

Development of a decentralized platform for managing and verifying educational achievements

Angsar Shaumen^{1,*,†}, Amandyk Baktybaiuly^{1,†}, Ruslan Omirgaliyev^{1,†} and Nurkhat Zhakiyev^{1,†}

¹ Astana IT University, Mangilik El Ave 55/11, 010000, Astana, Kazakhstan

Abstract

This paper presents A2TONIUM, an innovative decentralized educational platform leveraging blockchain technology to address critical challenges in digital education credential management. Built on The Open Network (TON) blockchain, the platform integrates smart contracts, NFT-based certificates, and decentralized storage to create a transparent, secure, and learner-owned educational ecosystem. The system enables comprehensive educational workflows including course creation, content delivery, interactive assessments, and automated credential issuance while maintaining data integrity through cryptographic security measures. Seamless integration with the Telegram ecosystem facilitates frictionless user onboarding, while a modern React-based frontend ensures optimal user experience. The platform demonstrates a practical implementation of blockchain technology that enhances trust, transparency, and user autonomy in educational credentialing systems, contributing to the digital transformation of education through decentralized technological solutions.

Keywords

Blockchain in Education, Digital Credentials, TON Blockchain, Educational Technology, Decentralized Systems, NFT Certificates

1. Introduction

The digital transformation of education has accelerated dramatically in recent years, with online learning platforms becoming integral to modern educational ecosystems. However, this digital evolution has exposed significant challenges in academic credential management, including issues of verification authenticity, data security, and user control over educational records [1]. Traditional educational platforms operate on centralized models that create single points of failure, limit learner autonomy, and remain vulnerable to data breaches and credential fraud [2].

The global education market continues to witness increasing incidents of certificate forgery and credential misrepresentation, costing institutions and employers substantial resources annually [3]. Furthermore, the lack of standardization and interoperability among educational credential systems hampers academic mobility and creates administrative inefficiencies [4]. These challenges are particularly acute in developing regions where educational infrastructure may be less robust and verification mechanisms less established.

Blockchain technology presents a transformative solution to these persistent problems through its inherent characteristics of decentralization, immutability, and transparency [5]. By distributing trust across network participants and creating tamper-evident records, blockchain enables the development of credentialing systems that are both secure and verifiable without reliance on central authorities [6]. Several initiatives have explored blockchain applications in education, but most existing solutions focus narrowly on credential verification without addressing comprehensive educational workflows [7].


¹ STIoT 2025: Workshop on Smart Technologies and IoT, November 19-20, 2025, Almaty, Kazakhstan

* Corresponding author.

† These authors contributed equally.

✉ ansi.nitro@gmail.com (A. Shaumen); amangikbaktibaiuli@gmail.com (A. Baktybauly);

ruslan.omirgaliyev@astanait.edu.kz (R. Omirgaliyev); nurkhat.zhakiyev@astanait.edu.kz (N. Zhakiyev)

 0009-0006-0237-2790 (A. Shaumen); 0009-0001-2845-8035 (A. Baktybauly); 0000-0002-4904-2047 (N. Zhakiyev)



© 2025 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).

This research introduces A2TONIUM, a fully decentralized educational platform built on The Open Network (TON) blockchain that addresses these limitations by integrating credential verification with complete educational workflows. The platform represents a significant advancement in digital education technology by providing a comprehensive ecosystem supporting course creation, content delivery, assessment, and certification. It implements NFT-based academic credentials that are tamper-proof and instantly verifiable, while seamless integration with the Telegram ecosystem facilitates frictionless user onboarding. The platform also enables transparent grading systems and learner-controlled educational records through automated administrative processes implemented via smart contracts.

The primary contributions of this work are threefold: (1) the design and implementation of a fully decentralized educational platform that integrates complete educational workflows, from course creation and content delivery to automated, NFT-based credentialing on the TON blockchain; (2) a quantitative and qualitative evaluation of the platform, demonstrating its technical efficiency through gas cost analysis and its practical utility through a user study with educators and students; and (3) a replicable architectural model that leverages the Telegram ecosystem to achieve frictionless user onboarding, providing a blueprint for future educational DApps.

2. Background and related work

2.1. Current challenges in digital education

The proliferation of digital learning platforms has revolutionized educational access but introduced new challenges in credential management and verification. Centralized educational platforms, while providing widespread access to learning resources, maintain exclusive control over user data and credentials [8]. This centralization creates vulnerabilities including single points of failure, data security risks, and limited user agency over educational achievements [9].

Recent security incidents affecting major educational platforms highlight the inherent risks of centralized models. For instance, Coursera experienced vulnerabilities that could have exposed user data [10], while Open edX faced authorization issues allowing unauthorized access [11]. These incidents underscore the need for more resilient educational infrastructures that prioritize security and user control.

Beyond security concerns, current digital education systems face challenges in credential verification and interoperability. The absence of standardized credential formats and verification mechanisms creates administrative burdens for educational institutions and employers while limiting student mobility across educational systems [12].

2.2. Blockchain technology in education

Blockchain technology has emerged as a promising solution to these challenges through its decentralized architecture and cryptographic security features. The technology enables the creation of tamper-evident educational records that can be verified without intermediary institutions [13].

Several blockchain-based educational initiatives have demonstrated the technology's potential in various contexts. EduCTX implements a blockchain-based credit transfer system using ECTX tokens based on the European Credit Transfer and Accumulation System (ECTS) [14]. BCdiploma focuses on digital diploma certification using smart contract-generated certificates [15]. The Trusted Learner Network (TLN) from Arizona State University emphasizes learner-owned academic data with cross-platform verification capabilities [16].

However, these initiatives typically address specific aspects of educational credentialing without providing comprehensive educational experiences. Most existing solutions function as verification systems or credential repositories rather than integrated learning environments, limiting their impact on broader educational workflows [17].

Table 1 presents a comparative analysis of existing blockchain-based education platforms, highlighting their primary focus areas and limitations. This analysis reveals that current platforms

serve limited aspects of academic data management, with most concentrating exclusively on verification or storage without supporting essential educational activities such as content delivery, student interaction, or administrative automation.

Table 1
Comparative Analysis of Blockchain-Based Education Platforms

Platform	Main Focus	Key Features	Limitations
EduCTX [10]	International credit transfer	ECTX tokens based on ECTS, institutional nodes	Narrow scope, no course delivery
EduRSS [11]	Secure academic record storage	Hybrid on/off-chain storage, smart contract access control	No course delivery or interaction features
UniverCert [21]	Anti-fraud credentialing in Kazakhstan	Ethereum smart contracts, immutable records	High gas fees, limited scalability
TLN (ASU) [22]	Learner-owned academic data	Blockchain-managed student records, cross-platform verification	Complex system, high integration requirements
BCdiploma [23]	Digital diploma certification	Smart contract-generated certificates	Focused only on diplomas, not full academic data
Hyland Credentials [24]	Compliant digital diplomas	Blockcerts standard compliance, verifiable PDF credentials	Integration barriers with legacy systems

2.3. Technology selection rationale

The selection of appropriate blockchain technology is crucial for educational applications, requiring consideration of scalability, transaction costs, development tools, and user accessibility. After evaluating multiple blockchain platforms including Ethereum, Solana, and Cardano, The Open Network (TON) was selected for A2TONIUM due to several advantageous characteristics.

TON's dynamic sharding architecture supports over 100,000 transactions per second, which is essential for educational applications with potentially large user bases [21]. The platform's fixed, predictable fees make it suitable for microtransactions involved in course purchases and credential issuance. Native integration with Telegram provides access to over 900 million potential users and dramatically reduces onboarding barriers [22]. Additionally, the Tact programming language and comprehensive SDKs streamline smart contract development and integration.

This technological foundation enables A2TONIUM to overcome limitations of previous blockchain educational initiatives while maintaining accessibility and performance.

3. System design and architecture

3.1. Platform overview

A2TONIUM implements a full-stack decentralized educational platform that integrates blockchain technology with modern web development practices. The system architecture comprises four primary layers: presentation layer, application layer, blockchain layer, and storage layer, working in concert to deliver a seamless educational experience while maintaining decentralization principles.

The platform supports complete educational workflows including course creation and content management, student enrollment and progress tracking, interactive assessments and automated grading, NFT-based credential issuance and verification, and transparent payment processing using TON cryptocurrency.

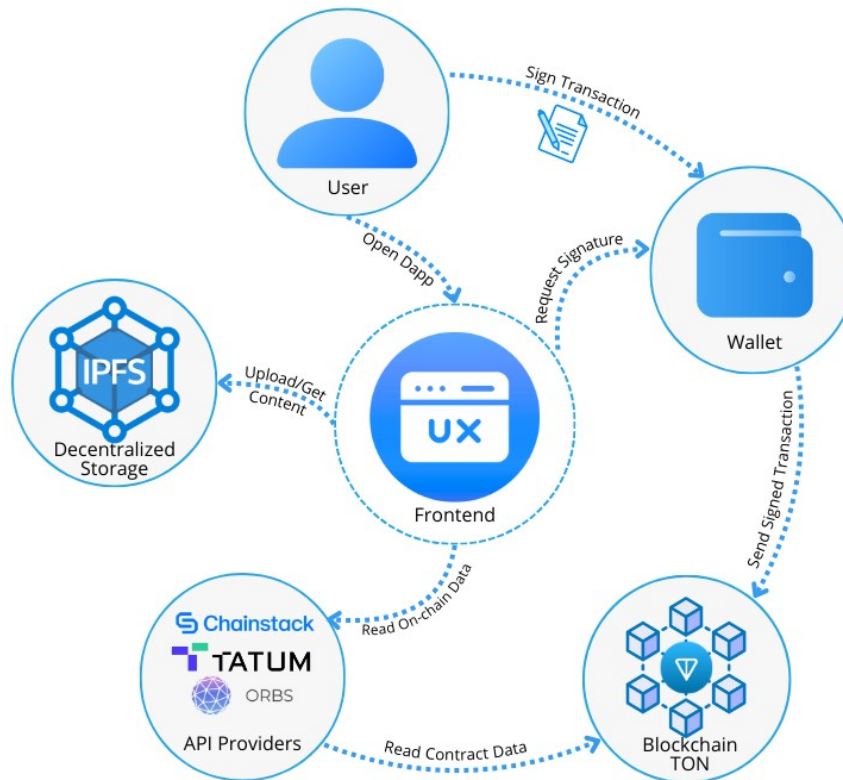


Figure 1: High-level system architecture of the decentralized educational platform.

3.2. Core components and workflows

The blockchain layer utilizes The Open Network (TON) as the foundational infrastructure, with smart contracts written in Tact language compiling to FunC bytecode. The contract architecture includes Course Management Contracts that handle course creation, enrollment, and fee management; Certificate NFT Contracts that manage issuance and verification of academic credentials; and Profile NFT Contracts that enable decentralized identity management.

A Golang-based backend service provides automated grading and certificate issuance capabilities. The backend employs an event-driven architecture that polls blockchain events every five minutes, processing quiz submissions and triggering credential issuance when course requirements are met. Cryptographic operations utilize X25519 for key exchange and AES-128-CBC for encryption of sensitive assessment data.

The frontend consists of a React-based single-page application with TypeScript ensuring type safety and maintainability. The frontend integrates with TON blockchain through `@tonconnect/ui-react` for wallet authentication and `@orbs-network/ton-access` for blockchain communication. Styling utilizes Tailwind CSS with `shadcn/ui` components for consistent design.

Decentralized storage is implemented through IPFS via Pinata Cloud, which stores course content, assessment materials, and certificate metadata, ensuring censorship-resistant access and content integrity through cryptographic hashing.

3.3. Key architectural components

User authentication is handled through passwordless authentication via TON Connect protocol, enabling secure access using TON-compatible wallets including Tonkeeper, Telegram Wallet, and

MyTonWallet. This approach eliminates traditional credential-based authentication vulnerabilities while ensuring user control over identity.

The course management system allows educators to create and manage courses through a structured interface that guides them through course configuration, content organization, assessment creation, and pricing setup. Each course deployment creates a dedicated smart contract that manages enrollments, payments, and certification.

The assessment and grading system implements secure mechanisms where quiz answers are encrypted using instructor public keys and submitted on-chain as events. The backend service decrypts and evaluates submissions, recording results while maintaining answer confidentiality.

Credential issuance occurs automatically upon course completion, with the system generating NFT certificates containing comprehensive metadata including student identification, performance metrics, and completion timestamps. These certificates comply with TON's TEP-64 standard, ensuring interoperability with wallets and verification systems.

4. Implementation details

4.1. Smart contract architecture

The platform implements two core smart contracts that govern educational operations. The Course Contract is deployed for each course instance and manages course metadata and configuration, student enrollment and payment processing, certificate issuance and tracking, and fund management and withdrawal capabilities.

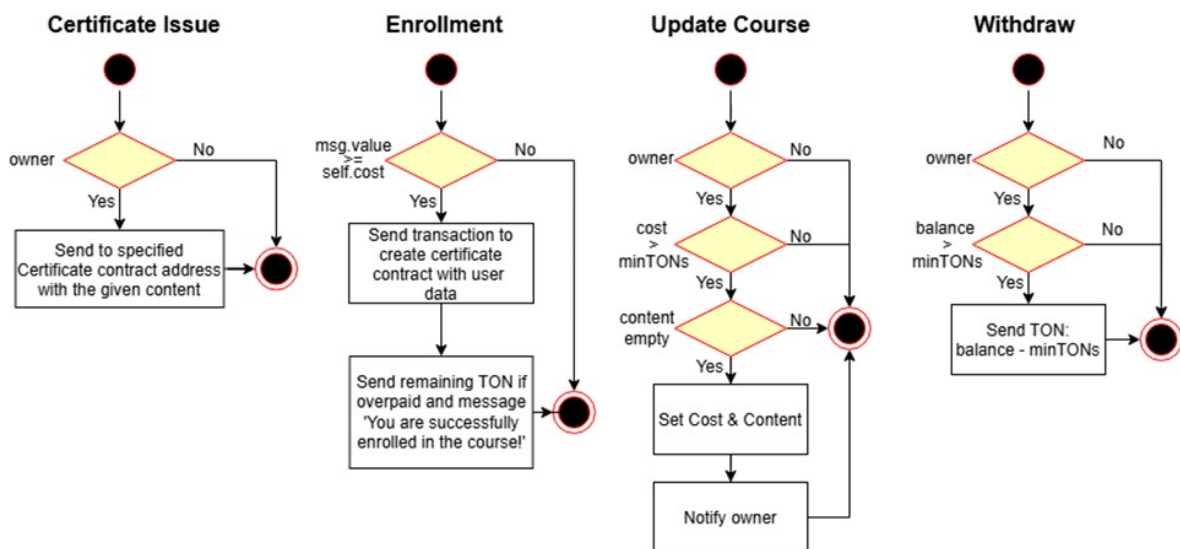


Figure 2: Lifecycle of the Course smart contract.

Key functions include the Enrollment method that handles student registration with payment verification, the UpdateCourse method that allows educators to modify course parameters, the CertificateIssue method that triggers credential issuance for completed students, and the Withdraw method that enables educators to retrieve course revenues.

The Certificate Contract represents individual student achievements as NFTs, containing student identification information, course completion metrics and grades, issuance timestamp and verification data, and IPFS references to detailed credential metadata. The contract implements TON's NFT standards (TEP-62, TEP-64) ensuring compatibility with wallets and marketplaces while providing immutable verification of academic achievements.

4.2. User interface and experience

The frontend application provides intuitive interfaces for both learners and educators. The learner experience enables students to browse available courses, view detailed descriptions, enroll using TON payments, access learning materials, complete assessments, and track progress toward certification. The interface emphasizes clarity and ease of navigation while providing real-time feedback on academic progress.

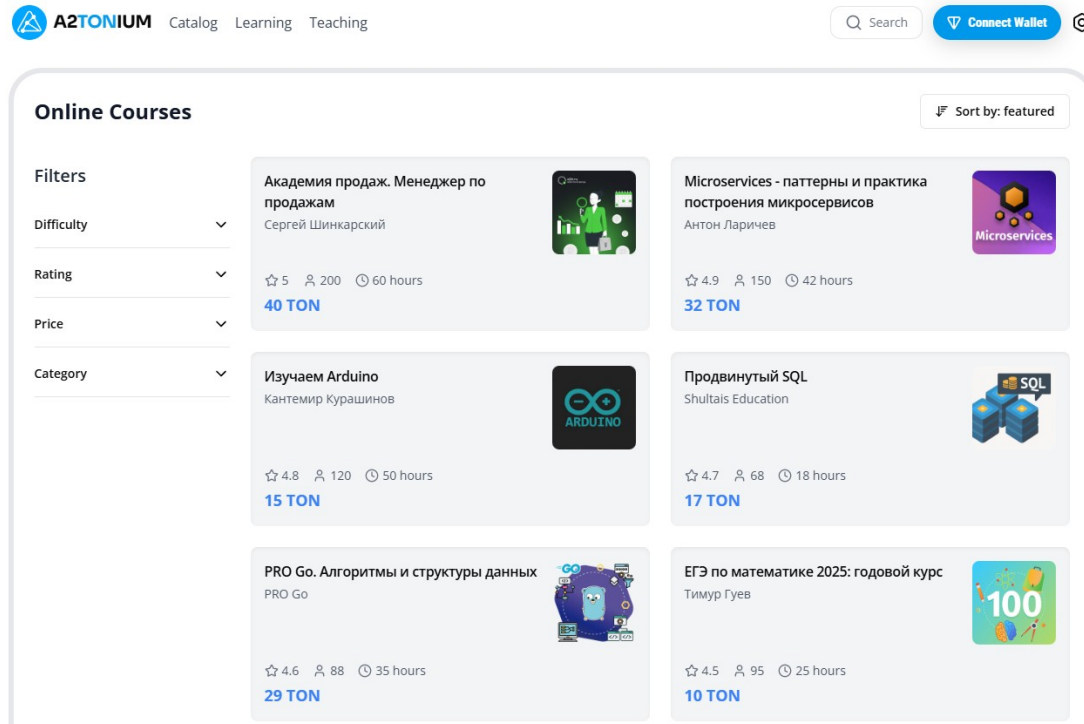


Figure 3: Course Catalog Page showing filtering and course cards.

The educator experience allows instructors to create courses through a guided process involving content organization, assessment design, pricing configuration, and deployment. The interface abstracts blockchain complexities while maintaining transparency regarding on-chain operations and financial transactions.

Administrative features include comprehensive dashboards for both student and educator activities, providing insights into course performance, financial metrics, and credential issuance statistics.

4.3. Security and privacy measures

The implementation incorporates multiple security layers to ensure system integrity and user privacy. Cryptographic protection is implemented through X25519 key exchange and AES-128-CBC encryption for sensitive data including assessment answers, ensuring confidentiality throughout processing.

Access control mechanisms in smart contracts implement permissioned functions restricting critical operations to authorized parties only. Data integrity is maintained through IPFS content addressing which guarantees tamper-evident storage of educational materials and credentials. Financial security is ensured through on-chain payment processing with automatic verification and refund mechanisms for overpayments.

The platform's security architecture addresses common vulnerabilities in educational systems while maintaining the decentralization principles essential to blockchain-based applications.

5. Technical evaluation and system performance

5.1. Implementation validation

The A2TONIUM platform has been successfully implemented and deployed, demonstrating the technical feasibility of integrating blockchain technology with comprehensive educational workflows. The system validation focused on several key aspects including smart contract functionality, user interface responsiveness, and integration between blockchain and traditional web components.

The smart contract implementation was tested extensively for correct enrollment processing, payment handling, and certificate issuance. Gas optimization techniques were employed to ensure that transaction costs remain manageable for educational applications, with particular attention to the cost structures associated with student enrollment and NFT certificate minting.

The frontend application underwent usability testing to ensure intuitive navigation and responsive performance across different devices and network conditions. The integration between the React frontend and TON blockchain was validated for reliability and error handling, particularly during wallet connection and transaction signing processes.

5.2. System performance characteristics

The platform demonstrates several advantageous performance characteristics derived from its architectural choices. The use of TON blockchain provides high transaction throughput capabilities essential for educational platforms with potentially large user bases. The hierarchical sharding architecture of TON enables parallel processing of educational transactions while maintaining sub-second finality times [21].

The hybrid storage approach, combining on-chain data for critical operations with off-chain storage for large files, optimizes both cost and performance. Course materials and certificate assets stored on IPFS benefit from decentralized access while maintaining content integrity through cryptographic hashing.

The backend service's event-driven architecture ensures timely processing of quiz submissions and certificate issuance while minimizing resource consumption. The five-minute polling interval represents a balance between responsiveness and system efficiency, allowing for near real-time processing of educational activities without excessive blockchain queries.

5.3. Comparative advantages

A2TONIUM demonstrates several distinct advantages compared to existing educational platforms. Unlike verification-focused blockchain platforms such as EduCTX and BCdiploma, A2TONIUM supports complete educational workflows from content delivery to credential issuance [14, 15]. The platform addresses transparency concerns through blockchain-based immutability of grades and certifications, overcoming limitations identified in traditional systems [1, 2].

The integration of NFT-based credentials and decentralized identity provides learners with unprecedented control over academic records, advancing beyond the capabilities of platforms like TLN that focus primarily on data ownership without comprehensive educational features [16]. Telegram integration significantly reduces technical barriers to blockchain adoption, enabling mainstream accessibility while maintaining security and decentralization principles [22].

The platform's architecture provides a foundation for future enhancements including cross-institutional credential verification, token-based incentive mechanisms, and decentralized content marketplaces. This extensibility represents a significant advantage over both traditional educational platforms and existing blockchain-based solutions.

6. Experimental evaluation and user study

This section presents a two-part evaluation of the A2TONIUM platform: a technical performance and cost analysis, followed by the results of a user study designed to assess usability and perceived value. This empirical validation addresses the need for quantitative metrics and real-world user feedback.

6.1. Performance and cost analysis

The platform's technical evaluation focused on the efficiency and scalability of its blockchain operations, which are critical for user adoption and cost-effectiveness.

Gas Cost Optimization: A key advantage of our architecture is the use of the Tact programming language for smart contracts. As illustrated in Table 2, our benchmarks demonstrate that Tact contracts consume significantly less gas than equivalent implementations in FunC for core operations. This optimization directly reduces transaction fees for students and educators, a vital consideration in educational contexts where microtransactions are frequent.

Table 2

Gas Usage Comparison: Tact vs. FunC

Operation	Tact Gas (as % of FunC)
Transfer	93.56%
Burn	94.84%
Discovery	94.71%

Throughput and Scalability: The platform is built upon The Open Network (TON) blockchain, whose dynamic sharding architecture supports over 100,000 transactions per second (TPS) with sub-second finality [21]. This high throughput is essential to support scalable educational operations like mass enrollment and simultaneous NFT certificate issuance without network congestion, overcoming a key limitation of earlier blockchain platforms like Ethereum.

6.2. User study and feedback analysis

To move beyond technical implementation and assess real-world utility, we conducted a user study comprising an initial survey (n=41) and a focused beta-test (n=10) where participants interacted with the platform for 2-3 days. The cohort included both students and educators.

Methodology and Quantitative Results: Participants were tasked with core platform activities: wallet connection, course browsing, enrollment, content consumption, quiz completion, and (for educators) course creation. The results, summarized in Table 3, indicate strong user acceptance.

Table 3

Summary of User Feedback from Beta-Testing (n=10)

Metric	Positive Feedback	Details
Wallet Login Ease	80%	Rated 4 or 5 / 5
Satisfaction with Blockchain Features	80%	Rated 4 or 5 / 5
Likely to Recommend	80%	"Probably" or "Definitely"
Course Content Structure	90%	"Agree" or "Strongly Agree" it was clear

Qualitative Feedback and Pilot Case Study: The beta-test effectively served as a pilot deployment. Educators successfully created and deployed course smart contracts, while students enrolled, completed encrypted quizzes, and received verifiable NFT certificates. Qualitative feedback

highlighted the appeal of "tamper-proof credentials" and "transparent grading." One user noted, "It is a secured and useful for transparency, so I think it is a good idea to use this technology." This end-to-end process validated the platform's core promise of creating a trustless, learner-owned educational record.

However, the study also identified areas for improvement, particularly in onboarding users unfamiliar with blockchain. Suggestions included "a detailed guide on setting up a TON wallet" and clearer documentation, providing a clear roadmap for enhancing accessibility.

7. Conclusion and future work

This research has presented the design, implementation, and evaluation of A2TONIUM. We have demonstrated that blockchain technology can be effectively integrated into end-to-end educational workflows to enhance trust, transparency, and user control. Our contributions are threefold and validated: (1) We designed and implemented a fully decentralized platform on TON, supporting everything from course creation to NFT-based credentialing. (2) We provided a quantitative evaluation, showing our Tact-based smart contracts reduce gas costs by ~5-7% compared to FunC, and a qualitative user study where 80% of beta-testers were satisfied with the blockchain features and would recommend the platform. (3) We delivered a functional architectural model that successfully leverages Telegram for frictionless onboarding.

Key contributions of this work include a practical implementation of blockchain technology in education that supports comprehensive learning experiences, seamless integration with existing ecosystems to reduce adoption barriers, and architectural patterns for decentralized educational applications that balance security, performance, and usability.

The platform's successful implementation provides a viable model for future educational technology development, demonstrating that blockchain-based solutions can address real-world challenges in credential verification, data security, and user control. The integration of TON blockchain with educational workflows represents a significant advancement in applying blockchain technology to practical educational contexts.

Future work will focus on several directions including enhanced onboarding experiences for users unfamiliar with blockchain technology, deeper integration with the TON ecosystem including token-based incentives, expansion of assessment types and learning analytics capabilities, implementation of cross-institutional credential verification networks, and development of mobile applications leveraging Telegram's ubiquitous presence.

A2TONIUM represents a significant step toward more transparent, secure, and user-centric educational ecosystems. By demonstrating practical blockchain applications in education, this research contributes to the ongoing digital transformation of learning and credentialing systems, potentially influencing how educational achievements are recorded, verified, and valued in increasingly digital societies.

Acknowledgements

This research is funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (No. AP19579354).

Declaration on Generative AI

The authors have not employed any Generative AI tools.

References

- [1] P. Staff: How manual record management is hurting your school. Parchment (2024).

- [2] Ripah, N.M., Bunawan, A.-A., Shoid, M.S.: The challenges in implementing proper recordkeeping practices at public universities. *International Journal of Academic Research in Business and Social Sciences* 12(7) (2022).
- [3] Liu, Y., et al.: EduChain: A Blockchain-Based Education Data Management System. *Communications in Computer and Information Science* (2021).
- [4] Grajek, J.: 2022 EDUCAUSE Horizon Report: Teaching and Learning Edition. (2022).
- [5] Turkanovic, M., et al.: EduCTX: A Blockchain-Based Higher Education Credit Platform. *IEEE Access* 6, 5112–5127 (2018).
- [6] Park, J.: Promises and challenges of Blockchain in education. *Smart Learning Environments* 8(1) (2021).
- [7] Koshiry, A.E., et al.: Unlocking the power of blockchain in education. *Blockchain Research and Applications* 4(4), 100165 (2023).
- [8] Bhaskar, P., Tiwari, C.K., Joshi, A.: Blockchain in education management: present and future applications. *Interactive Technology and Smart Education* 18(1), 1–17 (2020).
- [9] Li, H., Han, D.: EDURSS: A Blockchain-Based Educational Records Secure Storage and Sharing Scheme. *IEEE Access* 7, 179273–179289 (2019).
- [10] Riley, D.: Coursera platform vulnerabilities could have exposed user data. *SiliconANGLE* (2021).
- [11] National Institute of Standards and Technology: CVE-2024-22209: Improper Authorization in Open edX – NVD. (2024).
- [12] Rustemi, A., et al.: A Systematic Literature Review on Blockchain-Based Systems for Academic Certificate Verification. *IEEE Access* 11, 64679–64696 (2023).
- [13] Tanriverdf, M.: PublicEduChain: A Framework for Sharing Student-Owned Educational Data on Public Blockchain Network. *IEEE Access* 12, 51772–51785 (2024).
- [14] Turkanovic, M., et al.: EduCTX: A Blockchain-Based Higher Education Credit Platform. *IEEE Access* 6, 5112–5127 (2018).
- [15] BCdiploma: Blockchain certified data. (2023).
- [16] Arizona State University: Trusted Learner Network (TLN). (2023).
- [17] Ma, Y., Fang, Y.: Current status, issues, and challenges of blockchain applications in education. *IJET* 15(12), 20 (2020).
- [18] Li, H., Han, D.: EDURSS: A Blockchain-Based Educational Records Secure Storage and Sharing Scheme. *IEEE Access* 7, 179273–179289 (2019).
- [19] Kistaubayev, Y., et al.: Ethereum-Based Information System for Digital Higher Education Registry and Verification of Student Achievement Documents. *Future Internet* 15(1), 3 (2022)
- [20] Hyland: Hyland Credentials. (2023).
- [21] TON Documentation: TON Architecture and Technical Documentation. (2025).
- [22] DEFI.org: DEFI.org – the Open Network (TON). (2023).