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Smart Contracts in Blockchain-Based Digital Education Platforms

Abstract


The integration of smart contracts into blockchain-based digital educational platforms enables radically increased transparency, security, and automation of processes: from issuing verifiable certificates and automatic course enrollment to distributing scholarships and motivating students through tokenized rewards. This article examines the theoretical foundations of smart contracts, their use, architectural solutions, and implementation, as well as a practical section with an implementation example in Solidity. These factors determined the primary objective of this work: a conceptual analysis of the integration of blockchain technologies into online educational platforms. The methodological framework is based on a comprehensive approach, including the systematization of theoretical data and a critical analysis of the implementation of decentralized ledgers in modern digital systems. Particular attention is paid to the analysis of mechanisms for ensuring the immutability of academic achievement data, thereby eliminating the possibility of diploma falsification. A model of a decentralized autonomous educational environment facilitating the development of individual learning paths is also proposed.

An example of successful cases of integrating distributed ledgers into a learning management system (LMS) is provided, demonstrating a reduction in administrative costs. The conclusion, of course, summarizes the research and outlines prospects for scaling similar systems within the global educational space.

Keywords: *digital platform, educational platform, blockchain, information technology, contract, smart contracts*

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Blokçeyn əsaslı rəqəmsal təhsil platformalarında ağıllı müqavilələr

Xülasə

Ağıllı müqavilələrin blokçeyn əsaslı rəqəmsal təhsil platformalarına inteqrasiyası şəffaflığın, təhlükəsizliyin və proseslərin avtomatlaşdırılmasının kökündən artırılmasına şərait verir: təsdiqlənə bilən sertifikatların verilməsindən və avtomatik kurs qeydiyyatından tutmuş təqaüdlərin paylanmasına və tələbələrin tokenləşdirilmiş mükafatlar vasitəsilə motivasiyasına qədər. Bu məqalədə ağıllı müqavilələrin nəzəri əsasları, onların istifadəsi, memarlıq həlləri və tətbiqi, eləcə də Solidity-də tətbiq nümunəsi olan praktik bölmə araşdırılır. Bu amillər bu işin əsas məqsədini müəyyən etdi: blokçeyn texnologiyalarının onlayn təhsil platformalarına inteqrasiyasının konseptual təhlili. Metodik çərçivə nəzəri məlumatların sistemləşdirilməsi və müasir rəqəmsal sistemlərdə mərkəzləşdirilməmiş kitabların tətbiqinin tənqidi təhlili daxil olmaqla hərtərəfli yanaşmaya əsaslanır. Akademik nailiyyət məlumatlarının dəyişməzliyini təmin etmək mexanizmlərinin təhlilinə xüsusi diqqət yetirilir və bununla da diplom saxtəkarlığı ehtimalını aradan qaldırır. Fərdi təlim yollarının inkişafını asanlaşdıran mərkəzləşdirilməmiş muxtar təhsil mühitinin modeli də təklif olunur. Paylanmış kitabların təlim idarəetmə sistemində (LMS) inteqrasiyasının uğurlu hallarına nümunə təqdim olunur və inzibati xərclərin azaldığını göstərir. Nəticə, əlbəttə ki, tədqiqatı ümumiləşdirir və qlobal təhsil məkanında oxşar sistemlərin miqyaslandırılması perspektivlərini müəyyən edir.

***Açar sözlər:** rəqəmsal platforma, təhsil platforması, blokçeyn, informasiya texnologiyaları, müqavilə, ağıllı müqavilələr*

Introduction

Smart contracts are a fundamental component of modern blockchain platforms, enabling automated, deterministic, and decentralized execution of agreements. Since the concept of smart contracts by Nick Szabo (Satoshi Nakamoto) in 1994 and their practical implementation on Ethereum

in 2015, the technology has undergone significant evolution (Angraal, et al., 2017). Smart contracts are self-executing agent programs stored and executed in a distributed blockchain environment, ensuring immutability, transparency, and the elimination of the need for trusted intermediaries.

When a new block is created in the blockchain, its hash is generated—a unique 256-bit number. It contains information about the block itself and helps link it to previous blocks in the chain.

The block hash encodes several important pieces of information. First, it indicates the software version—the version of the client used to operate the network. Second, it records the hash of the previous block. This links each new block to the previous one, and the entire blockchain forms a unified system.

The block also includes a Coinbase transaction—the first transaction in the block. It records the reward for the miner who found and created the block. Additionally, the block's height is indicated—its serial number in the blockchain, indicating how far it is from the very first block.

An important part is the Merkle root—a special 256-bit value that stores summary information about all transactions within a block. This allows for quick verification of whether certain transactions are included in a given block.

A timestamp is also recorded in the block, indicating the date and time the block was created. The "target" parameter, in bits, determines the network difficulty level—how difficult it is to find a new block. Finally, a "nonce" is used—a special 32-bit number that miners constantly change to find a suitable block hash.

First, all new transactions are queued. Then, they are combined into a block. After this, miners begin searching for a value that will ensure the block hash meets network requirements. When a suitable hash is found, the block is considered created and added to the blockchain.

Since each block contains the hash of the previous block, the entire chain is linked. If you try to change the information in one block, its hash will also change, breaking the link with subsequent blocks. Therefore, changing data that has already been recorded is virtually impossible.

Verifying and adding new blocks to the network occurs through a process called mining.

Mining is the process by which transactions are verified and new blocks are created on the blockchain network. This is performed by specialized programs running on computers or hardware designed specifically for mining. The basis of mining is a hash. A hash is the result of processing block data using a special algorithm. The result is a string of numbers and letters of a fixed length, regardless of how much information was processed. Typically, these values are written in hexadecimal format, which can be converted to a standard numeric value if necessary.

During mining, programs constantly create new hashes. They try to find a hash equal to or less than a predetermined value set by the network. To achieve the desired result, the program modifies a special number called a nonce. Initially, its value is one, and then it increases by one with each new attempt.

The number of hashes a device can calculate in one second is called the hash rate. The higher the hash rate, the more attempts the device makes and the higher the probability of finding the desired hash.

All miners in the network perform these calculations simultaneously, effectively competing with each other. The miner who finds the correct hash first receives a reward. A new block is then created, added to the blockchain, and the process repeats for the next set of transactions.

This paper examines distributed ledger technology (blockchain) as the object of study, while the functionality of smart contracts is the subject matter. This article presents a systematic review of the theoretical foundations of smart contracts, an analysis of their application in various domains, and a practical demonstration of contract development and deployment using the Solidity language. Particular attention is paid to security, scalability, and integration with external data. The practical part includes the implementation of basic and extensible smart contract programming patterns.

Research

Traditional online education systems face a number of systemic challenges: certificate fraud, lack of trust in academic performance data, high administrative costs, difficulty transferring credits between institutions, and opaque funding distribution. As of 2025-2026, the technology will be

actively used for issuing digital diplomas and certificates; automating payments and content access; and creating decentralized educational service markets (Monrat, 2019).

Current research focuses on vulnerability analysis, performance optimization, and expanding application areas—from decentralized finance (DeFi) to supply chain management and digital identity. Despite significant progress, security issues (reentrancy, integer overflow, etc.), high transaction costs, and legal interpretation remain pressing. The introduction of smart contracts in education opens up new opportunities for increasing transparency, efficiency, and automation of management and educational processes. An analysis of practical experience in the digital transformation of educational institutions shows that this technology can be successfully integrated into various areas of activity—from administration to monitoring academic results. One of the key advantages of using smart contracts in education is the automation of organizational procedures.

For example, it is possible to automate the process of student enrollment, scholarship awards, tuition payments, and the issuance of certificates upon meeting established requirements. This helps reduce administrative costs and minimize the impact of human error (Dhillon, Met, et al., 2017). Furthermore, smart contracts can ensure the transparent storage and transmission of student performance data. Information on exam results, course completion, and qualifications can be recorded in a distributed system, eliminating the possibility of forgery or unauthorized modification (Schuhknecht, et al., 2019; Peng, et al., 2020; Yang, et al., 2022). The figure shows a basic model for blockchain and smart contracts in education (Figure 1).

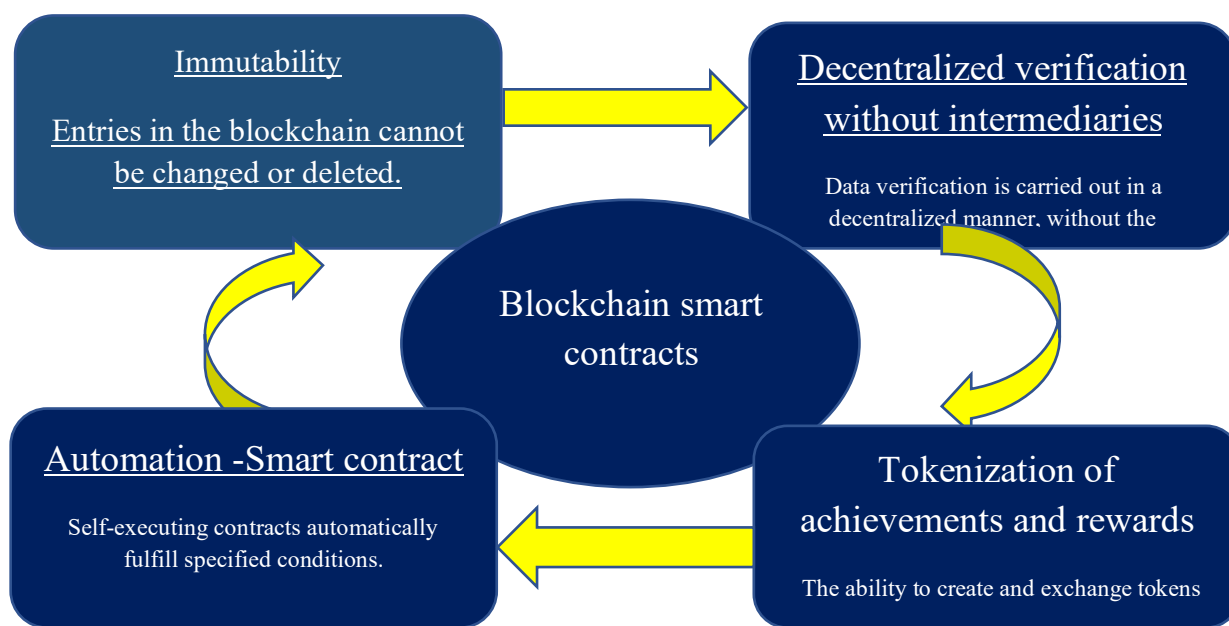


Figure 1: A basic model

An additional benefit is increased trust between participants in the educational process. Employers gain the ability to quickly verify the authenticity of diplomas and certificates, and students can be confident in the objective assessment of their achievements. Thus, the use of smart contracts in education contributes to the digitalization of the industry, improves the quality of governance, and creates a more transparent and reliable educational environment. In terms of architecture and operating principles, a smart contract is software code that is hosted at a unique address on the blockchain network and executed by the virtual machine of the corresponding platform, such as Ethereum using the Ethereum Virtual Machine.

Once deployed, the contract becomes part of the distributed ledger and operates within the established algorithms without the involvement of intermediaries. Architecturally, a smart contract consists of a set of functions and data stored on the blockchain. Users or other contracts interact with

it through transactions, initiating specific operations. All actions are recorded in the ledger, ensuring transparency and verifiability of processes.

To demonstrate practical implementation, we will consider an example in Solidity based on Ethereum. This paper will use smart contracts for educational platforms. An example (Figure 2) of writing a smart contract for issuing a verifiable certificate is provided.

Smart contracts operate based on a number of key principles. First, determinism: given the same input data, the execution result will always be the same. This guarantees predictability and eliminates the possibility of arbitrary code interpretation.

Second, isolation: execution occurs in a special virtual environment (a "sandbox"), preventing direct access to external resources and reducing the risk of unauthorized interference.

Third, immutability: once placed on the blockchain, the smart contract code generally cannot be changed. This ensures a high level of trust in the system, as the terms of execution are fixed in advance and cannot be unilaterally revised (Mohammed, 2023). Thus, smart contracts are autonomous digital mechanisms whose operation is based on the principles of transparency, security, and automation of the execution of obligations.

```
// SPDX-License-Identifier: MITpragma solidity ^0.8.20;

import "@openzeppelin/contracts/token/ERC721/ERC721.sol";
import "@openzeppelin/contracts/access/Ownable.sol";
import "@openzeppelin/contracts/utils/Strings.sol";

contract XXXCertificate is ERC721, Ownable {
    uint256 private _tokenIdCounter;

    mapping(uint256 => string) private _certificateMetadata;
    mapping(address => uint256[]) private _studentCertificates;

    event CertificateIssued(address indexed student, uint256 tokenId, string courseCode);

    constructor() ERC721("XXXCertificate", "XXXX") Ownable(msg.sender) {}

    function issueCertificate(
        address student,
        string memory courseCode,
        string memory metadataURI
    ) external onlyOwner {
        _tokenIdCounter++;
        uint256 newTokenId = _tokenIdCounter;

        _safeMint(student, newTokenId);
        _certificateMetadata[newTokenId] = metadataURI;
        _studentCertificates[student].push(newTokenId);

        emit CertificateIssued(student, newTokenId, courseCode);
    }

    function tokenIdURI(uint256 tokenId) public view virtual override returns (string memory) {
        _requireOwned(tokenId);
        return _certificateMetadata[tokenId];
    }
    function getStudentCertificates(address student) external view
        returns (uint256[] memory) {
        return _studentCertificates[student];
    }
}
```

Figure 2. Example of blockchain data

Here's how the entire process looks: first, there's preparation, i.e., contract deployment. We release this contract to the network, for example, Ethereum. At this point, you become the Owner (in our case, the Owner). The contract is named XXXCertificate and the symbol XXXX, which is the short currency name for certificates only. Next, of course, is the certificate creation, i.e., the issuance process. When a student completes a course, the owner calls the issueCertificate function. At this point, several tasks occur:

Counter: The counter robot within the contract increments by 1; for example, this would be certificate #105.

Mint: The system creates a unique digital token (NFT) and instantly sends it to the student's wallet.

Data recording: The information "Certificate #105 belongs to this student and is related to the 'Programming' course" is written to the blockchain.

Notification: The contract "broadcasts" to the entire network, i.e., An emit event indicates that a new document has been issued. This is necessary so that websites or applications immediately see the update. Then, storage and verification occur. Of course, the received certificate subsequently lives in the student's wallet.

The student can use the get Student Certificates function to see a list of all their diplomas received through this system.

Anyone can verify the authenticity: simply call the token URI function to get a link to the official description of this specific certificate.

By implementing the process of verifying, validating, and confirming transactions, a tamper-proof record of blocks and the blockchain is created by recording a transaction in the distributed ledger and implementing a consensus protocol for agreeing on the block to be added to the chain. Thus, validation, verification, consensus, and an immutable record ensure the trust and security of the blockchain.

Transactions are verified and broadcast. Many transactions form a block. Many blocks form a chain via a digital data channel. Blocks undergo a consensus process to select the next block to be added to the chain. The selected block is verified and added to the current chain.

Conclusion

Smart contracts are transforming digital educational platforms from centralized databases into trusted, automated, and globally verifiable ecosystems. Practical examples show that even a basic implementation already enables automation of key processes and increases trust. In the coming years, we expect the widespread emergence of hybrid platforms combining blockchain, AI, and decentralized storage.

International experience confirms that the use of smart contracts extends far beyond the financial sector, banking, and insurance. Today, they are actively considered as a tool for increasing efficiency in public administration, business, healthcare, and other sectors. For example, the implementation of smart contracts for medical payment systems allows for automated payments and significantly reduces the risk of abuse, such as the unjustified prescription of additional procedures or medications. The music industry also offers significant opportunities for the application of this technology. Copyright holders can record ownership information for their works in a distributed ledger and configure smart contracts so that royalties are paid automatically when the compositions are commercially used. This increases the transparency of payments and ensures the protection of performers' interests.

The automotive industry is also considered a promising area. Distributed ledger technologies combined with smart contracts can be used to store reliable data on vehicle maintenance, accidents, and previous owners, increasing trust among market participants.

The study noted that active preparatory work is currently underway to integrate innovative solutions into digital platforms, including artificial intelligence and distributed ledger technologies. The findings suggest that smart contracts represent one of the most promising areas for the development of distributed systems in the context of digital transformation.

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