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Original Contribution

BLOCKCHAIN TECHNOLOGY AND ITS APPLICATION IN THE CERTIFICATION OF EDUCATIONAL ACHIEVEMENTS

Desislava N. Ivanova

DEPARTMENT OF COMMUNICATION AND COMPUTER ENGINEERING AND SECURITY TECHNOLOGIES, FACULTY OF TECHNICAL SCIENCES, KONSTANTIN PRESLAVSKY UNIVERSITY OF SHUMEN, SHUMEN 9712,115, UNIVERSITETSKA STR., E-MAIL: d.n.ivanova@shu.bg

ABSTRACT: *Blockchain technology has gained significant attention in education due to its potential to improve the verification of diplomas, certificates, and skills. By ensuring decentralization, transparency, and immutability, it offers a secure and efficient alternative to traditional systems that are often slow and vulnerable to fraud. This paper reviews key applications of blockchain in the educational sector, with a focus on credential verification and smart contracts. It also discusses current challenges such as scalability, regulations, and energy consumption. The findings suggest that blockchain can contribute to greater trust, efficiency, and global mobility in education.*

KEY WORDS: *Blockchain, education, credential verification, smart contracts, decentralization.*

1. Introduction

Over the past decade, blockchain technology has established itself as one of the major innovations in the field of information technology. Initially developed for the needs of cryptocurrencies, it quickly attracted the attention of other sectors such as healthcare, supply chain management, public administration and education [1]. The main reason for this widespread interest is related to its unique characteristics: decentralized information storage model, high security and immutability of data. These qualities make it particularly suitable for environments where it is necessary to ensure trust between different actors without the presence of a central intermediary.

In education, blockchain is seen as a potential solution to a number of existing problems. Most attention is being paid to the certification of educational achievements - diplomas, certificates and qualifications. Traditional verification methods often prove slow, expensive and highly vulnerable [15] to forgery. This creates challenges not only for individual institutions, but also for the

international mobility of students and professionals, since the recognition of diplomas and qualifications often involves heavy administrative procedures [2].

The application of blockchain in this area opens up opportunities to build a new type of educational infrastructure where the certification of achievement is both secure, transparent and globally accessible. In this way, technology can contribute to improving the quality and efficiency of the educational process, as well as to better match labor market needs with acquired skills.

2. Theoretical foundations of blockchain technology

Blockchain technology is a distributed ledger in which transactions or records are stored in linked blocks of data. Each block contains a timestamp, a cryptographic hash of the previous block, and transaction information, which ensures immutability and traceability of the data [3]. Due to this structure, data recorded in a blockchain cannot be tampered with without altering all subsequent blocks and achieving consensus among network participants.

The main characteristics that distinguish blockchain from traditional centralized systems are decentralization, transparency, and immutability. Decentralization means that there is no single authority controlling the entire process - instead, data is stored simultaneously across multiple nodes. Transparency ensures that every transaction can be verified by all participants in the system, while immutability provides confidence that once information is entered, it cannot be changed or deleted [4].

In addition to the basic functions, blockchain enables the implementation of smart contracts - automated programs that execute predefined conditions without the need for an intermediary. This functionality is particularly useful in the educational context, where it can be used to automatically authenticate credits, courses or certificates as soon as the learner fulfils the necessary requirements [5].

According to recent survey research, blockchain is seen as a fundamental technological basis for the creation of an "educational passport" - a digital profile that contains all of an individual's academic and professional achievements throughout their life [1]. This lays the foundation for the integration of lifelong learning principles and for a more flexible recognition of qualifications internationally.

Figure 1 presents the basic model of a blockchain. Each unit of data is organized into a "block" that contains three main elements: useful information (Data), its own cryptographic fingerprint (Hash) and the fingerprint of the previous block (Prev. Hash). Due to these interrelationships, a continuous "block chain" is formed in which any change would result in a mismatch and would automatically reveal itself. This feature makes the technology extremely suitable for secure storage of educational achievements, as any attempts to forge diplomas or certificates would be immediately detected.

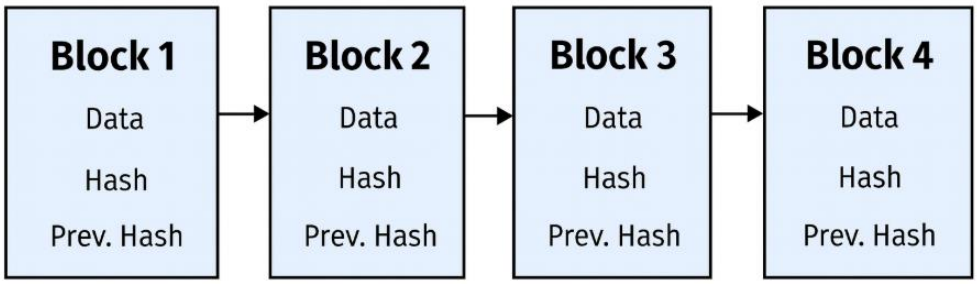

Fig. 1. Basic blockchain model

In a centralized architecture, all data and requests are processed by a single server, creating a "single point of failure" and vulnerability [15] to failure or malicious interference. On the flip side, a decentralized blockchain network consists of multiple peer nodes that collectively maintain the ledger. There is no central server - each node has a copy of the chain and can participate in the verification process. This increases resilience and transparency by allowing institutions, employers and learners to easily verify the authenticity of a credential without the need for a central intermediary. An architecture of a centralized and decentralized system is shown in figure 2.

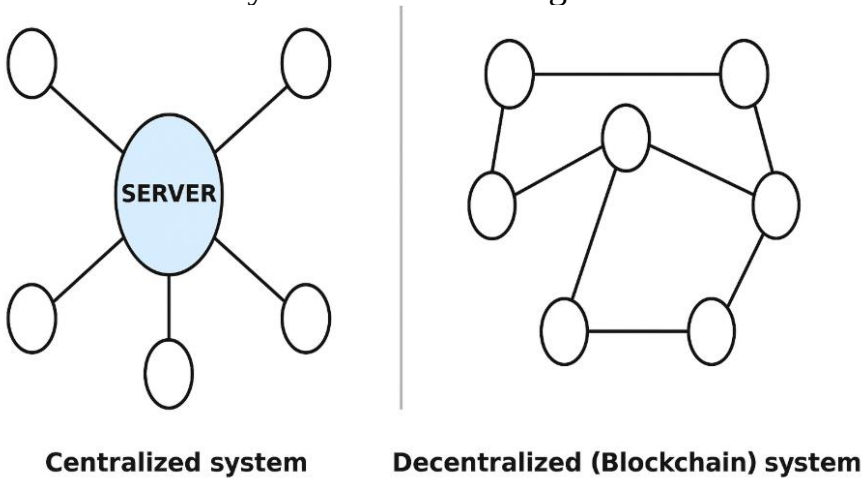

Fig. 2. Centralized and decentralized (blockchain) system

Fig. 3 shows the application of a smart contract for automatic certificate issuance. The process proceeds in four steps: (1) the learner completes a course, (2) the institution formally signs the results, (3) the smart contract verifies the predefined conditions (e.g., minimum grade), and (4) in case of completion, the certificate is automatically saved in the blockchain. The process is thus fully automated and reliable, eliminating the possibility of manipulation and speeding up verification. In the context of education, this solution facilitates learner mobility and increases the credibility of the achievement recognition system.

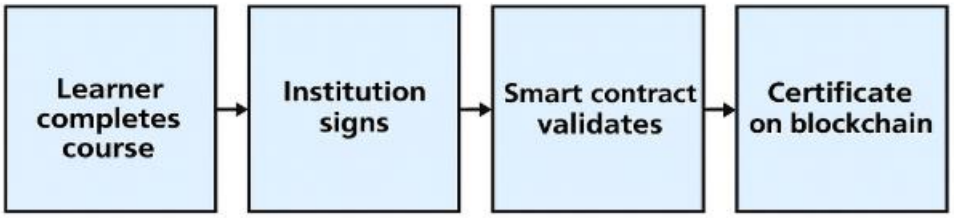

Fig. 3. Smart contract for automatic certificate issuance

2. Problems in traditional certification systems

Traditional credentialing systems rely on centralized databases and paper documents. While this model has proven its effectiveness over decades, in the context of globalization and digitalization it shows a number of limitations [6].

First of all, there is a significant risk of falsification. Research shows that employers and institutions are increasingly confronted with fake diplomas or certificates that are hardly distinguishable from the original ones [7]. Traditional verification methods require contact with the issuing institution, a process that takes time and does not always provide the necessary transparency.

Secondly, the slow process of international recognition of qualifications is a problem. When learners are mobile between countries and educational institutions, the verification of diplomas and academic credits can take weeks or even months [8]. This creates an administrative burden and hinders the rapid integration of professionals into new academic or professional environments.

Third, the centralized model suffers from a lack of sustainability and transparency. In the event of a failure or cyber-attack on the central database, access to certificates can be compromised [9]. In addition, learners have limited control over their own achievements - diplomas and certificates remain 'locked' in institutional registers and are difficult to transfer between different educational and professional contexts.

Traditional systems often do not reflect the dynamics of lifelong learning. More and more learners acquire skills through short courses, online training and micro-certificates. However, centralized registries are designed primarily for formal education and cannot effectively integrate these new forms of achievement [10].

All of these issues highlight the need to introduce more secure and effective credentialing solutions that meet the needs of the modern education ecosystem. This is where blockchain technology is being successfully implemented.

3. Applications of blockchain in education

In recent years, there has been increased interest in the practical application of blockchain technology in education. Numerous initiatives are being

developed to address issues related to authentication, transparency and learner mobility.

One of the most widely discussed areas is the authentication of diplomas and certificates. Universities such as the Massachusetts Institute of Technology (MIT) are already experimenting with digital diplomas issued and stored on a blockchain, allowing employers and institutions to quickly and securely verify their authenticity [2]. This solution eliminates the risk of forgery and significantly reduces the time required for verification.

Another important example relates to European initiatives for educational mobility. The European Commission has launched the European Blockchain Services Infrastructure (EBSI) project, which aims to build a cross-border infrastructure for digital identities and diplomas. In this way, learners will be able to transfer their credentials between different member states without facing long administrative procedures [11].

Blockchain also offers new opportunities for integrating informal and continuing education. Certificates, which are often issued after short courses or online training, can be registered in a decentralized system. This allows learners to build a 'digital portfolio' of achievements that is transparent, easily transferable and internationally recognized [10].

The combination of these applications shows that blockchain can be seen not just as a technological innovation, but as a strategic step towards building a more flexible, secure and connected learning ecosystem.

4. Challenges and limitations of blockchain in education

Despite the many advantages and innovative applications [16], the implementation of blockchain in the educational sphere is accompanied by a number of challenges and limitations.

Technological complexity and scalability remain a serious issue. Many public blockchain networks are characterized by slow transaction processing and high data storage costs, making them difficult to implement in systems with large numbers of learners [6].

Legal and regulatory issues require special attention. In the European context, for example, the question of how blockchain solutions fit with the General Data Protection Regulation (GDPR) is being raised. While data immutability is one of the main advantages of the technology, it potentially conflicts with the right to "forget" and control over personal information [2].

Energy consumption is a factor that cannot be ignored. Although education typically uses lighter and private blockchain networks rather than energy-intensive systems such as those for cryptocurrencies, public concerns about the sustainability of the technology remain relevant [7].

It should be noted that there are also organizational challenges - blockchain implementation requires not only technological readiness, but also a change in

the management culture of educational institutions. Many educational institutions are still wary of data sharing and coordination within a decentralized network.

The importance of developing integrated and secure information systems that guarantee data reliability and protection is highlighted in recent research, emphasizing principles that are closely aligned with the objectives of blockchain-based educational solutions [8].

In this sense, while blockchain offers promising opportunities for the future of education, its successful implementation depends on overcoming these technological, legal and organizational barriers.

5. Future perspectives and trends

Despite the challenges, the development of blockchain in education shows significant potential to transform the sector in the coming years. Several trends are emerging that could change the way knowledge and skills are managed and credentialed.

There is increased interest in the integration between blockchain and artificial intelligence (AI). The use of AI algorithms in combination with decentralized registries can provide automated mechanisms for competency assessment and personalized learning pathways that are recorded directly in the blockchain [9]. This would create dynamic learner portfolios that adapt to the skills being acquired in real time.

The concept of Web3 and Decentralized Identifiers (DIDs) is also of interest. Learners will have their own digital identity through which they can manage access to their diplomas and certificates. Thus, control over personal educational data shifts from institutions to the learners themselves, increasing their autonomy and protecting their personal information [10].

The future of blockchain in education is also about global interoperability. International initiatives such as the European Blockchain Services Infrastructure (EBSI) show that it is possible to build cross-border authentication systems that can be used across countries and institutions [3]. Such projects will facilitate academic and professional mobility by significantly reducing administrative barriers.

The future prospects for blockchain in education go beyond the purely technological aspect. They imply a complete transformation of the educational ecosystem, where transparency, learner autonomy and global connectivity will be placed at the center of the process.

Broader studies on security management also emphasize the importance of integrating protective mechanisms into evolving digital ecosystems, highlighting that sustainable development in sectors such as education depends on maintaining both data and organizational security [13].

The continuous improvement of data transmission technologies also supports the development of secure and efficient blockchain infrastructures. Recent studies highlight the importance of reliable communication modules for managing and analyzing distributed information in real time [14].

6. Conclusion

Blockchain technology is establishing itself as a solution for modernizing processes in education. With its unique features - decentralization, transparency, immutability and security - it offers an effective answer to the challenges of credentialing, certificates and competences. Analysis of existing applications shows that blockchain can provide faster and more reliable verification of achievements, facilitate international mobility, and give learners greater control over their educational data.

At the same time, implementing blockchain in educational practice is not without its challenges. Technological constraints, regulatory requirements and the need for organizational change highlight that blockchain is not a one-size-fits-all solution, but a tool whose successful implementation depends on careful planning and collaboration between different stakeholders.

Future trends point to integration with artificial intelligence, the development of decentralized identities, and the building of cross-border infrastructures that can transform the education ecosystem on a global scale. In this context, blockchain should not be seen as a mere technological novelty, but as a strategic opportunity to enhance the credibility, quality and flexibility of education in the 21st century.

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