A Modular Smart Contract Architecture for a Decentralized E-Learning Ecosystem Based on Purechain Blockchain

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Abstract

Traditional e-learning and academic administration systems face persistent challenges, including credential fraud, inefficient verification processes, and a lack of transparency in financial aid distribution. This paper proposes a blockchain-integrated e-learning platform designed to address these issues by creating a secure, transparent, and automated ecosystem for academic records and financial aid. We present a hybrid architecture that leverages a high-performance permissioned blockchain, Purechain, to manage trust-critical functions while retaining conventional databases for dynamic content. The system is built around four modular smart contracts: IdentityRegistry, AcademicManager, EduToken, and ScholarshipFactory. The key innovation is the programmatic linkage between on-chain academic performance and automated scholarship disbursement, enabling a trustless, unbiased, and efficient financial aid model.

CCS Concepts

• **Networks → Peer-to-peer protocols**.

Keywords

Blockchain, E-learning, Smart Contracts, Decentralized Identity, Academic Records

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1 Introduction

The advent of blockchain technology, first conceptualized for the Bitcoin cryptocurrency [1, 2, 10], has catalyzed a paradigm shift in how digital information is recorded, shared, and secured. At its core, a blockchain is a Distributed Ledger Technology (DLT) that maintains a continuously growing list of cryptographically linked records, or blocks [10, 11]. This architecture establishes a decentralized, immutable, and transparent database replicated across a peer-to-peer network, eliminating the need for a central authority and enabling parties to transact directly in a trusted environment [4, 9, 10]. The potential of this technology to disrupt intermediary-reliant models has spurred immense interest far beyond its financial origins [4, 8].

Blockchain's evolution is often viewed in stages: Blockchain 1.0 for cryptocurrencies, and Blockchain 2.0, which introduced smart contracts self-executing programs that automatically enforce agreements when predefined conditions are met [2, 11]. We are now in the era of Blockchain 3.0, where applications are being explored across diverse sectors, including supply chain, healthcare, and notably, education [1, 2, 8, 9].

In parallel, the education sector has undergone a digital transformation, adopting Big Data, AI, and Massive Open Online Courses (MOOCs) to enhance learning [8]. However, this ecosystem remains largely centralized and faces significant challenges. Academic records systems are often siloed within institutions, hindering credential verification and credit transfer [4, 9]. Fraudulent certificates persist as a major issue, eroding trust among institutions, students, and employers [2, 9]. Furthermore, students have limited control over their educational data, relying on institutions as lifelong custodians in a process that can be slow and costly, while centralized databases remain vulnerable to security breaches [4, 9, 11].

Blockchain technology offers a compelling solution to these challenges [4, 10]. Its fundamental characteristics facilitate a new model for academic management. The **immutability** of the ledger provides a tamper-proof "trust anchor" for academic records, drastically reducing diploma fraud [9, 11]. **Decentralization** supports self-sovereign identity, empowering learners to own and manage their lifelong learning records independently of the issuing institution [4, 11]. Finally, **disintermediation** allows employers to verify credentials directly on the ledger, significantly reducing the administrative burden and costs of manual verification [1, 4].

This paper proposes a technical architecture for an e-learning platform that harnesses these capabilities. Our platform focuses on four key areas:

(1) **Certificate Issuance and Verification:** Digital, cryptographically signed certificates are issued with their hash recorded on the blockchain, creating a permanent and verifiable proof of issuance that can be instantly authenticated by third parties [4, 11].
(2) **Staff and Student Identification:** A secure digital identity, anchored to the blockchain, grants users access to platform resources, enhancing privacy and reducing administrative overhead [1, 4].
(3) **Results and Transcripts:** An immutable lifelong learning ledger is created for each student, where every grade and academic credit is recorded as a transaction, building a permanent and auditable transcript [2, 11].

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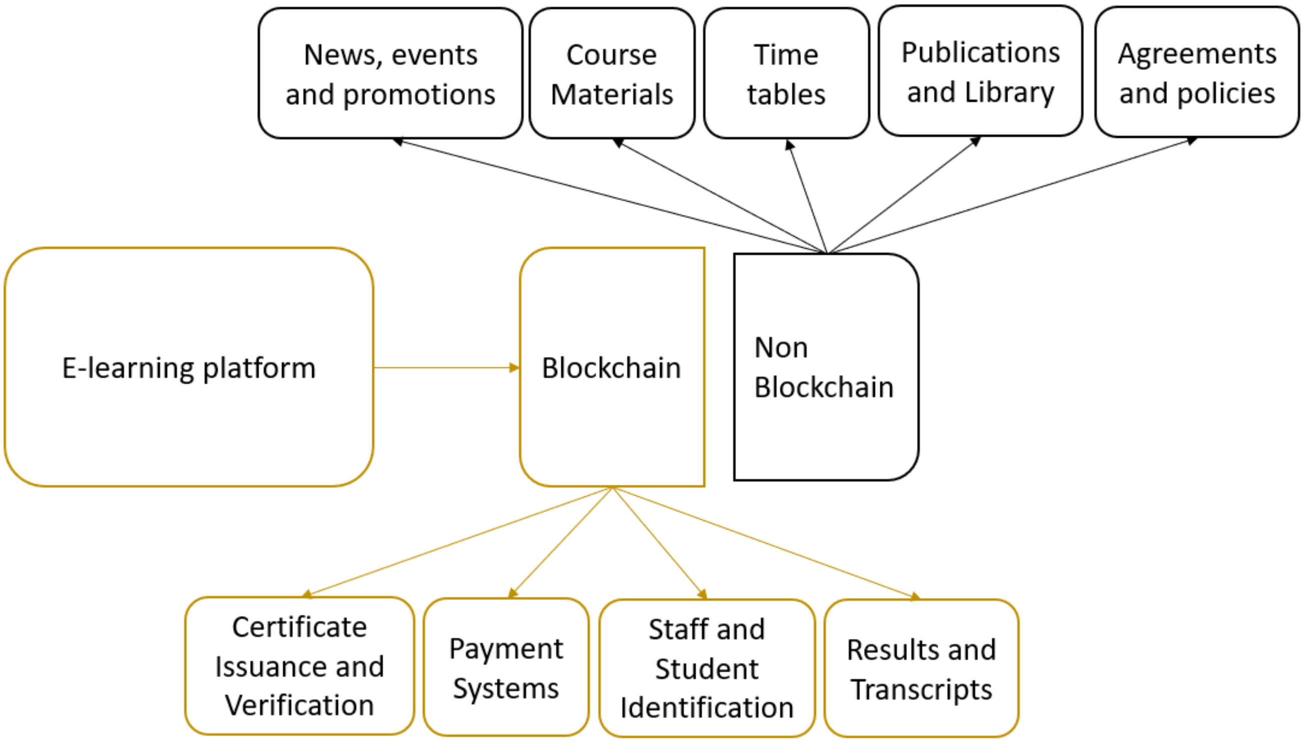

Figure 1: The high-level system architecture, illustrating the bifurcation into Non-Blockchain and Blockchain components. The blockchain is dedicated to functions requiring high trust and immutability, which are the focus of this work.

(4) **Automated Payment Systems:** The platform integrates a payment system for tuition and fees, utilizing smart contracts to automate scholarships and grant disbursements based on predefined academic milestones [4, 8].

While acknowledging challenges such as scalability, data privacy, and cost [1, 8, 11], this paper provides a practical technical blueprint for developers and institutions. To the best of our knowledge, it is the first paper that attempts to integrate several use cases of blockchain in e-learning to form a robust interconnected ecosystem. The remainder of this paper is organized as follows. Section II presents the overall system architecture. Section III details the implementation of the core blockchain modules. Section IV discusses the system's benefits, and Section V concludes with a summary and directions for future research.

2 System Model

The architecture of the proposed e-learning platform is a hybrid model designed to strategically leverage the unique capabilities of blockchain while maintaining the efficiency of traditional databases. As illustrated in Fig. 1, the platform's backend is bifurcated into a Non-Blockchain Component and a Blockchain Component to optimize scalability, cost, and performance.

2.1 Overall Architecture

The platform's front-end serves as the primary user interface, routing all interactions through a central application server. This server acts as a gateway, directing requests to the appropriate backend component.

2.1.1 The Non-Blockchain Component. This component operates as a conventional, centralized web architecture, utilizing a standard relational or document-based database on a central server. It is responsible for managing high-volume, dynamic, or non-sensitive data that does not require the immutability and cryptographic overhead of a blockchain. As shown in the system model, this includes:

(1) News, events, and promotions: Dynamic content that is frequently updated.
(2) Course Materials: Large files, such as lecture videos and syllabi, where on-chain storage would be prohibitively expensive and inefficient.
(3) Timetables: Operational data subject to frequent changes.
(4) Publications and Library: A digital repository for large documents.
(5) Agreements and policies: General institutional documents.

By handling these functions "off-chain" on a central server, the system ensures that the blockchain ledger remains uncluttered, scalable, and dedicated to its core purpose of serving as an immutable ledger of trust.

2.1.2 The Blockchain Component. The core of this work, this component is an ecosystem of smart contracts running on a blockchain network . We propose a consortium model where educational institutions and accreditation bodies operate validator nodes. This approach provides the decentralization and immutability of a public chain while offering the privacy, control, and high throughput required for an enterprise academic system. It is composed of the four key modules detailed below.

2.2 Blockchain Component Modules

The blockchain architecture is built around four primary modules, each addressing a critical function.

2.2.1 Certificate Issuance and Verification. This module tackles academic credential fraud by creating an immutable, provable record of every credential [2, 9].

(1) **Issuance Process:** The registrar generates a digital certificate (e.g., PDF), which is added to IPFS to produce a unique Content Identifier (CID). This CID is embedded in a transaction, signed by the institution, and recorded on the blockchain. This serves as permanent, time-stamped proof of issuance without storing the large file on-chain [3, 4].
(2) **Verification Process:** A student presents the certificate's CID to an employer, who uses a public portal to query the blockchain. A successful match confirms the CID was officially recorded by the institution, providing instant proof of authenticity.

2.2.2 Staff and Student Identification. This module replaces centralized identity systems with a decentralized, self-sovereign identity (SSI) model [4, 11].

(1) **Identity Creation:** Upon enrollment, the institution creates a Decentralized Identifier (DID) for the user. The associated DID Document is stored on IPFS, and the on-chain transaction records only the DID and the IPFS hash.
(2) **User Control:** The user controls their DID via a private key in a secure mobile wallet, allowing them to manage their identity and credentials.
(3) **Authentication:** The user signs by providing a secret signature, proving ownership of their DID. This model enhances privacy by separating the on-chain identifier from off-chain identity data, providing a lifelong, portable academic identity [1, 4].

2.2.3 Results and Transcripts. This module creates a granular and immutable academic transcript by combining on-chain transactions with off-chain storage.

(1) **Recording Results:** Individual grades are recorded as on-chain transactions signed by a faculty member, containing the student's DID, course ID, and grade.
(2) **Building the Transcript:** These transactions accumulate on the ledger, forming a complete, auditable academic history. The system can compile these records into a formatted transcript, store it on IPFS, and record its hash on-chain as a verifiable "snapshot."
(3) **Smart Contracts for Automation:** A smart contract representing a degree program can automatically track a student's progress by monitoring grade transactions. Upon fulfillment of requirements, the contract can trigger the issuance of the final transcript and certificate [9].

2.2.4 Payment Systems. This module handles all financial transactions, using smart contracts for automation and transparency.

(1) **Tuition and Fees:** The platform integrates a payment gateway for tuition using cryptocurrencies or a dedicated "education token," creating an auditable financial ledger that reduces fees and settlement times [4].
(2) **Automated Financial Aid:** Smart contracts manage scholarships and grants. A donor places funds in a contract programmed to monitor a student's on-chain academic record. If conditions are met (e.g., maintaining a certain GPA), the contract automatically releases funds to the student's wallet, eliminating administrative overhead [9].

This hybrid architecture isolates functions of trust and verification onto a dedicated blockchain, leveraging IPFS for decentralized off-chain storage. This combined "trust layer" empowers users, eliminates fraud, and automates complex processes, creating a secure, efficient, and robustly decentralized e-learning ecosystem.

3 System Implementation

This section details the implementation of our decentralized system for managing academic records and automated financial aid. The architecture is designed to create a secure, transparent, and auditable ecosystem by migrating critical processes from siloed databases to an immutable on-chain ledger.

3.1 Architectural Overview

The system is built upon four core, modular smart contracts: IdentityRegistry.sol, EduToken.sol, AcademicManager.sol, and ScholarshipFactory.sol. These contracts are deployed and interconnected on the Purechain network, a platform chosen for its high performance and resource efficiency [7]. This implementation creates a trustless environment where identity is cryptographically verified, academic records are immutably stored, financial assets are securely held, and financial aid is automatically executed based on on-chain academic performance.

3.2 The Purechain Network: A Suitable Foundation

The choice of a foundational blockchain is critical. Public networks like Ethereum are too slow and costly for an academic institution's transaction patterns. Our system is deployed on **Purechain**, a resource-optimized permissioned blockchain ideal for enterprise applications. Its suitability stems from several key advantages:

(1) **High-Performance and Scalability:** Academic institutions have "bursty" transaction loads, such as posting thousands of grades. Purechain handles an average of over **2,300 transactions per second (TPS)**, ensuring the system can manage high-volume events without congestion or prohibitive fees.
(2) **Resource Efficiency:** Purechain uses a **Smart Auto Mining (SAM)** algorithm [5], which adjusts mining activity to

the live transaction load and pauses block production during idle periods. This drastically reduces energy consumption and operational costs for a university network.

(3) **Enhanced Reliability:** As a permissioned network, Purechain provides robust security through its **Proof-of-Authority and Association (PoA²)** consensus mechanism [6]. PoA² actively monitors validators and replaces any that are underperforming, guaranteeing network uptime and integrity for a system managing sensitive data.
(4) **Full EVM Compatibility:** Purechain is fully compatible with the Ethereum Virtual Machine (EVM), allowing our Solidity smart contracts to be deployed without modification and leveraging the mature Ethereum development ecosystem (Remix, Hardhat, MetaMask).

3.3 Core Smart Contract Components

The system's logic is encapsulated in four primary, decoupled contracts.

3.3.1 IdentityRegistry.sol: The Foundation of Trust. This contract is the single source of truth for all system identities, acting as the "root of trust" to verify permissions for all other contracts. Its primary purpose is to map a user's wallet address to a persistent Decentralized Identifier (DID) and a specific organizational role (e.g., FACULTY_ROLE).

3.3.2 EduToken.sol: The Financial Engine. This contract defines the system's internal ERC20 token (EDUT), used for financial aid. It is a standard OpenZeppelin ERC20 contract with AccessControl, granting a MINTER_ROLE to the institution. This gives the institution the exclusive ability to mint new tokens to fund the scholarship ecosystem.

3.3.3 AcademicManager.sol: The Academic Ledger. This hub manages all non-financial academic records. It serves as an immutable, verifiable record of a student's academic history, functioning as both a certificate registry and a transcript manager. Its key functions include recording grades and issuing certificates (by storing their IPFS hash). Its most critical external function is calculateGPA(), a view function that displays a student's GPA from their on-chain grades.

3.3.4 ScholarshipFactory.sol & Scholarship.sol: The Automation Hub. This pair of contracts uses the "Factory Pattern" to automate financial aid. The ScholarshipFactory is a single, permanent contract that allows a registrar to deploy new, separate Scholarship.sol contracts for specific students. Each clone contract is a self-contained vault holding EduToken for one student. Its core function, checkAndDisburse(), can be triggered by anyone. In a single atomic transaction, it:

(1) Calls AcademicManager to get the student's current GPA.
(2) Compares the current GPA to the required GPA.
(3) If the condition is met, calls IdentityRegistry to get the student's wallet address.
(4) Finally, calls EduToken to transfer the scholarship funds to the student.

3.4 Deployment and Connectivity Flow

The contracts form a deeply interconnected system, and their deployment order is critical:

(1) IdentityRegistry.sol is deployed first.
(2) EduToken.sol is deployed second.
(3) AcademicManager.sol is deployed third, requiring the IdentityRegistry address in its constructor.
(4) ScholarshipFactory.sol is deployed last, requiring the addresses of the other three contracts in its constructor.

The details of all the functions in the various smart contracts are shown in TABLE 1 This sequence creates an immutable, on-chain web of contracts. The ScholarshipFactory becomes the central hub, passing the necessary contract addresses to each new Scholarship clone it creates. This modular implementation on the Purechain network results in a trustless, transparent, and fully automated system for managing the core functions of a modern academic institution.

4 Potential Benefits of the Proposed System

The proposed decentralized system offers significant advantages over traditional, centralized academic and financial aid management. By migrating critical processes to an on-chain, smart contract-based architecture, the system introduces new levels of trust, automation, and efficiency for all stakeholders.

The primary benefits of this model include:

(1) **Automated and Trustless Financial Aid:** The most significant innovation is the ScholarshipFactory's ability to programmatically link financial disbursement directly to academic performance. The checkAndDisburse function within each Scholarship contract automatically queries the AcademicManager for a student's on-chain GPA. If the predefined criteria are met, funds are released instantly. This model eliminates the bureaucratic overhead, processing delays, and potential for human bias inherent in manual scholarship administration.
(2) **Data Integrity and Fraud Prevention:** Academic records, once recorded by a verified faculty member via the AcademicManager, are immutable. This cryptographic security makes it virtually impossible for unauthorized parties to alter grades or fabricate credentials, significantly reducing academic fraud. The IdentityRegistry contract ensures that only individuals with the proper FACULTY_ROLE or REGISTRAR_ROLE can write data, securing the system at the point of entry.
(3) **Complete Transparency and Auditability:** Every action within the ecosystem—from a role change in the IdentityRegistry to a grade being posted or a scholarship being funded and disbursed—is a verifiable transaction on the blockchain. This creates a permanent, transparent, and irrefutable audit trail for administrators, donors, and students.
(4) **Student Empowerment and Data Portability:** The system shifts data ownership. Students are no longer solely reliant on the institution to act as a custodian for their records. Using their Decentralized Identifier (DID) managed by the IdentityRegistry, they can provide cryptographic proof of their

Table 1: Comprehensive overview of the core smart contract suite, including function signatures, access control policies, and high-level descriptions.

Function Signature	Access Control	Description
IdentityRegistry.sol — The Foundation of Trust		
`constructor()`	Deployer Only	Initializes the registry and assigns administrator and registrar roles.
`registerIdentity(address _wallet, bytes32 _did, bytes32 _role)`	REGISTRAR_ROLE	Associates a wallet address with a decentralized identifier and assigns an organizational role.
`deactivateIdentity( bytes32 _did)`	REGISTRAR_ROLE	Marks an identity as inactive for revocation or graduation.
`activateIdentity(bytes32 _did)`	REGISTRAR_ROLE	Reactivates a previously deactivated identity.
`updateRole(bytes32 _did, bytes32 _newRole)`	REGISTRAR_ROLE	Updates the organizational role associated with a DID.
`getRole(bytes32 _did)`	Public View	Returns the role assigned to the specified DID.
`getDid(address _wallet)`	Public View	Retrieves the DID bound to a wallet address.
`getAddress(bytes32 _did)`	Public View	Returns the wallet address associated with a DID.
`isIdentityActive(bytes32 _did)`	Public View	Checks whether an identity is currently active.
`getIdentity(bytes32 _did)`	Public View	Returns the complete identity record.
EduToken.sol — The Financial Engine		
`constructor(address initialOwner)`	Deployer Only	Deploys the ERC20 education token and assigns minting privileges.
`mint(address to, uint256 amount)`	MINTER_ROLE	Mints new tokens and credits them to the recipient address.
Includes all standard ERC20 functions (transfer, approve, balanceOf, etc.)		
AcademicManager.sol — The Academic Ledger		
`constructor(address _identityRegistryAddress)`	Deployer Only	Stores the address of the identity registry contract.
`recordGrade(bytes32 _studentDid, string _courseId, uint256 _grade )`	FACULTY_ROLE	Records a validated academic grade on-chain.
`issueCertificate(bytes32 _recipientDid, string _ipfsCid)`	FACULTY or REGISTRAR	Issues a verifiable certificate linked to IPFS storage.
`calculateGPA(bytes32 _studentDid)`	Public View	Computes the GPA from all recorded grades.
`getGrades(bytes32 _studentDid)`	Public View	Returns all grades recorded for the student.
`getCertificates(bytes32 _studentDid)`	Public View	Returns all issued certificates.
ScholarshipFactory.sol & Scholarship.sol — The Automation Hub		
`constructor(address _identityRegistry, ...)`	Deployer Only	Registers the addresses of all core system contracts.
`createScholarship(bytes32 _studentDid, ...)`	REGISTRAR_ROLE	Deploys a new scholarship contract for a specific student.
`fundScholarship()`	Public	Allows donors to fund the scholarship using EduToken.
`checkAndDisburse()`	Public	Automatically disburses funds when GPA conditions are met.
`getScholarshipsByStudent( bytes32 _studentDid)`	Public View	Returns all scholarships associated with a student.
`getScholarshipsByDonor( address _donor)`	Public View	Returns all scholarships funded by a donor.

grades and certificates to any third party (e.g., employers, other universities) instantly and without friction.

(5) **Operational Efficiency and Cost Reduction:** By automating the verification and disbursement of financial aid and streamlining credential-sharing, the system drastically reduces the administrative workload. This frees up university resources, reduces operational costs associated with manual data handling, and accelerates processes that traditionally take weeks or months.

5 Conclusion and Future Work

In this paper, we have designed and detailed a comprehensive, blockchain-based system to enhance the integrity, efficiency, and transparency of modern e-learning platforms. By implementing a modular architecture on the Purechain network, our solution effectively addresses critical vulnerabilities in traditional academic systems, such as credential fraud and bureaucratic inefficiencies in financial aid administration. The system's backbone, composed of the IdentityRegistry, EduToken, AcademicManager, and ScholarshipFactory smart contracts, creates a robust and auditable ecosystem for managing student identities, academic records, and financial transactions.

The most significant contribution of this work is the demonstration of a fully automated, trustless financial aid system. By programmatically linking scholarship disbursements to a student's verifiable on-chain academic performance, our model eliminates manual overhead, potential for human bias, and processing delays. This approach empowers students with greater control over their academic data, provides donors and administrators with complete transparency, and significantly reduces the operational costs associated with legacy processes. The proposed architecture serves as a practical framework for educational institutions seeking to build the next generation of secure, efficient, and learner-centric platforms.

For future work, several research avenues can be explored. First, integrating zero-knowledge proofs (ZKPs) could enhance student privacy, allowing them to prove fulfillment of academic criteria (e.g., "GPA is above 3.5") without revealing their specific grades. Second, developing a standardized interoperability protocol would be crucial for enabling seamless credit transfers across a consortium of institutions running similar blockchain systems. Finally, focusing on the user experience (UX) by creating intuitive digital wallets and interfaces will be essential for abstracting the underlying complexity of blockchain and encouraging widespread adoption among non-technical users.

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References

[1] Ali Alammary, Samah Alhazmi, Marwah Almasri, and Saira Gillani. 2019. Blockchain-Based Applications in Education: A Systematic Review. *Applied Sciences* 9, 12 (2019), 2400. doi:10.3390/app9122400

[2] Preeti Bhaskar, Chandan Kumar Tiwari, and Amit Joshi. 2021. Blockchain in education management: present and future applications. *Interactive Technology and Smart Education* 18, 1 (2021), 1–17. doi:10.1108/ITSE-07-2020-0102

[3] Erik Daniel and Florian Tschorsch. 2022. IPFS and Friends: A Qualitative Comparison of Next Generation Peer-to-Peer Data Networks. *IEEE Communications Surveys & Tutorials* 24, 1 (2022), 31–52. doi:10.1109/COMST.2022.3143147

[4] Alexander Grech and Anthony F. Camilleri. 2017. *Blockchain in Education*. Technical Report. Publications Office of the European Union. doi:10.2760/60649 JRC Science for Policy Report, EUR 28778 EN.

[5] Ikechi Saviour Igboanusi, Allwinnaldo Allwinnaldo, Revin Naufal Alief, Muhammad Rasyid Redha Ansori, Jae-Min Lee, and Dong-Seong Kim. 2022. Smart auto mining (SAM) for industrial IoT blockchain network. *IET Communications* 16, 18 (2022), 2123–2132. arXiv:https://ietresearch.onlinelibrary.wiley.com/doi/pdf/10.1049/cmu2.12465 doi:10.1049/cmu2.12465

[6] Dong-Seong Kim, Ikechi Saviour Igboanusi, Love Allen Chijioke Ahakonye, and Goodness Oluchi Anyanwu. 2025. Proof-of-Authority-and-Association Consensus Algorithm for IoT Blockchain Networks. In *2025 IEEE International Conference on Consumer Electronics (ICCE)*. 1–6. doi:10.1109/ICCE63647.2025.10930052

[7] Dong-Seong Kim, Esmot Ara Tuli, Igboanusi Ikechi Saviour, Md Mehedi Hasan Somrat, and Xuan-Qui Pham. 2025. Blockchain-as-a-Service: A Pure Chain Approach. *Blockchain: Research and Applications* (2025), 100397. doi:10.1016/j.bcra.2025.100397

[8] Jae Park. 2021. Promises and challenges of Blockchain in education. *Smart Learning Environments* 8, 1 (2021), 33. doi:10.1186/s40561-021-00179-2

[9] Ricardo Raimundo and Albérico Rosário. 2021. Blockchain System in the Higher Education. *European Journal of Investigation in Health, Psychology and Education* 11, 1 (2021), 276–293. doi:10.3390/ejihpe11010021

[10] Gautam Srivastava, Shalini Dhar, Ashutosh Dhar Dwivedi, and Jorge Crichigno. 2019. Blockchain Education. In *2019 IEEE Canadian Conference of Electrical and Computer Engineering (CCECE)*. 1–5. doi:10.1109/CCECE.2019.8861595

[11] Mara-Florina Steiu. 2019. *Blockchain in education: Opportunities, applications, and challenges*. Technical Report. Working Paper.