A Model for using Blockchain Technology in Educational Systems

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Abstract

Blockchain are transparent, tamper-resistant, digital ledgers, implemented in a distributed network of peer-to-peer nodes, in which transactions are made securely and usually without the approval of a central and trusted authority. Thus, blockchains allow peer-to-peer nodes that do not have a trust relationship to exchange data without third parties or intermediaries. This data could correspond to money, contracts, land titles, medical and educational records, certificates, purchase and sale of goods/services, or any other transactions or assets that could be digitized. Blockchain offers lots of advantages, in finance, healthcare, government services, educational sectors, and the Internet of Things. Applying blockchain technology in educational systems will take the management of academic records and the issuing of graduates› certificates to a higher level of trust, in addition to minimizing lots of work and costs. The proposed model calls for a unit within the Ministry of Higher Education using blockchain technology, that will offer a potential solution for student's data storage, students' exchange between institutions and certificates issuing and verification. This will lead to multiple advantages in decentralization, scalability, reliability, and security.

Keywords: Blockchain, Educational Systems, Academic Records, Credential Verification, Certificate Validation.

1. Introduction

Due to the introduction of a safe and decentralized method for storing and verifying transactions, the blockchain technology concept has transformed many industries. Blockchain was first introduced as the underlying technology for the cryptocurrency Bitcoin, but it has since grown into a powerful tool with many uses outside of virtual currencies.

A blockchain is fundamentally a distributed network of peer-to-peer nodes that implements an open and resistant digital ledger [1]. Blockchain works without a central hub or middleman, in contrast to conventional centralized systems. As a substitute, it enables many parties to securely communicate with one another and carry out transactions without the need of intermediaries or third parties.

It is considered as a peer-to-peer network in which transactions are safely carried out between nodes without the requirement for a centralized authority›s approval. A complete copy of the ledger is stored on each node in the network. Each transaction is verified using a consensus mechanism, which involves asynchronous messaging between multiple network nodes. Examples of this messaging include the announcement of a transaction that represents an event in the system, or the creation and broadcasting of a block containing the transaction›s details. Each node should then validate by examining the new block›s transaction sequence to ensure consistency. The Proof-of-Work and Proof-of-Stake consensus techniques are few examples for the used consensus algorithms [2].

2. Bitcoin and Blockchain

2.1 Bitcoin

Blockchain is the technology that enables bitcoin transactions to be recorded and stored, however bitcoin and blockchain are not the same thing [3].

A paper titled «Bitcoin: A Peer-To-Peer Electronic Cash System» was published in 2008 by a person or a group, written under the name Satoshi Nakamoto [4]. The peer-to-peer electronic cash presented in this study would enable internet payments to be sent directly between parties without going through a banking institution. The first application of this idea was with Bitcoin. The term «cryptocurrencies» is now used to refer to all networks and mediums of exchange that safeguard transactions using cryptography as opposed to those systems where transactions are routed through a centralized, reliable institution.

2.2 Blockchain Characteristics

The most important feature of blockchain is its decentralized nature. Each node in a blockchain network keeps an exact duplicate of the ledger, ensuring data redundancy and transparency [1]. On the blockchain, transactions are organized into blocks that are then cryptographically connected to form a chain. Because of the chaining method, it is impossible to change or tamper with previously recorded data, ensuring the immutability of the data. Table 1 lists the major aspects of blockchain technology.

Table 1. Aspects of Blockchain Technology

Characteristic	Description
Decentralization	There is no central authority or third party controlling the network. Instead, the blockchain is maintained and validated by multiple nodes, ensuring transparency, and eliminating the requirement for a reliable third party.
Transparency	The blockchain's transparency and auditability make it possible for everyone to see every transaction and data entry. The ledger is accessible to all network members in the same version.
Immutability	When a transaction is recorded on the blockchain, it turns out to be incredibly hard to change or mess with. The data's integrity is guaranteed by the chaining of blocks with cryptographic hashes, making it extremely resistant to change.

Security	Digital signatures are used to verify and authenticate transactions, and consensus algorithms ensure that transactions are valid before they are added to the blockchain. Additionally, blockchain is more resistant to attacks than centralized systems, due to its decentralized nature.
Trust and Consensus	Blockchain permits participants to arrive at an agreement on the condition of the record without depending on a central authority. Consensus algorithms, such as proof-of-work (PoW) or proof-of-stake (PoS), empower understanding among nodes and prevent malicious exercises by requiring a larger part or partners' agreement.
Traceability and Auditability	An audit trail of the entire transaction history can be created by following every transaction that is recorded on the blockchain. This feature makes it easier to find and investigate fraudulent activities in addition to increasing accountability.
Efficiency and Speed	While traditional monetary frameworks might include middle people and tedious cycles, blockchain can smooth out exchanges by empowering shared moves without the requirement for intermediaries. Particularly, regarding supply chain management and cross-border payments, this may result in faster and more effective transactions.

2.3 Blockchain Types

Based on its intended use and distinctive characteristics, blockchains are divided into various categories [6]:

• Public Blockchains: Anybody can join the network, take part in the process of reaching consensus, and confirm transactions. Several instances of public blockchains include Bitcoin and Ethereum. They are often decentralized, offer security and transparency, but they could not be scalable.

• Private Blockchains: Sometimes referred to as permissioned blockchains, limiting the access to a select group of users who have been given authorization to join the network. These players are frequently reputable and well-known organizations, including consortium members or commercial partners. In contexts where privacy, control, and scalability are crucial, they are frequently utilized in businesses.

• Consortium blockchains: are a half breed between open and private blockchains, where many organizations come together to create a network, whereas agreement is accomplished by a limited number of nodes. They offer more security and flexibility than public blockchains whereas permitting controlled enrollment.

Table 2 shows the differences between the three types of Blockchain [6].

Property	Public	Private	Consortium
Consensus determination	- All nodes	- One centralized node	- Predefined list of nodes
Consensus process	- Permissionless, everyone can join the consensus process	Permissioned, pre-authorization is required	
Identity anonymity	- Nodes are (pseudo) anonymous	- Nodes are known	
Read permission	- Public data are shared	- Restricted but can be shared	
Immutability	- Altering is almost impossible because transactions are shared with different nodes in the distributed network	- Altering is possible if the pre-authorized nodes want to	

Infrastructure	Decentralized	Centralized as it is controlled by one node	Semi-centralized as it is controlled by many nodes
Efficiency	- Low; many nodes, making transaction processing quite long	- High - Restricted, with few nodes, so fast transaction processing, and high latency	

3. Consensus algorithms of Blockchain

Blockchain systems operate in a decentralized manner, negating the necessity for a third-party that is considered trustworthy. To effectively address disputes between nodes, counteract security breaches, and guarantee the dependability and consistency of data and transactions, blockchain employs a decentralized consensus protocol. This protocol mandates a shared agreement among all nodes regarding the method of content updating. Furthermore, it requires that blocks can only be incorporated into the ledger when a majority agrees, thus maintaining a constant state. This consensus mechanism forms the foundation for generating and appending blocks to the ledger.

Consensus algorithms, in the blockchain field, are specific protocols adopted by distributed networks to attain concurrence regarding the state of the blockchain [7]. These algorithms ensure common validation and sequencing of transactions among all network participants, thus preventing double-spending and maintaining the integrity of the blockchain. These algorithms involve distinct mechanisms employed to achieve consensus and strengthen security in a distributed system.

Prominent consensus algorithms [5] utilized in blockchain technology, include proof-of-work (PoW) and proof-of-stake (PoS). For example, PoW is notorious for its substantial energy consumption due to the competitive nature of miners striving to create blocks by solving complex mathematical puzzles. Miners, in this context, are specific nodes that engage in the process of verifying blocks before appending them to the blockchain structure. Conversely, in PoS, individuals with larger stakes gradually gather more influence, as their likelihood of obtaining a block is dependent on their stake size.

3.1 Proof of Works

The concept of Proof of Work (PoW) was initially introduced by Dwork and Naor, in 1993, with the aim of stopping unsolicited emails and regulating access to shared resources. In 2008, Bitcoin incorporated this concept into its protocol as a consensus algorithm, serving the purpose of achieving agreement on transactions and avoiding the occurrence of double spending attacks.

Consequently, PoW stands as the earliest and pioneering consensus algorithm employed in the context of Blockchain technology. The fundamental notion revolves around motivating miners to employ their computational ability to solve a sophisticated puzzle grounded in a mathematical problem. Once the puzzle is successfully solved, the miner spreads the resulting block across the network for validation by other miners, who assess the correctness of the solution. Upon verification, the block becomes an addition to the Blockchain. Although PoW requires substantial computational capacity and energy usage, its security and reliability have been demonstrated over the passage of time.

3.2 Proof of Stake

Proof of Stake (PoS) stands as an alternate consensus algorithm initially introduced through the Peercoin cryptocurrency, by King and Nadal in 2012. In contrast to the competitive process hinging on energy usage, PoS adopts a selection mechanism that factors in the stakes held by validators. These validators, like miners in a Proof of Work (PoW) setup, are chosen through a selection process that permits the network to choose the node responsible for authenticating the new block. This authentication is proved by demonstrating ownership of a specific coin amount, measured using the «coin age» parameter, which essentially represents the product of the currency quantity and its duration of possession.

Upon the selection of a validator, they validate the block by placing a wager on it and subsequently receive a reward corresponding to the wager they staked. The likelihood of being chosen as a validator is proportional to the volume of cryptocurrency held by an individual. PoS mandates participants to immobilize a designated quantity of their cryptocurrency as collateral. This approach diminishes the necessity for resource-intensive computational power and controls energy consumption.

3.3 Delegated Proof of Stake

Delegated Proof of Stake (DPoS) represents a modified version of the PoS mechanism, incorporating a voting system based on participants› reputations. In contrast to involving all individuals as potential block creators, DPoS hinges on a select group of elected delegates who rotate in generating blocks. These delegates are chosen through a voting process by stakeholders within the network, and their responsibilities encompass transaction validation and blockchain upkeep. The primary objective of DPoS is to enhance scalability and transaction processing capacity by limiting the count of validators involved.

4. Blockchain Advantages and Disadvantages

Blockchain technology possesses several benefits that render it appealing across diverse domains. [8, 9]. Firstly, its decentralized nature ensures robustness against singular vulnerabilities and network attacks, given the absence of a susceptible central server. Furthermore, the transparency and traceability inherent in blockchain facilitate straightforward validation and tracking of transactions, fostering trust and accountability.

Moreover, blockchain delivers heightened security and privacy through the application of cryptographic methods. Participants can engage with the blockchain network using generated addresses, preserving their anonymity, and diminishing the need for centralized entities to verify identities. The utilization of hashing algorithms and consensus mechanisms contributes layers of security to safeguard the integrity of stored data within the blockchain.

Hashing constitutes a pivotal cornerstone of blockchain›s expertise. Each block holds data to be stored, and every subsequent block incorporated into the chain is encoded with a «hash» - a code produced through arithmetic manipulation of the block›s data. This hash serves as a form of digital fingerprint and is often used to secure passwords. Additionally, each newly added block incorporates the hash of the preceding block, forming part of its own hash. Consequently, attempting to alter any new or old block becomes exceptionally challenging. The interlinking of blocks through their hashes creates a tamper-resistant chain, as modifying a single block necessitates rewriting the entire blockchain. This linkage mechanism substantially fortifies security against tampering.

Despite its array of advantages, blockchain technology encounters certain barriers [10].

• Scalability poses a notable issue due to escalating transaction volumes and the continuous storage of data across all network nodes.

• The complexity of blockchain programming and its alignment with global laws and regulations present additional challenges.

• Concerns encompassing consensus algorithms like proof-of-work (PoW) and proof-of-stake (PoS), relate to issues such as energy consumption for PoW and the potential concentration of wealth for PoS.

5. Blockchain in Education

Blockchain technology possesses the capacity to revolutionize multiple industries through its offerings of transparency, security, immutability, and decentralized governance. Its influence spans sectors such as finance, healthcare, government services, education, and the Internet of Things (IoT) [11].

In traditional education, the storage and exchange of physical records and documents play a crucial role and continue to be extensively utilized in educational institutions such as universities, institutes, schools, as well as within ministries of education [12, 13].

However, this reliance on physical records gives rise to various issues. One such concern is the vulnerability associated with having records stored in a single location, leading to a scenario where unexpected events could result in severe loss. Should these physical records be damaged or destroyed due to unforeseen circumstances, recovery becomes a difficult challenge.

Furthermore, difficulties emerge when attempting to exchange records between different institutions, particularly in cases involving student transfers between institutions. The process of exchanging records is complicated and time intensive. For instance, if a student desires to switch from one institution to another, the task of transferring their records becomes cumbersome. Students also encounter challenges during admission applications as they are required to furnish their entire educational history. There exists no universally accepted standard system capable of delivering such services to all institutions.

Additionally, institutions engage in numerous repetitive transactions involving students, employees, suppliers, vendors, and government bodies. Instances of corruption at higher levels of authority are conceivable. The integration of decentralized auditing into the financial systems of institutions presents a potential remedy to mitigate such corruption.

In the context of organizations needing to recruit graduates, extensive documentation is often demanded to confirm a candidate›s suitability for the offered positions. This process places a significant time and effort burden on both the student and the institution. Thus, a centralized entity possessing comprehensive data about students and graduates could streamline and simplify administrative procedures that necessitate validation. Employing blockchain technology in this context emerges as a viable solution, as it ensures the integrity of all student data, preserving it in an unaltered state and allowing for retrieval as needed.

5.1 Academic Records Management

Blockchain technology has the potential to significantly impact the management of academic records and transcripts in the educational sector [14]. Here›s how blockchain can be used in this context:

• Immutable Records: Blockchain provides a secure and tamper-proof way to store academic records. Each academic achievement, such as degrees, diplomas, and certificates, can be recorded as a transaction on the blockchain, creating an immutable and transparent record. This ensures the integrity and authenticity of the credentials, making it difficult for them to be forged or manipulated.

• Verification and Authentication: Employers, educational institutions, and other relevant parties can easily verify the authenticity of academic records stored on the blockchain. By accessing the decentralized ledger, they can independently verify the records without relying on a central authority. This streamlines the verification process, reduces administrative burdens, and mitigates the risk of fraudulent credentials.

• Ownership and Control: With blockchain, individuals can have ownership and control over their academic records. Students can maintain a digital wallet containing their verified credentials and share them with prospective employers or other institutions as needed. This eliminates the need for intermediaries and gives individuals greater control over their educational data.

• Credential Transparency and Transferability: Blockchain enables transparent and auditable records of educational achievements. Students can track their progress, view completed courses, and monitor their achievements in a secure and decentralized manner. Additionally, the transferability of credentials becomes easier as blockchain allows for seamless sharing and transfer of records between educational institutions or employers, facilitating a smoother transition for students.

• Enhanced Data Security and Privacy: Blockchain employs cryptographic techniques to protect sensitive data, ensuring its security and privacy. Personally identifiable information can be stored off-chain, while the blockchain ledger maintains a reference to the data, preserving privacy while still allowing for verification. This helps address concerns related to data breaches and unauthorized access to personal information.

• Streamlined Processes and Reduced Costs: Adopting blockchain for academic records and transcripts can streamline administrative processes, reducing paperwork, manual verification efforts, and the need for physical document handling. This can result in cost savings for educational institutions and faster, more efficient credential verification for employers and other stakeholders.

• Lifelong Learning and Micro-credentials: Blockchain can facilitate the recognition and management of micro-credentials and lifelong learning achievements. Students can accumulate a variety of credentials, including short courses, certifications, and badges, and store them on the blockchain. This promotes a more comprehensive and holistic representation of an individual›s skills and competencies, beyond traditional degree programs.

• Fraud Prevention and Academic Integrity: By utilizing blockchain, educational institutions can combat credential fraud and enhance academic integrity. The transparent and immutable nature of blockchain records makes it easier to identify and prevent cases of credential misrepresentation or plagiarism. This helps maintain the credibility and reputation of educational institutions.

It›s worth noting that the implementation of blockchain in the education sector for academic records and transcripts is still in its early stages. However, several pilot projects and initiatives are exploring its potential benefits, and it is expected that the adoption of blockchain technology in this area will increase in the coming years.

5.2 Credential Verification

Blockchain technology offers the potential to transform the authentication of credentials within the education sector, presenting mass of advantages [15]. Here›s a look at how blockchain can be employed in this context:

• Decentralized Validation: Blockchain furnishes a decentralized framework for confirming educational credentials. In place of relying on a central entity or third-party authentication services, blockchain functions as a distributed ledger where educational institutions can record and validate credentials. This obviates the necessity for manual verification processes and limits the risk of counterfeit qualifications.

• Immutable Records: Credentials stored on the blockchain are immutable and resistant to tampering. Once a credential is incorporated into the blockchain, any alteration or deletion necessitates consensus across the network. This upholds the credentials› integrity and authenticity, rendering them difficult to forge or manipulate.

• Instantaneous Confirmation: Blockchain-driven credential verification enables real-time confirmation of educational achievements. Employers, educational institutions, or other relevant entities can directly access the blockchain to verify a credential, bypassing time-consuming manual procedures. This accelerates the verification process and minimizes delays in confirmation.

• Elevated Trust and Transparency: Blockchain offers a transparent and auditable system for confirming credentials. The decentralized nature of blockchain guarantees that all transactions and credential updates are visible to relevant parties. Such transparency nurtures trust among stakeholders, as they can autonomously verify credential authenticity without relying on a central authority.

• Privacy and Data Protection: While blockchain offers transparency, it also accommodates personal data protection. This ensures privacy while facilitating verification of credential legitimacy.

• Interoperability and Standardization: Blockchain can promote interoperability and standardization of credential authentication across diverse educational institutions and organizations. Through the adoption of shared standards and protocols, institutions can easily exchange and authenticate credentials, simplifying the process and limiting redundant verification efforts.

• Cost and Efficiency Gains: Integrating blockchain for credential validation can yield cost savings for educational institutions and employers alike. It diminishes the administrative burden associated with manual verification procedures, like contacting issuing institutions or relying on third-party validation services. This produces improved efficiency and decreases operational expenses.

• Global Acceptance: Blockchain-based credential validation can amplify the recognition of educational qualifications on a global scale. As the blockchain functions as a decentralized network, it allows for cross-border validation without complex and time-intensive procedures. This particularly benefits international students or professionals seeking overseas employment or further education.

Although blockchain›s potential for credential validation in education is promising, challenges such as interoperability, scalability, and the need for widespread adoption must be acknowledged. Nonetheless, multiple initiatives and projects are exploring blockchain›s application for this purpose, indicative of a growing interest in leveraging this technology to streamline and enhance the credential verification process.

5.3 Blockchain Models and Frameworks for Educational Systems

Numerous blockchain models and frameworks tailored for educational systems have emerged [15, 16], including:

• Blockcerts, an open standard and framework devised by Learning Machine and MIT Media Lab, serves to generate, distribute, and validate blockchain-based educational credentials. It enables educational institutions to issue secure digital certificates to students, easily verifiable by employers and other institutions.

• Open Badges, an open standard by the Mozilla Foundation, facilitates the creation and issuance of digital badges signifying learning accomplishments. Although not exclusively reliant on blockchain, Open Badges can be integrated with blockchain platforms to heighten badge security and authentication.

• Learning Machine›s Federated Issuing System, a blockchain-driven credentialing platform, provides a Federated Issuing System that permits educational institutions to create and validate digital credentials utilizing blockchain technology. This establishes a secure and interoperable framework for credential management across multiple institutions.

• Sony Global Education›s Blockchain-based Platform pioneers a blockchain-centered solution for educational data management. This platform ensures secure storage and sharing of educational records, encompassing academic transcripts and certificates, all while maintaining data privacy and integrity.

• Learning Economy, a blockchain-powered platform, envisions a decentralized marketplace for educational resources, credentials, and services. It grants learners access to diverse educational content and services, all while preserving transparency, traceability, and equitable compensation for content creators.

• BitDegree, an online learning platform, harnessing blockchain for learning motivation. It provides token rewards and scholarships to learners who complete courses and achieve learning milestones. This blockchain-based system guarantees transparency and trust throughout the reward distribution process.

• WISE Network (Worldwide Integrated Scholarly Environment), a blockchain-infused platform, seeks to revolutionize scholarly publishing and peer review. It creates a decentralized, transparent infrastructure for academic researchers to publish, share, and assess scholarly content.

These examples offer just a glimpse into the array of blockchain models and frameworks employed or proposed for integration into educational systems. It›s important to recognize that blockchain›s integration into education is still evolving, with diverse organizations and initiatives actively exploring and cultivating inventive applications of blockchain technology in the educational field.

6. Blockchain Proposed Model for Educational Students› Data

The proposed model advocates for the establishment of a unit within the higher education ministry that employs blockchain models for safeguarding educational data and records of students and graduates, thereby facilitating verification procedures for various organizations› recruiters.

6.1 Proposed Model

The proposed model suggests the creation of a new unit in the higher ministry of education, that comprises two partitions:

• The initial partition stores undergraduates› data, encompassing grade records and GPAs (Grade Point Average) at each educational level. This aids students during transitions between institutions.

• The second one, stores graduates› certificates, offering benefits to graduates and prospective employers by enabling the verification of candidates› information.

Outlined below are the models for those partitions, which employ blockchains to preserve either students or graduates› data for situations such as students› transfer or certificates› validation.

Partition 1:

The operational process of the first partition is illustrated in the following steps:

1. A higher education institution initiates a transaction containing student data.

2. A block representing the transaction is generated and disseminated to all participants, including the higher education ministry and other higher education institutions.

3. Validation of the transaction block is exclusive to the unit within the higher education ministry.

4. Upon validation, the block is incorporated into the blockchain. Whenever a student seeks to

transfer to another institution, the latter can verify the student›s data from the blockchain.

Partition 2:

The operational process of the second partition is outlined below:

1. Per semester, a higher education institution solicits a transaction encompassing graduates› certificate.
2. A block symbolizing the transaction is formulated and shared across all nodes.
3. Validation of the transaction block remains the role of the unit within the higher education ministry.
4. Upon validation, the block is integrated into the blockchain.

Each educational institution follows these steps to append their graduates› certificates. Subsequently, any organization›s recruiters can access a candidate›s certificate for job assessments.

Figure 1 shows the model›s different entities and the flow of data, since the issuing of the transactions› requests, for students and graduates updated data, to the validation of the higher ministry of education and finally having all the data available to all educational institutions and organizations› recruiters.

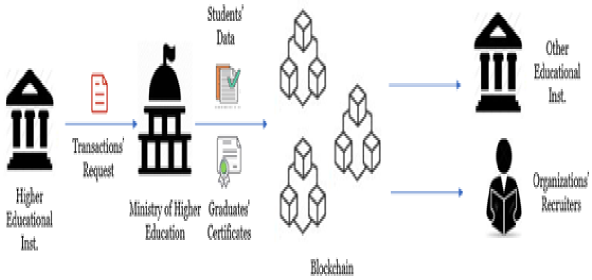

Figure 1. Proposed Model showing the data flow between the different entities

6.2 Proposed Model Advantages

Blockchain technology offers an array of potential solutions that could play a pivotal role within educational systems. In the proposed model, implementing blockchain technology yields several advantages:

- Decentralization: Distributing data across numerous entities effectively eliminates central failure points and bottlenecks.
- Scalability: Avoiding scenarios where one or a few entities control the storage and processing of information for multiple individuals.
- Reliability: Information remains unaltered, immutable, and spread across time within the blockchain. Any participant can verify data authenticity and confirm its lack of alteration.
- Security: Treating information and communications as blockchain transactions can reinforce security.

Ultimately, this framework reduces administrative costs, time, labor, and simplifies bureaucracy.

7. Conclusion and Prospects for the Future

Blockchain technology stands as a groundbreaking avenue for enhancing the interaction between public services and educational systems, fostering transparency. Its novelty lies in its skilled combination of transparency, integrity, confidentiality, and accountability when carefully implemented.

The integration of blockchain technology within the educational sector bears the potential to improve administrative burdens in diverse scenarios, such as verification and migration processes. Furthermore, it holds the promise of reducing the expenses and exertions linked to conventional manual procedures. Moreover, it introduces a streamlined mechanism for employers to effortlessly access and authenticate certificates during the hiring process through a singular application, eliminating the need to engage the issuing institution separately.

8. List of Abbreviations

DPoS	Delegated Proof of Stake
GPA	Grade Point Average
IoT	Internet of Things
PoS	Proof-of-Stake
PoW	Proof-of-Work
WISE Network	Worldwide Integrated Scholarly Environment

9. References

[1] Monrat, Ahmed Afif, Olov Schelén, and Karl Andersson. «A survey of blockchain from the perspectives of applications, challenges, and opportunities.» (2019) IEEE Access 7: 117134-117151.

[2] Lykidis, Ioannis, George Drosatos, and Konstantinos Rantos. «The use of blockchain technology in e-government services.» (2021) Computers 10.12: 168.

[3] Crosby, Michael, et al. «Blockchain technology: Beyond bitcoin.» (2016) Applied Innovation 2.671 :10-.

[4] Nakamoto, Satoshi. «Bitcoin: A peer-to-peer electronic cash system.» (2008) Decentralized business review.

[5] Zheng, Zibin, et al. «Blockchain challenges and opportunities: A survey.» (2018) International journal of web and grid services 14.4: 352375-.

[6] Bhutta, Muhammad Nasir Mumtaz, et al. «A survey on blockchain technology: Evolution, architecture and security.» (2021) Ieee Access 9: 6104861073-.

[7] Azbeg, Kebira, et al. «An overview of blockchain consensus algorithms: Comparison, challenges and future directions.» (2021) Advances on Smart and Soft Computing: Proceedings of ICACIn 2020: 357369-.

[8] Bodkhe, Umesh, et al. «Blockchain for industry 4.0: A comprehensive review.» (2020) IEEE Access 8: 7976479800-.

[9] Baiod, Wajde, Janet Light, and Aniket Mahanti. «Blockchain technology and its applications across multiple domains: A survey.» (2021) Journal of International Technology and Information Management 29.4: 78119-.

[10] Damoska Sekuloska, J., and A. Erceg. «Blockchain Technology toward Creating a Smart Local Food Supply Chain.» (2022) Computers 2022, 11(6), 95.

[11] Ali, Omar, et al. «A comparative study: Blockchain technology utilization benefits, challenges and functionalities.» (2021) Ieee Access 9: 1273012749-.

[12] Yumna, Hafiza, et al. «Use of blockchain in education: a systematic literature review.» (2019) Intelligent Information and Database Systems: 11th Asian Conference, ACIIDS 2019, Yogyakarta, Indonesia, April 8-11, 2019, Proceedings, Part II 11. Springer International Publishing.

[13] Turcu, Cristina, Cornel Turcu, and Iuliana Chiuchisan. «Blockchain and its Potential in Education.» (2019) arXiv preprint arXiv:1903.09300.

[14] Raimundo, Ricardo, and Albérico Rosário. «Blockchain system in the higher education.» (2021) European Journal of Investigation in Health, Psychology and Education 11.1: 276293-.

[15] Saleh, Omar S., Osman Ghazali, and Muhammad Ehsan Rana. «Blockchain based framework for educational certificates verification.» (2020) Journal of critical reviews 7.3: 7984-.

[16] Ullah, Nazir, et al. «Blockchain technology adoption in smart learning environments.» (2021) Sustainability 13.4: 1801.