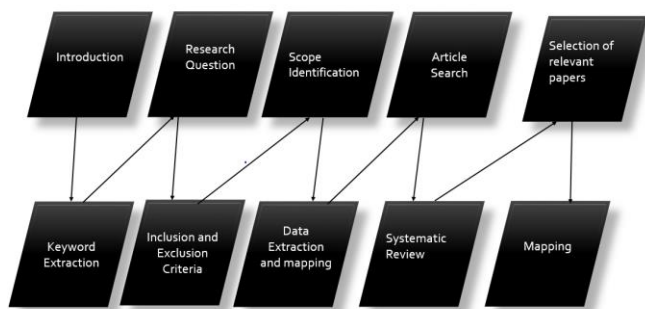


Figure 3.0: Research Methodology

A. Research Questions

In order to establish the most substantial research findings, the following research questions were formulated;

- 1) What are the research works on Blockchain for sustainable higher education?
- 2) What are the research challenges on Blockchain for sustainable higher education?

3) What attempts have been made by researchers for tackling such challenges?

4) What is the extent of BC research for sustainable higher education in low-income countries?

5) What other emerging technologies can be incorporated with BC for sustainable higher education?

B. Research Taxonomy

In general, every research work has some key terms associated to that particular field. These key terms are regarded as the Taxonomy of the research. From the taxonomy, researchers select words relevant to their methodologies or the direction of the research they may want to adopt. Using a virtualization tool, the co-occurrence of such key terms was conducted from 127 relevant articles of the Scopus database repository and subsequently 38 words co-occurred. This is presented in figure 3.0.

C. Keyword Extraction

In this section, all the relevant papers were categorized and analysed based on the formulated questions and research objectives. And from the abstracts of the eligible papers, keywords were extracted and narrowed to the most relevant ones with regards to the research goals. Finally, the keywords relevant to this systematic work selected were “Blockchain”, “smart contracts”, “Consensus algorithms”, “SDG 4.0.0.” and “Emerging Technology”.

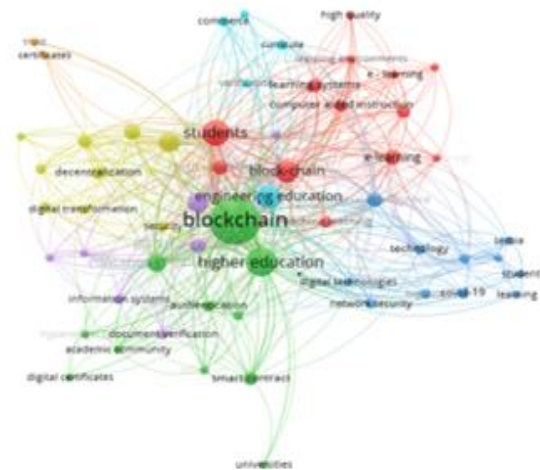


Figure 4.0 Keyword Extraction

D. Academic Database Repositories

The literatures in these research were selected based on the keywords presented in section 4.1. These articles were from reputable journals, book sections, conference proceedings and reports. Table 2.0 presents the academic databases used for article extraction. The searches were conducted from 2009 to

2022. We based the literatures reviewed mostly on papers from Scopus, IEEE Explorer, and Springer. This is due to their high index impact, high quality journals especially in the fields of physical sciences and information technology.

TABLE 2: ACADEMIC DATABASES USED AND THEIR LINKS

Academic Database	Links	Query Strings
Scopus	https://www.scopus.com/	TITLE-ABS KEY (Blockchain) AND OR TITLE-ABS-KEY (sustain*) AND TITLE-ABS-KEY (high* education) AND (LIMIT TO (PUBYEAR , 2023) TO (PUBYEAR , 2016)
IEEE Xplore	http://ieeexplore.ieee.org/	((("Document Title": Blockchain) AND "Document Title": sustainable) AND "Document Title": higher) AND "Document Title": education)
Science Direct	http://www.sciencedirect.com/	'Blockchain AND higher AND education'
SpringerLink	http://www.link.springer.com/	'Blockchain AND sustainable AND higher AND education'

E. Inclusion and Exclusion Criteria

The setting up of such criteria was conducted to collect the most relevant information to address the set objective more appropriately. Therefore, the review was designed based on 9 elements as shown in Table 4.

Criteria	Description
Paper Title	Title of the research work
Author(s)	The name(s) of the research Author(s)
Paper type	Conference, journal, report, or book chapter
Research Area	The paper focus and subject of interest
Publication date	Publication year
Publication location	Country of conference or organization
Paper purpose	Aim of the paper and subsequent objectives
Language	Only English Language
Implementation	Paper structure and research implementation

F. Eligibility Result

A total of 448 papers were obtained from the selected academic databases. In the first stage of the screening process, after applying the criteria in section 4.4 on the articles, we removed 187 irrelevant articles based on the set criteria. 24 duplicates were removed based on title. 58 papers were omitted

because they were not concentrating on higher education specifically. We also rejected 71 papers that discussed the general aspects of Blockchain. When the abstracts and conclusions were considered, a total of 67 articles were rejected. Finally, 41 papers were analyzed for systematic mapping of the research.

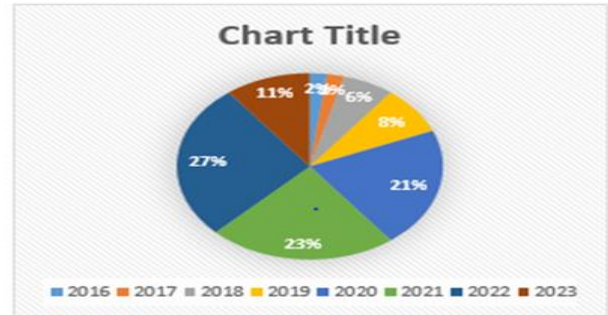


Figure 5.0: Research Growth in Blockchain for sustainable Education

It is important to note that all of the papers were published after 2015. This shows that this is a modern and novel area of research. Thus, the number of publications on this topic appears to be increasing each year, reflecting an increase in interest in the Blockchain adoption of higher education.

G. Collaboration among countries

Unlike with developing nations where there is little or no collaboration amongst researchers regarding the adoption of Blockchain in the education, developed nation like Russia, the United Kingdom, China, Australia, United States and India has gone far in research collaboration. These six nations are the only countries that collaborated for a sustainable Blockchain adoption in the education system among the 52 countries in the reviewed literatures.

Figure 6.0 presents the extent of collaboration among such countries.

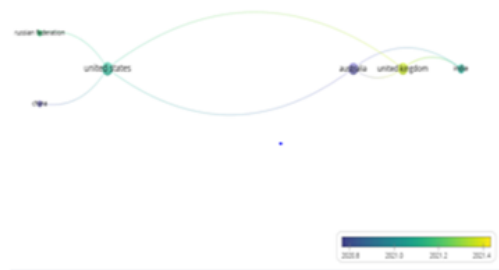


Figure 6.0: Collaboration among Countries

IV. LITERATURE REVIEW

Despite the enthusiastic progress in the adoption of Blockchain in education in recent literatures, the review for its adoption together with smart contracts as infrastructure in the education is still in its infancy stage [14]. Blockchain and smart contract technologies are increasingly involved in education for building

infrastructure for all forms of teaching and learning. One of the earlier adopters of Blockchain technology for academic purposes is the Holberton School of Software Engineering, a California-based institution established in 2015. The institution offers learners a paper certificate at the end of the program as well as a digital certificate that is inserted into the Bitcoin Blockchain. In addition to utilizing an existing public Blockchain such as Bitcoin, other efforts have been made to use Blockchain technology to address issues of authoring, managing, and delivering learning resources.

[15] presented a review on Blockchain technology in the education industry, emphasizing the opportunities for disrupting the current value chain of academic institutions. They pointed out that most of the currently proposed applications of Blockchain in academic institutions represent a sustaining innovation, merely changing one technology for other, thereby making limited use of the improved qualities provided by the Blockchain like reliability and ease of access. [16] wrote on certificate-verifying Blockchain for verifying falsification of graduation certificate. Blockchain was combined with artificial intelligence, Mask R-Convolutional Neural Networks (R-CNN) specifically for the Architecture. Block verification was also performed using the Fast R-CNN and Mask R-CNN together with multi-layer consensus algorithm. The study was validated with a virtual environment. [17] demonstrated the application of Blockchain in higher education considering its potential to store and share reliable data (academic records). They sought to identify the influence of trust in the adoption and implementation of Blockchain by the Brazilian Higher Education Institute. One of their findings is that confidence in the new technology would come with the decision of more and more institutions to adopt and implement Blockchain. They found out that trust is present in the relationship of potential HEI users of Blockchain because the security and transparency offered by this technology. [18] investigated how the current health professions educational institutions can move from the traditional assembly-line hierarchical structure using Blockchain. They showed that Blockchain can provide an ideal data management framework for high-order applications such as learning systems and credentialing in an open and distributed fashion. Thereby allowing for the creation of decentralized adaptive competency curricula, simplification of credentialing and certification, leveling of information asymmetry among educational market stakeholders, assuring alignment with societal priorities, supporting equity and transparency.

[19] proposed a Collaborative Learning and Student Work Evaluation (CLSWE) model based on Blockchain. The CLSWE model offers the possibility of improving cooperation between higher-education institutions and companies that seek the “employable skills” of proactive students. A survey was conducted to test for the acceptability of the model and it revealed the willingness to introduce Blockchain in education. A platform with a database created in the MySQL language for the testing model was built. A better sustainability of the education process and collaborative learning with Blockchain was achieved. [20] illustrated the use of Blockchain in enhancing e-certificate data security. They proved that Blockchain has a big impact especially in education by creating

a global trust network, immutable and authenticated chain that can shape a better world for Indonesia as a superpower. With good execution using the SHA-256 hash, e-certificate Blockchain was presented for high impact on the quality of potential human resources in educational institutions. [21] used Blockchain technology for a new learning model in the form of SCI-B (Student-Centered iLearning Blockchain) which is able to manage and store all transactions and can provide intensive assessments through digital certificates for the academic world. They stated that the model can be used for all training institutions because it can adapt to the specific professional needs of the occupational sector. The model was validated by the existence of a web application. [22] proposed a hybrid Blockchain-based platform that brings together all possible stakeholders in higher education sector. Using a hybrid Blockchain, the study was tested in two of the most instable low-income countries: Syria and Sudan. They found out that the platform is feasible and can serve as a marketplace for all stakeholders in the higher education system and would increase the internationalization of higher education. The study opined that the platform will ensure inclusiveness and equitable education and promotes lifelong learning opportunities for students from low-income countries and thus meets the fourth goal of Sustainable development. [23] proposed a consortium Blockchain that provides a unified and trusted data-sharing infrastructure for open learning. The Blockchain framework was implemented using Hyperledger Fabric 1.4 with a proof-of-concept consensus integrating two educational institutions. A set of experiment was designed and executed to verify the system’s viability and scalability. The result showed that the Blockchain system is competent and outperforms related works compared. [24] represented a Blockchain platform connected to a decentralized network that provides communication between independent nodes representing entities of a higher education, forming a decentralized register of information managed using a DHT (distributed hash table) of user addresses and any DBMS. A gaming approach was used to represent the context of the educational process in higher educational institutions. The study envisioned an increase in the reliability and efficiency of information systems within educational institutions. [7] presented an architecture called “HEDU-Ledger”, a Hyperledger fabric applications for degree attestation verification and traceability between universities. The Hyperledger fabric endorses attestation records first, and then validates (committer) the degree and maintains the secure chain of tracing between stakeholder peer nodes. The system provides robustness in terms of security and privacy of records and maintains integrity with secure preservation as compared to that of the other state-of-the-art methods. [25] designed a Blockchain-based academic record verification system for students, employers and higher education institutions. The system enables students to present academic accomplishments to employers, within a trusted framework. An MD5 hashing algorithm on a public Blockchain was used for encrypting the data, thereby increasing security and ensuring privacy. The Blockchain was connected to the front-end users with a smart contract. This is to remove the necessity of human management and thus significantly reduce the risks of documentation fraud for educational institutions and employers. [8] demonstrated the use of Blockchain in higher education by implementing a

Blockchain-based university transcript system. The transcript data was stored in BigChainDB's Blockchain metadata and manipulated using NoSQL. The model was evaluated and tested on real university dataset. [26] implemented the digitization of degree certificates and academic credits for higher education in the Brazilian education system. A transparent model based on Blockchain was proposed for registering students and their academic credits in a chain of records. Smart contracts were used to enable reliable and decentralized issuance of degree certificates through the validation of a historical database. Remix IDE was used to compute the gas fees from the smart contracts code. For future work, it was suggested that a permissioned Blockchain be used. [27] proposed a global higher education credit platform, "EduCTX" based on European Credit Transfer and Accumulation System (ECTS). The credit and grading system offer a globally unified viewpoint for students and other stakeholders. An ECTX tokens representing an equivalent to student's credit value for a completed course was created, as with the ECTS credits. Each student is assigned a dedicated EduCTX Blockchain wallet with ECTX tokens. Every time a student completes a course, the institution transfers the appropriate number of ECTX tokens to his Blockchain address. The student is able to globally prove his completed courses by simply presenting his Blockchain address. The model was built on an open-source ARK Blockchain platform using proof-of-concept consensus. [28] Proposed an approach using Blockchain in the University of Fernando Pessoa academic information. They proposed the adoption of a solution based on Blockchain called "Blockcerts", to store diploma information, enabling anyone to check and visualize their information. They implemented a prototype and discuss the implications of the technology and of the underlying business processes. [29] Proposed a novel Blockchain-based technique for creating an environment where individuals can be the custodians of their official education records and can easily share those records with others. The miners in the network are those adding blocks to the Blockchain. The solution in their work incorporates the advanced features of Blockchain for education providers to issue official certificates that supply proof of completion or achievement. These certificates can be collected by individuals and shared directly with anyone who requires official documents.

Table 5.0 is a categorization of the application of BC in education and the research works conducted.

Category	Explanation	Example
Review Literatures	This involves literature reviews conducted by researchers during the period defined in this study	[15], [30], [31], [32], [33], [34], [35], [36], [37],
Digital Certificates	Reducing dependency on needing intermediaries (e.g., universities and employers) for holding, checking and validating qualifications and credentials of students	[7], [16], [38], [20], [39], [40], [41], [42], [43], [44], [45]
Information Management	These are articles on the applications of BC	[17], [14], [21], [22], [46], [24], [25], [18]

	for keeping, sharing and managements of students' records across institutions	
Students' Assessments	Articles in this category describes automated mechanisms for the production of exams and assessment schemes for university students.	[19], [28], [6], [47]
Transcripts	This includes work on the accessing and transferring of academic credits or transcripts between universities	[8], [27], [23], [29], [26], [48]
Libraries	For archiving and improving the administrative tasks with the researchers by providing digital rights for the users.	[49]
Support services	These applications are intended to create cryptocurrency for the regulation of the educational products and services industry, (e.g. support services, participation in online courses, regulated studies)	[1], [50], [51]
Earnings	Such implementations connect learning to earnings. The Blockchain technology is used in this case to store the studying hours or teaching and not the digital currency	[52], [53]
Others	Some researchers combine more than one application of Blockchain in their implementation.	[54],

Blockchain technology adoption for sustainable learning as presented in Table 8.0 is explained graphically in Figure 4.0



Figure 7.0: Blockchain Adoption for sustainable Learning

V. BLOCKCHAIN AND EMERGING TECHNOLOGIES FOR SUSTAINABLE HEIS

The adoption of Blockchain Technology if combined with other emerging technologies has the potential to significantly impact the field of higher education. System transparency, efficiency and security in various processes can be achieved if combined with other related technologies thereby enhancing sustainability and innovations in higher educational institutions. Some of these emerging technologies that can be incorporated with Blockchain for sustainable higher education include.

Artificial Intelligence (AI), Machine Learning/Deep Learning: AI-powered chatbots and virtual assistants can streamline administrative tasks, answer student queries, and provide personalized learning experiences. Blockchain can secure and verify the data used by such Artificial Intelligence models, ensuring data integrity and privacy.

Internet of Things (IoT): Internet of Things (IoT) can be seen as a network of several physical objects which are provided with Internet connection. Such devices acquire information about the surrounding environment, and they communicate with each other and with software systems through the Internet. (Alam & Benaida, 2020) has presented research on how Blockchain can be incorporated to IoT devices for tracking and managing physical resources on campuses. Also (Haris & Al-Maadeed, 2020) showed that it is possible to integrate Blockchain and Data from IoT sensors to ensure transparency and traceability.

Decentralized Identity (DID): DID systems enable students to have control over their personal data and credentials. Integrating DID with Blockchain ensures that these credentials are tamper-proof and verifiable, thus reducing the risk of certificate forgeries or fraud.

Augmented and Virtual Reality (AR/VR): AR and VR can enhance remote learning experiences and provide immersive training environments. Blockchain can record and verify achievements or certifications earned through AR/VR-based educational programs.

Edge Computing: Edge computing can improve the performance and responsiveness of Blockchain networks in educational settings. (Zhang et al., 2019) has demonstrated that when these techniques are incorporated, it ensures fast and reliable access to data and services for students and faculty. (Bhat et al., 2020) opined that the merging of Blockchain, IoT and edge computing can be the most important factor for empowering new technologies. Thus achieving self-verifying, self-executing, immutability, data reliability, and confidentiality.

Open Educational Resources (OER): Blockchain can be used to track the creation, sharing, and utilization of OER, ensuring proper attribution and compensation for content creators while making educational materials more accessible.

Supply Chain Management: Blockchain can be used to verify the authenticity of educational materials and textbooks, reducing the prevalence of counterfeit textbooks and ensuring students have access to legitimate and affordable learning resources.

By combining Blockchain with these emerging technologies, higher education institutions can create more sustainable, transparent, and efficient systems that benefit students, faculty, and administrators while reducing administrative costs and enhancing educational outcomes. However, it's essential to carefully consider the specific needs and challenges of each institution when implementing these technologies.

VI. CHALLENGES OF ADOPTING BLOCKCHAIN

Like with every technology, Blockchain also has some associated challenges.

Awareness: Actors in the education sector are not familiar with Blockchain technology and its potential applications. This hinders its acceptability as well as growth with regards to education.

Usability: Blockchain technology can be complex to implement and manage, especially for institutions that lack the necessary technical expertise. The development and maintenance of Blockchain-based solutions can be challenging and costly, hence making its usage very difficult. More so, Blockchain-based systems often require users to manage private keys and wallets, this may intimidate non-technical users. Ensuring a user-friendly experience is crucial for adoption.

Scalability: Scalability remains a significant challenge for many Blockchain networks. Educational institutions often have a large number of students and staff, and existing Blockchain platforms may struggle to handle the volume of transactions and data associated with such institutions.

System Integration: system integration is a fundamental issue in the adoption of Blockchain technology for education. The existing educational systems and infrastructure if it should be

integrated into the Blockchain can be complex and time-consuming. This may require changes to legacy systems and a significant investment in IT resources.

Cost: Implementing Blockchain is cost intensive. This is more peculiar with the developing nations and with smaller educational institutions that are characterized with limited budgets. The cost of hardware, software, and ongoing maintenance can be a barrier to the adoption of Blockchain.

Security: While security is a key characteristic of Blockchain, it is at the same time not immune to security vulnerabilities. Smart contracts in particular can be attacked by malicious users thereby making it vulnerable to coding errors and exploits.

Inertia to Change: People naturally are resistant to change. This is a common challenge in any sector and education is not also excluded. Staff and students may not be willing to adopt any new technology or changing from a traditional system.

Regulatory and Privacy Concerns: The use of Blockchain in education may raise regulatory and privacy concerns, especially regarding the storage and sharing of sensitive student data. Compliance with data protection regulations, such as General Data Protection Regulation (GDPR) can be a significant challenge in the adoption of Blockchain.

Environmental Factors: Blockchain networks especially those built on proof-of-work consensus consume significant amounts of energy. This can raise environmental concerns, especially in educational institutions that prioritize sustainability.

Therefore, it is worth noting that institutions carefully assess their specific needs and challenges before adopting Blockchain solutions and to consider the potential benefits and risks associated with Blockchain technology. These challenges are summarized and described in Figure. 8.0.

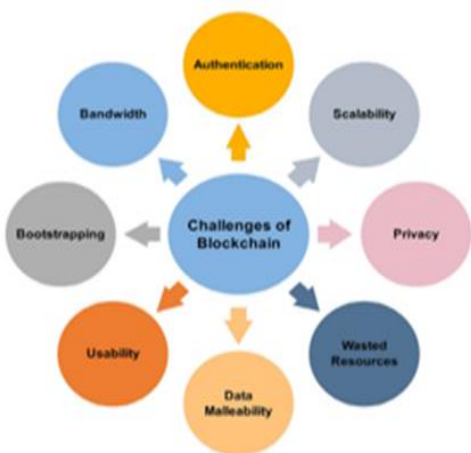


Figure 8.0 Challenges of Adopting Blockchain

VII. CONCLUSION

The quest for a sustainable educational system is still a distant dream for several developing nations. SDG 4.0 which ensures total inclusion and ease of access to education is a recent emerging philosophy founded on sustainability principles and in response to the UN announced Sustainable Development Goals (SDGs). Therefore, it is pertinent that emerging technologies be implemented to empower educational institutions to achieve Sustainable teaching and learning. It is worth noting that the adoption of Blockchain singly may not yield the most desired result without other related emerging technologies. Therefore, it is necessary to relate BC technology with other smart technologies for achieving the set objectives of SDG 4.0. Although the research focused solely on Blockchain for Education, there are numerous applications of this emerging technology on systems that leverage on decentralized platforms especially where trust is a key factor. Other sectors where Blockchain is playing key roles include energy, finance, resource management, healthcare, and agriculture. Thus, it can be concluded that the role of Blockchain when integrated with other enabling technologies in the development of a sustainable educational system include the following.

- Building a holistic environment built on trust and transparent
- A secured and flexible institution can be achieved.
- protection of institution data will be done more effectively
- Accesses to information can be effectively defined
- Trust will be achieved between all participating stakeholders.
- Better performance evaluation

VIII. RECOMMENDATIONS

In this section, some useful recommendations on how to overcome the issues and challenges of adopting Blockchain for HEI as pointed out in section VI is given;

- **Scalability:** in order to check scalability, there is need for an increase in the sizes of blocks use in building the BC. More so, Proof of work is one consensus that can be considered for its scalability.
- **Privacy:** building membership with pseudo-identities instead of correct identities can checkmate issues related to bridge of privacy. The asymmetric encryption of transaction data, and the use of proxy re-encryption technology can protect user's identity from malicious users.
- **Usability:** there is need for creating more awareness and sensitization regarding the application of BC in the educational sector especially with the developing Nations. Government and all stakeholders involve need to scale up campaigns on the adoption of Blockchain and other emerging technologies.
- **Wasted resources:** BC consumes so much resources, especially energy. Therefore, measures such as the usage of renewable energy sources and reuse of heat generated from the computer servers be considered. More so, effective and efficient task-scheduling

algorithm be used to maximize the utilization of resources.

- Other issues such as Data malleability, bandwidth, bootstrapping can be checked with proper planning, improved cryptographic techniques and robustness of the overall system.

IX. FUTURE DIRECTIONS

In order to establish a sustainable education in the developing nations built on the bases of Blockchain technology, the government and other institution stakeholders should design policies for the proper implementation and adoption of Blockchain-based applications in the educational sector. This will help in encouraging the use of the technology and thereby boosting and reviving it for sustainable development. Furthermore, extensive training of manpower in the Educational institutions need to be carried out. Staff, management and members should undergo training regarding the development and usage of the technology. Promotional activities, conferences and workshops be organized to create more awareness and consciousness towards Blockchain. At the same time, metrics based on factors affecting sustainability like population, literacy rate and GDP be proposed so that a quantifiable definition of sustainability be established. Again, solutions to the underlying issues negating the adoption of Blockchain for Education be investigated and the solutions to achieve the set objectives of SDG 4.0 be investigated especially for the developing nation. Finally, for future work, the review should have a broader coverage of the implications of Blockchain in other domains aside education. In depth analysis of the challenges of Blockchain be looked into especially scalability and privacy. Despite these limitations, the research can help practitioners and researchers in exploring the usability and challenges of Blockchain in the Education domain.

REFERENCES

- [1] Aamir, M., Qureshi, R., Khan, F. A., & Huzaifa, M. (2020). Blockchain Based Academic Records Verification in Smart Cities. *Wireless Personal Communications*, 113(3), 1397–1406. <https://doi.org/10.1007/s11277-020-07226-0>
- [2] Alam, T., & Benaida, M. (2020). Blockchain and Internet of Things in Higher Education. *Universal Journal of Educational Research*, 8(5), 2164–2174. <https://doi.org/10.13189/ujer.2020.080556>
- [3] Alexopoulos, N., Daubert, J., Muhlhauser, M., & Habib, S. M. (2017). Beyond the Hype: On Using Blockchains in Trust Management for Authentication. 2017 IEEE Trustcom/BigDataSE/ICSS, 546–553. <https://doi.org/10.1109/Trustcom/BigDataSE/ICSS.2017.283>
- [4] Allen, C., Metternicht, G., & Wiedmann, T. (2018). Initial progress in implementing the Sustainable Development Goals (SDGs): A review of evidence from countries. *Sustainability Science*, 13(5), 1453–1467. <https://doi.org/10.1007/s11625-018-0572-3>
- [5] Alnafrah, I., & Mouselli, S. (2021). Revitalizing Blockchain technology potentials for smooth academic records management and verification in low-income countries. *International Journal of Educational Development*, 85, 102460. <https://doi.org/10.1016/j.ijedudev.2021.102460>
- [6] Alshahrani, M., Beloff, N., & White, M. (2020). Revolutionising Higher Education by Adopting Blockchain Technology in the Certification Process. 2020 International Conference on Innovation and Intelligence for Informatics, Computing and Technologies (3ICT), 1–6. <https://doi.org/10.1109/3ICT51146.2020.9311970>
- [7] Altamimi, A., Al-Bashayreh, M., AL-Oudat, M., & Almajali, D. (2022). Blockchain technology adoption for sustainable learning. *International Journal of Data and Network Science*, 6(3), 983–994. <https://doi.org/10.5267/j.ijdns.2022.1.013>
- [8] Anwar, A. S., Rahardja, U., Prawiyogi, A. G., Santoso, N. P. L., & Maulana, S. (2021). ILearning Model Approach in Creating Blockchain Based Higher Education Trust. *International Journal of Artificial Intelligence Research*, 6(1). <https://doi.org/10.29099/ijair.v6i1.258>
- [9] Arndt, T., & Guercio, A. (2020). Blockchain-Based Transcripts for Mobile Higher-Education. *International Journal of Information and Education Technology*, 10(2), 84–89. <https://doi.org/10.18178/ijiet.2020.10.2.1344>
- [10] Awaji, B., Solaiman, E., & Alshri, A. (2020). Blockchain-Based Applications in Higher Education: A Systematic Mapping Study. 9.
- [11] Awaji, B., Solaiman, E., & Marshall, L. (2020). Blockchain-Based Trusted Achievement Record System Design. *Proceedings of the 5th International Conference on Information and Education Innovations*, 46–51. <https://doi.org/10.1145/3411681.3411689>
- [12] Ayub Khan, A., Laghari, A. A., Shaikh, A. A., Bourouis, S., Mamlouk, A. M., & Alshazly, H. (2021). Educational Blockchain: A Secure Degree Attestation and Verification Traceability Architecture for Higher Education Commission. *Applied Sciences*, 11(22), 10917. <https://doi.org/10.3390/app112210917>
- [13] Bahrami, M., Movahedian, A., & Deldari, A. (2020). A Comprehensive Blockchain-based solution For Academic Certificates Management Using Smart Contracts. 2020 10th International Conference on Computer and Knowledge Engineering (ICCKE), 573–578. <https://doi.org/10.1109/ICCKE50421.2020.9303656>
- [14] Bjelobaba, G., Paunovic, M., Savic, A., Stefanovic, H., Doganjic, J., & Miladinovic Bogavac, Z. (2022). Blockchain Technologies and Digitalization in Function of Student Work Evaluation. *Sustainability*, 14(9), 5333. <https://doi.org/10.3390/su14095333>
- [15] Bucea-Manea-Toniş, R., Martins, O. M. D., Bucea-Manea-Toniş, R., Gheorghită, C., Kuleto, V., Ilić, M. P., & Simion, V.-E. (2021). Blockchain Technology Enhances Sustainable Higher Education. *Sustainability*, 13(22), 12347. <https://doi.org/10.3390/su132212347>
- [16] Cabrera, D., Nickson, C. P., Roland, D., Hall, E., & Ankel, F. (2022). Distributed Autonomous Organization of Learning: Future Structure for Health Professions Education Institutions. *JMIR Medical Education*, 8(1), e28770. <https://doi.org/10.2196/28770>
- [17] Capece, G., Levaldi Ghiron, N., & Pasquale, F. (2020). Blockchain Technology: Redefining Trust for Digital Certificates. *Sustainability*, 12(21), 8952. <https://doi.org/10.3390/su12218952>
- [18] Capetillo, A., Camacho, D., & Alanis, M. (2022). Blockchain education: Challenging the long-standing model of academic institutions. *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 16(2), 791–802. <https://doi.org/10.1007/s12008-022-00886-1>
- [19] Chivu, R.-G., Popa, I.-C., Orzan, M.-C., Marinescu, C., Florescu, M. S., & Orzan, A.-O. (2022). The Role of Blockchain Technologies in the Sustainable Development of Students' Learning Process. *Sustainability*, 14(3), 1406. <https://doi.org/10.3390/su14031406>
- [20] Edastama, P., Purnama, S., Widayanti, R., & Meria, L. (2021). The Potential Blockchain Technology in Higher Education Learning Innovations in Era 4.0. 1(1), 10.
- [21] Filvã, D. A., García-Peñalvo, F. J., Forment, M. A., Escudero, D. F., & Casañ, M. J. (2018). Privacy and identity management in Learning Analytics processes with Blockchain. *Proceedings of the Sixth International Conference on Technological Ecosystems for Enhancing Multiculturality*, 997–1003. <https://doi.org/10.1145/3284179.3284354>
- [22] García-Feijoo, M., Eizaguirre, A., & Rica-Aspiunza, A. (2020). Systematic Review of Sustainable-Development-Goal Deployment in Business Schools. *Sustainability*, 12(1), 440. <https://doi.org/10.3390/su12010440>
- [23] Garg, A., A. S., Kumar, P., Madhukar, M., Loyola-González, O., & Kumar, M. (2022). Blockchain-based online education content ranking. *Education and Information Technologies*, 27(4), 4793–4815. <https://doi.org/10.1007/s10639-021-10797-5>
- [24] Gayathiri, A., Jayachitra, J., & Matilda, S. (2020). Certificate validation using Blockchain. 2020 7th International Conference on Smart Structures and Systems (ICSSS), 1–4. <https://doi.org/10.1109/ICSSS49621.2020.9201988>
- [25] Han, M., Li, Z., He, J. (Selena), Wu, D., Xie, Y., & Baba, A. (2018). A Novel Blockchain-based Education Records Verification Solution. *Proceedings of the 19th Annual SIG Conference on Information Technology Education*, 178–183. <https://doi.org/10.1145/3241815.3241870>

- [26] Haque, B., Hasan, R., & Zihad, O. M. (2021). SmartOil: Blockchain and smart contract-based oil supply chain management. *IET Blockchain*, *blc2.12005*. <https://doi.org/10.1049/blc2.12005>
- [27] Honesti, L., Aini, Q., Setiawan, M. I., Puji Lestari Santoso, N., & Prihastiyi, W. Y. (2021). Smart Contract-based Gamification Scheme for College in Higher Education. *APTISI Transactions on Management (ATM)*, *6(2)*, 102–111. <https://doi.org/10.33050/atm.v6i2.1533>
- [28] Kamišalić, A., Turkanović, M., Mrdović, S., & Heričko, M. (2019). A Preliminary Review of Blockchain-Based Solutions in Higher Education. In L. Uden, D. Liberona, G. Sanchez, & S. Rodríguez-González (Eds.), *Learning Technology for Education Challenges* (Vol. 1011, pp. 114–124). Springer International Publishing. https://doi.org/10.1007/978-3-030-20798-4_11
- [29] Karale, A., Khanuja, H., & Department Of Computer Engineering, Marthwada Mitra Mandal's College Of Engineering, Pune. (2019). Implementation of Blockchain Technology in Education System. *International Journal of Recent Technology and Engineering (IJRTE)*, *8(2)*, 3823–3828. <https://doi.org/10.35940/ijrte.B2462.078219>
- [30] Kaur, A., Nayyar, A., & Singh, P. (2020). BLOCKCHAIN: A PATH TO THE FUTURE. In G. Shrivastava, D. Le, & K. Sharma (Eds.), *Cryptocurrencies and Blockchain Technology Applications* (1st ed., pp. 25–42). Wiley. <https://doi.org/10.1002/9781119621201.ch2>
- [31] Khan, M. A., Algarni, F., & Quasim, M. T. (2020). Decentralised Internet of Things. In M. A. Khan, M. T. Quasim, F. Algarni, & A. Alharthi (Eds.), *Decentralised Internet of Things* (Vol. 71, pp. 3–20). Springer International Publishing. https://doi.org/10.1007/978-3-030-38677-1_1
- [32] Kim, S.-K. (2022). Blockchain Smart Contract to Prevent Forgery of Degree Certificates: Artificial Intelligence Consensus Algorithm. *Electronics*, *11(14)*, 2112. <https://doi.org/10.3390/electronics11142112>
- [33] Kraak, M., Ricker, B., & Engelhardt, Y. (2018). Challenges of Mapping Sustainable Development Goals Indicators Data. *ISPRS International Journal of Geo-Information*, *7(12)*, 482. <https://doi.org/10.3390/ijgi7120482>
- [34] Kuleto, V., Bucea-Manea-Țoniș, R., Bucea-Manea-Țoniș, R., Ilić, M. P., Martins, O. M. D., Ranković, M., & Coelho, A. S. (2022). The Potential of Blockchain Technology in Higher Education as Perceived by Students in Serbia, Romania, and Portugal. *Sustainability*, *14(2)*, 749. <https://doi.org/10.3390/su14020749>
- [35] Lawrence, A. W., Ihebuzor, N., & Lawrence, D. O. (2020). Some Challenges Militating against Developing Countries Achieving SDG 4 on Targets: Nigeria as Case Study. *Modern Economy*, *11(07)*, 1307–1328. <https://doi.org/10.4236/me.2020.117093>
- [36] Lizcano, D., Lara, J. A., White, B., & Aljawameh, S. (2020). Blockchain-based approach to create a model of trust in open and ubiquitous higher education. *Journal of Computing in Higher Education*, *32(1)*, 109–134. <https://doi.org/10.1007/s12528-019-09209-y>
- [37] Malsa, N., Vyas, V., Gautam, J., Shaw, R. N., & Ghosh, A. (2021). Framework and Smart Contract for Blockchain Enabled Certificate Verification System Using Robotics. In M. Bianchini, M. Simic, A. Ghosh, & R. N. Shaw (Eds.), *Machine Learning for Robotics Applications* (Vol. 960, pp. 125–138). Springer Singapore. https://doi.org/10.1007/978-981-16-0598-7_10
- [38] Matzutt, R., Pennekamp, J., & Wehrle, K. (2020). A Secure and Practical Decentralized Ecosystem for Shareable Education Material. *2020 International Conference on Information Networking (ICOIN)*, 529–534. <https://doi.org/10.1109/ICOIN48656.2020.9016478>
- [39] Nakamoto, S. (2008). Bitcoin: A Peer-to-Peer Electronic Cash System. 9.
- [40] Palma, L. M., Vigil, M. A. G., Pereira, F. L., & Martina, J. E. (2019). Blockchain and smart contracts for higher education registry in Brazil. *International Journal of Network Management*, *29(3)*, e2061. <https://doi.org/10.1002/nem.2061>
- [41] Panachev, A., Shcherbitsky, V., & Medvedev, M. A. (2021). Application of Blockchain technologies and game approach in the educational process of universities. *100004*. <https://doi.org/10.1063/5.0042076>
- [42] Rahardja, U., Hidayanto, A. N., Putra, P. O. H., & Hardini, M. (2021). Immutable Ubiquitous Digital Certificate Authentication Using Blockchain Protocol. *Journal of Applied Research and Technology*, *19(4)*, 308–321. <https://doi.org/10.22201/icat.24486736e.2021.19.4.1046>
- [43] Raimundo, R., & Rosário, A. (2021). Blockchain System in the Higher Education. *European Journal of Investigation in Health, Psychology and Education*, *11(1)*, 276–293. <https://doi.org/10.3390/ejihpe11010021>
- [44] Ramos, C. R. dos S., & Queiroz, M. M. (2022). Blockchain in education: The influence of trust on adoption and implementation. *RAUSP Management Journal*, *57(3)*, 316–331. <https://doi.org/10.1108/RAUSP-06-2021-0097>
- [45] RushabhBalpande, & Patil, K. (2021). Usability of Blockchain Technology in Higher Education: A systematic review identifying the current issues in the education system. *Journal of Physics: Conference Series*, *1964(4)*, 042017. <https://doi.org/10.1088/1742-6596/1964/4/042017>
- [46] Saadati, Z., Zeki, C. P., & Vatankhah Barenji, R. (2021). On the development of Blockchain-based learning management system as a metacognitive tool to support self-regulation learning in online higher education. *Interactive Learning Environments*, 1–24. <https://doi.org/10.1080/10494820.2021.1920429>
- [47] Sharma, S., & Batth, R. S. (2020). Blockchain Technology for Higher Education Sytem: A Mirror Review. *2020 International Conference on Intelligent Engineering and Management (ICIEM)*, 348–353. <https://doi.org/10.1109/ICIEM48762.2020.9160274>
- [48] Sharples, M., & Domingue, J. (2016). The Blockchain and Kudos: A Distributed System for Educational Record, Reputation and Reward. In K. Verbert, M. Sharples, & T. Klobučar (Eds.), *Adaptive and Adaptable Learning* (Vol. 9891, pp. 490–496). Springer International Publishing. https://doi.org/10.1007/978-3-319-45153-4_48
- [49] Son-Turan, S. (2022). Fostering Equality in Education: The Blockchain Business Model for Higher Education (BBM-HE). *Sustainability*, *14(5)*, 2955. <https://doi.org/10.3390/su14052955>
- [50] Sousa, M. J., Dal Mas, F., Gonçalves, S. P., & Calandra, D. (2022). AI and Blockchain as New Triggers in the Education Arena. *European Journal of Investigation in Health, Psychology and Education*, *12(4)*, 445–447. <https://doi.org/10.3390/ejihpe12040032>
- [51] Turkanovic, M., Holbl, M., Kosic, K., Hericko, M., & Kamisalic, A. (2018). EduCTX: A Blockchain-Based Higher Education Credit Platform. *IEEE Access*, *6*, 5112–5127. <https://doi.org/10.1109/ACCESS.2018.2789929>
- [52] Vidal, F., Gouveia, F., & Soares, C. (2019). Analysis of Blockchain Technology for Higher Education. *2019 International Conference on Cyber-Enabled Distributed Computing and Knowledge Discovery (CyberC)*, 28–33. <https://doi.org/10.1109/CyberC.2019.00015>
- [53] Xiao, J., Jiao, Y., Li, Y., & Jiang, Z. (2021). Towards a Trusted and Unified Consortium-Blockchain-Based Data Sharing Infrastructure for Open Learning—TolFob Architecture and Implementation. *Sustainability*, *13(24)*, 14069. <https://doi.org/10.3390/su132414069>
- [54] Xie, R., Wang, Y., Tan, M., Zhu, W., Yang, Z., Wu, J., & Jeon, G. (2020). Ethereum-Blockchain-Based Technology of Decentralized Smart Contract Certificate System.
- [55] <https://originstamp.com/blog/blockchain-1-vs-2-vs-3-whats-the-difference/>