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Development of a Blockchain-Based Learning Management Systems for Digital Learning Transparency

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Abstract: *Current blockchain-based Learning Management Systems (LMS) are predominantly limited to partial certificate validation using ERC-721 and face significant scalability constraints and high transaction costs on Layer-1 infrastructures, failing to address the complete educational lifecycle. This study proposes a novel end-to-end decentralized LMS architecture integrating the Manta Pacific Layer 2 network for cost efficiency, the ERC-1155 standard for bulk license management, and Livepeer/IPFS protocols for autonomous content distribution. Employing a prototyping method, system performance was evaluated on the Manta Pacific Sepolia Testnet through 97 transaction scenarios covering course creation, enrollment, and real-time progress tracking via the Goldsky Indexer. Testing parameters focused on gas efficiency, transaction latency, and data integrity. Test results demonstrate significant operational efficiency with an average gas cost of 260.899 wei per transaction and a stable average block confirmation time of 10.0 seconds. Forensic validation confirmed 100% data consistency between internal system logs and blockchain explorer trails, alongside the successful execution of an automatic, intermediary-free revenue split (90/10). The proposed architecture proves capable of overcoming cost and latency barriers in educational blockchain adoption, offering a transparent, accountable, and technically feasible infrastructure for institutional scale.*

Keywords: *Layer-2 Blockchain, Manta Pacific, ERC-1155, Decentralized LMS, Data Integrity, Livepeer.*

1. Introduction

The integrity of academic credentials faces fundamental challenges due to the vulnerability of centralized systems that rely on a single authority without independent verification mechanisms. Blockchain is a distributed ledger that guarantees data integrity through decentralization and cryptographic encryption, eliminating the risk of manipulation at a single central point [1]. This technology offers a solution through decentralized trust and data immutability, which has been proven in cross-border payment systems using blockchain [2]. The immutability characteristic ensures that all data is permanently recorded and cannot be manipulated [1], [2]. The success of blockchain in building trustworthy systems has sparked exploration of its application in higher education [3]. The lack of transparency in credential validation hinders independent verification, necessitating the need for decentralized systems to restore trust between students, investors, and the industry.

The digitalization of education experienced exponential acceleration during the COVID-19 pandemic, with a United Nations report indicating that 86% of children in developing countries, including Indonesia, are missing out on formal education opportunities [4]. This acceleration exposed critical weaknesses in manual verification methods in online learning platforms [5], as well as challenges of infrastructure readiness and technology adoption that remain obstacles in higher education [6]. Learning platforms face serious vulnerabilities such as Insecure Design and Broken Access Control, which allow unauthorized access without proper authentication [7]. Blockchain technology has been shown to accelerate the verification process and increase transparency and security in academic credentials [8]. While existing LMSs effectively support online learning [9], the limitations of manual validation systems create a trust gap that undermines stakeholders' confidence in the credibility of educational institutions [8], [10].

While several studies have explored blockchain in education, existing implementations face two fundamental limitations. First, digital certificate-based solutions utilize blockchain technology but are hampered by high transaction fees on Layer-1 networks and have not been integrated with learning content distribution [11]. Second, previous studies implementing NFTs for certificate management still use the ERC-721 standard, which requires separate contracts for each asset type, making it inefficient for large-scale management [12]. These gaps result in a non-holistic architecture that is difficult to implement in a real-world educational environment. This study proposes a novel architecture that integrates Manta Pacific as a Layer-2 for cost efficiency and scalability [13], and Livepeer for decentralized video content distribution [14]. The combination of this technology with IPFS distributed storage enables the system to transparently record credentials while managing the distribution of learning content with sustainable operational costs and security [15], [16], [17].

Based on this gap, this study answers two questions. First, how can a blockchain-based LMS architecture be built utilizing Layer-2 technology and decentralized content infrastructure to overcome cost and scalability limitations? Second, how can digital transparency mechanisms be achieved to ensure the integrity of publicly verifiable credentials? To answer these questions, the study designs and implements an LMS that integrates Manta Pacific with Livepeer Studio, then evaluates its effectiveness in achieving digital transparency and information security according to the principles of confidentiality, integrity, and availability [18]. This research contribution offers a secure, transparent, and feasible learning system architecture model for institutional-scale implementation.

2. Literature Review

Previous studies in educational blockchain have generally focused on utilizing smart contracts to prevent certificate forgery, but have faced significant technical challenges in terms of scalability and transaction processing speed. Bucea-Manea-Tonis et al. identified that slow transaction processing speeds on blockchain can create a bottleneck when attempting to scale educational processes globally [19]. This weakness is exacerbated by high infrastructure costs and the complexity of system integration, which hinder the adoption of blockchain technology in higher education institutions. Geraldina and Sihotang noted that blockchain implementation requires significant infrastructure investment and faces scalability challenges, especially as data volumes increase [8]. Furthermore, Raimundo and Rosário highlighted the strong administrative resistance to the adoption of this technology, fueled by institutional doubts about the ability of existing blockchain solutions to overcome administrative barriers through a more transparent and technologically advanced higher education system [3]. Data privacy issues have also emerged as a serious obstacle, with Ramadhan et al. noting that while blockchain promises higher security, privacy concerns should not be ignored, as its transparent nature can pose challenges in protecting sensitive student information [10].

In addition to these technical obstacles, limited functional scope is also a fundamental weakness of previous studies. The majority of research is limited to blockchain implementation for digital certificate management or academic credential verification, not encompassing a complete end-to-end learning system. Studies developing Decentralized Applications for digital certificate management only use ERC-721 NFTs to store diplomas and academic transcripts, without managing course licenses, learning content, or student learning progress [12]. Platforms like Blockcerts and EduCTX reviewed by Archa Erica et al. primarily function as diploma or credential wallets, rather than as comprehensive Learning Management Systems [10]. Geraldina and

Sihotang also highlight that the focus of previous research has been on document security and diploma verification, without shifting the paradigm to full integration within the LMS pedagogical flow that encompasses learning content, progress tracking, and certificate issuance in an integrated manner [8]. Raimundo and Rosário emphasize that the existing literature focuses mostly on diploma recordkeeping, indicating that "end-to-end blockchain LMS" is still very rarely developed [3].

In contrast to these partial approaches, this study develops an end-to-end blockchain LMS architecture that simultaneously addresses the technical and functional shortcomings of previous studies through the integration of four core components. First, the use of Manta Pacific as a Layer-2 with Celestia addresses the high gas fees and scalability bottlenecks identified by Bucea-Manea-Tonis et al. [19], while the implementation of the ERC-1155 standard allows the management of thousands of course licenses within a single contract addressing the inefficiencies of ERC-721 criticized in previous certificate management studies [12]. Second, the integration of Goldsky Indexer addresses criticisms of slow on-chain data access by providing real-time queries without intermediary infrastructure [20], while the combination of IPFS and Livepeer handles storage and streaming of heavy content with efficient bandwidth [14], [15]. The integration of these four components realizes an end-to-end LMS ecosystem that addresses the blockchain trilemma while connecting licensing and learning in a coherent decentralized infrastructure.

3.Methods

This research applies a prototyping method with an iterative design-evaluation-improvement cycle to minimize the risk of security vulnerabilities before permanent deployment to the blockchain (Figure 1). The system is built on the Manta Pacific Sepolia Testnet as a Celestia Data Availability-based Layer-2 with smart contracts written in Solidity version ^0.8.24. Frontend-blockchain interaction utilizes the Thirdweb SDK for wallet authentication and transaction execution, while the Goldsky Indexer (Hosted Subgraphs) captures on-chain events in real time without additional backend infrastructure. Content storage uses IPFS (via Pinata) for course metadata and Livepeer for streaming video transcoding, with CID hashes recorded on-chain to ensure data integrity.

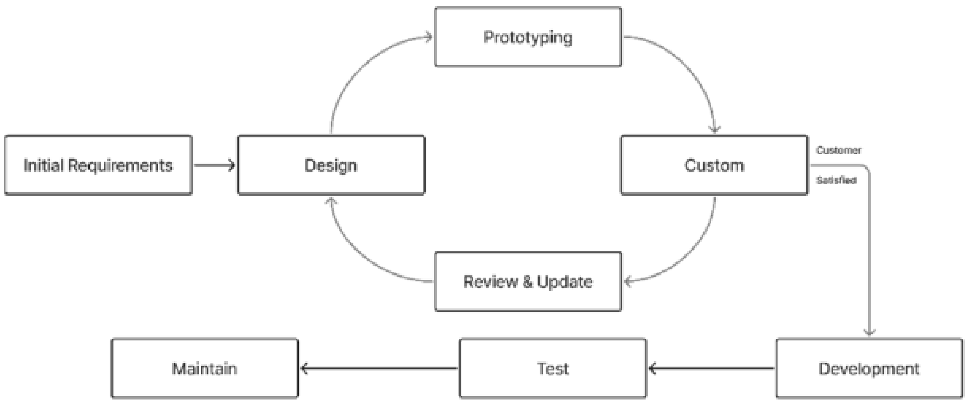


Figure 1. Prototyping Method

The system architecture combines on-chain components for ERC-1155 NFT license management and learning progress verification with off-chain components for multimedia content distribution (Figure 2). Primary data is obtained from transaction logs resulting from license minting simulations and module completion records executed directly on the testnet, while secondary data comes from literature studies of the ERC-1155 standard and the Ethereum Foundation's Layer-2 protocols. Since this is the system's development stage, validation is conducted through System Performance Testing without involving user respondents, by measuring three critical metrics: (1) Gas Efficiency to evaluate the execution cost per smart contract function, (2) Transaction Latency to measure the average block confirmation time, and (3) Data Integrity to verify the consistency between IPFS hashes recorded on-chain and actual files in decentralized storage. Testing is conducted on simulated transactions to ensure system reliability under standard load conditions.

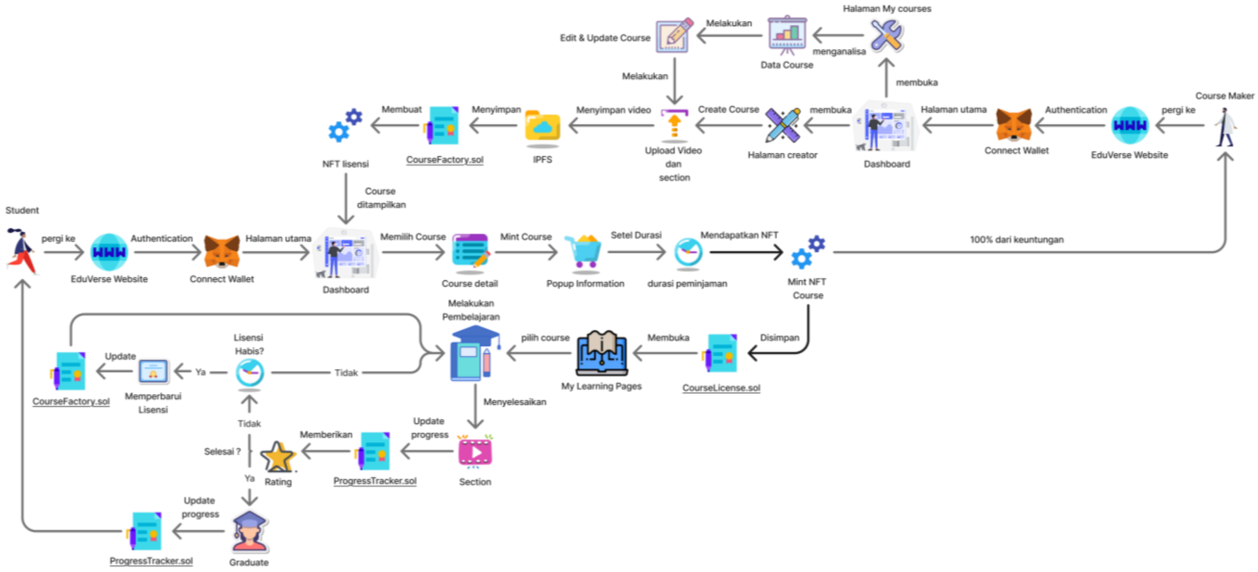


Figure 2. Learning Management System (LMS) Design

4. Results and Discussion

The EduVerse implementation was realized by connecting the Next.js web interface to the Manta Pacific Sepolia blockchain network, enabling the entire learning lifecycle to run decentralized. Testing was conducted through an end-to-end flow, starting from wallet connection, minting ERC-1155 NFT course licenses, tracking progress via an on-chain index, and finally publicly verifiable ratings and transactions. Validation of the system's success was measured through three main indicators: Gas Efficiency, which encompasses total transaction fees and contract load distribution; Transaction Latency, which encompasses block confirmation time and system throughput; and Data Integrity, which measures data consistency between internal records and public block explorers. This section presents the interface implementation results and on-chain transaction proofs to demonstrate that the developed mechanism is capable of providing transparency, speed, and reliability consistent with the principles of modern educational blockchains.

A. Course Maker Flow Implementation Results

The resulting Course Maker interface is designed to facilitate intuitive course content creation and management while remaining fully integrated with Web3 infrastructure. This process spans from course initialization to publication to the IPFS network and blockchain.

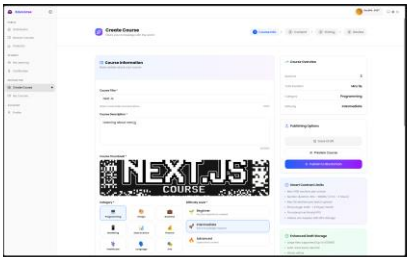


Figure 3. Course Creation Page

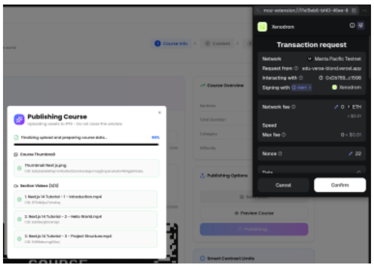


Figure 4. Transaction Confirmation with Wallet

Instructors begin content creation through the Course Maker interface (Figure 3) by filling in course metadata and uploading video materials, which will be processed through the Livepeer protocol for decentralized streaming. Once the data is complete, publication requires transaction confirmation through MetaMask (Figure 4) to allow interaction with the smart contract and pay gas fees, ensuring each course has a digital signature that is immutable and recorded on the Manta Pacific network.

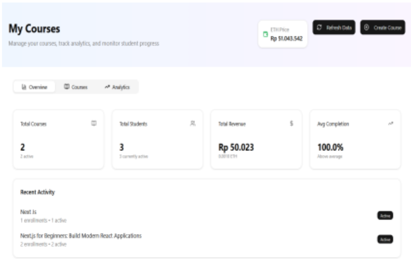


Figure 5. Course Maker Dashboard Overview

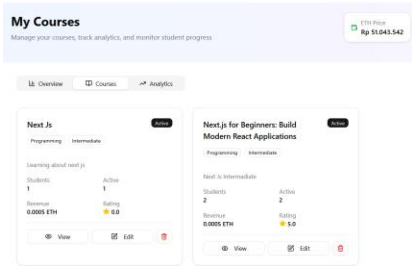


Figure 6. Dashboard My Courses List

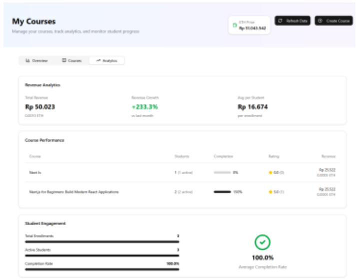


Figure 7. Dashboard Analytics Revenue

Once a course is published, instructors monitor its performance through an integrated dashboard that includes a summary of key metrics (Figure 5), a list of courses with status and revenue per course (Figure 6), and an analytics panel (Figure 7) that transparently visualizes revenue growth and completion rates over the blockchain network.

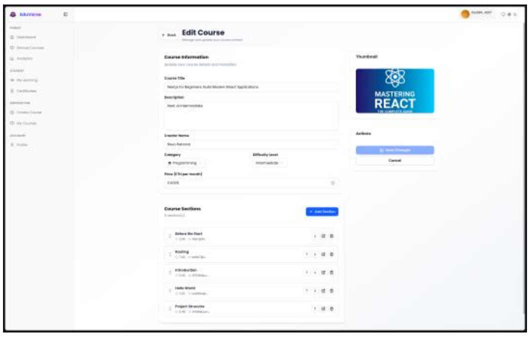
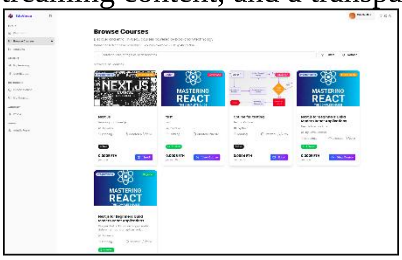


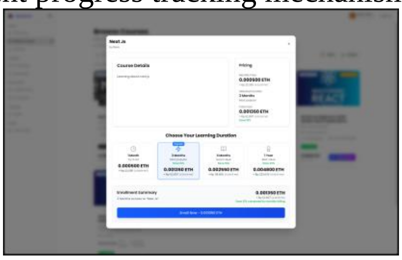
Figure 8. Edit Course Section Management

Instructors can update published course materials through the Edit Course interface (Figure 8). This page provides full control to modify course metadata, such as title, description, and curriculum structure, without disrupting existing license contracts. Any saved changes automatically trigger metadata updates across the IPFS network, ensuring that students' access to the materials is always in sync with the latest instructor-approved version.

B. Student Flow Implementation Results

The learner-side implementation is designed to provide a seamless yet cryptographically verified learning experience. This flow includes license validation, interaction with decentralized streaming content, and a transparent progress tracking mechanism.





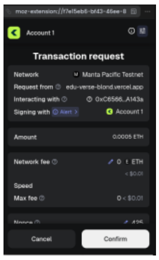


Figure 9. Students Explore the Public Catalog

Figure 10. Student Registration Plan Selection

Figure 11. Student Wallet Payment Confirmation

Students begin their interaction by browsing the active course catalog, which displays metadata from the blockchain (Figure 9). After selecting a course, they specify a license duration between 1 month and 1 year in the Plan Selection interface (Figure 10), with an automatically calculated ETH price. The process concludes with Payment Confirmation (Figure 11). At this stage, a digital transaction is signed to execute the mintLicense function, which transfers the fee to the instructor and mints an ERC-1155 NFT token as an access key, instantly changing the course status to "Enrolled" upon validation.

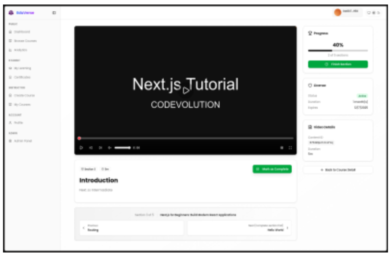


Figure 12. Student Video Player View

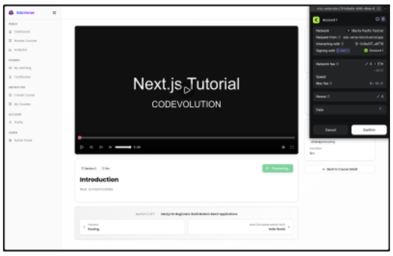


Figure 13. Student Lesson Complete Sign

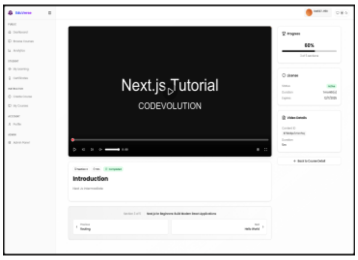


Figure 14. Progress Recorded

The learning interaction centers on a decentralized video player (Figure 12) that streams materials directly from the Livepeer network, ensuring censorship-free content without relying on a single server. Upon completing the material, the learner presses the Mark as Complete button (Figure 13) to validate their progress. This action triggers an on-chain transaction to the ProgressTracker smart contract, which verifies ownership of an active license in real time. The validation results are reflected in a visual indicator (Figure 14), where the module status changes to green (Completed) and progress is automatically incremented, ensuring that all learning progress data is authentic and permanently recorded on the blockchain.

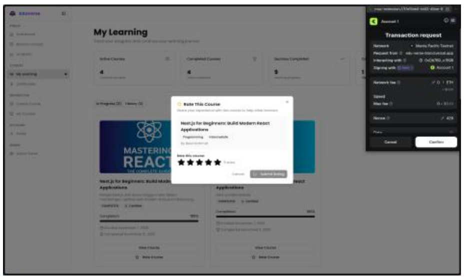


Figure 15. Course Rating Validation

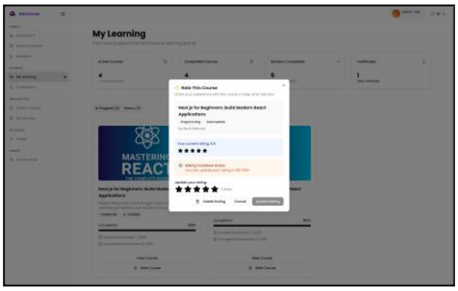


Figure 16. Rating Result

After completing a course, learners can leave a star rating through an intuitive modal (Figure 15), which requires wallet transaction confirmation to validate the user's authenticity and records the rating transparently on the blockchain. The system implements a cooldown mechanism as an advanced security feature of the smart contract (Figure 16), which prevents spamming or rating manipulation by limiting review updates to only after a specified period of time has elapsed. The rating data is then averaged on-chain and displayed in the course catalog, creating a transparent and difficult-to-fake instructor reputation system.

C. Analysis of System Implementation and Evidence of Digital Transparency

This section presents operational validation results based on empirical data from an LMS system deployment on the Manta Pacific testnet, demonstrating how the blockchain architecture addresses the identified research gap. The architecture separates functions across four independent smart contracts operating on the Manta Pacific Sepolia network, creating a separation of concerns that prevents a single point of failure. Load distribution is balanced, with CourseFactory and ProgressTracker each handling 29.9% of the 97 transactions, while CourseLicense and CertificateManager process 20.6% and 19.6% of transactions, respectively. This separation prevents an architectural bottleneck where the entire operation relies on a single component, unlike monolithic systems that experience bottlenecks during peak demand. This modularity addresses the limitations of previous studies that focused solely on a single certificate function without end-to-end integration encompassing course creation, progress tracking, licensing, and certification within a cohesive ecosystem.

Table 1. Distribution of Computing Load Between Smart Contract Modules

Smart Contract	Total Transaction	Load Percentage	Gase Used (wei)	Main Operational Function
CourseFactory	29	29.9%	5,344,022	Course creation, batch operations, rating system
ProgressTracker	29	29.9%	5.217.999	Section tracking, course completion records
CourseLicense	20	20.6%	3,756,263	Minting license ERC-1155, auto-renewals
CertificateManager	19	19.6%	2,893,377	Minting sertifikat NFT ERC-721, course additions
Total	97	100%	17.211.661	End-to-end learning management

Network metrics show stable block confirmation times at an average of 10.0 seconds with a 100% success rate for all executed transactions, demonstrating consistent reliability throughout the observation period. A stable gas price of 0.003000 Gwei provides predictable operational costs, allowing institutions to accurately calculate their total cost of ownership, with the total gas cost for 97 transactions recorded at 0.000099 ETH. The ProgressTracker contract, which consumed 5,217,999 wei for 29 transactions, averaged 260,899 wei per transaction, demonstrating the efficient execution of state-changing functions optimized through storage minimization and batch processing techniques. Layer-2 characteristics such as Manta Pacific enable higher throughput and lower costs compared to direct Layer-1 deployments due to more efficient off-chain computation and on-chain settlement, addressing the gap regarding high cost barriers to educational blockchain adoption, a major barrier to scalability. This data demonstrates that the system is capable of operating with sub-15 second latency, which is adequate for real-time learning workflows without compromising transaction finality or data integrity.

Table 2. Network Performance Metrics and Gas Efficiency

Performance Parameters	Measured Values	Operational Interpretation
Avg Block Time	10.0 detik	Transaction confirmation stability on the testnet network
Total Transactions	97	System capacity validated through real operations

Gas Price	0.003000 Gwei	Predictable cost per unit of computation
Total Gas Cost	0.000099 ETH	Aggregate fees for all 97 transactions
Gas per Tx (avg)	260.899 wei	Efficiency per state-changing operation on ProgressTracker
Success Rate	100%	There are no failed transactions or reversed calls
Current Block Height	#5,660,260	Real-time monitoring capability in block explorer

The system is designed to meet the maximum latency requirement of 15 seconds per transaction, which is necessary for an acceptable user experience in an interactive learning context. Measurement results show an average block time of 9.97 seconds (displayed as 10.0 seconds on the dashboard after rounding), which is below the threshold by a margin of 33.5%, providing an adequate buffer for variations in network congestion. Actual throughput recorded at 0.13 transactions per hour (83 transactions in the observation period of ~27 days based on 234,914 blocks), which reflects realistic usage patterns in the early adoption phase of the educational platform. Peak burst capability reaches 3 transactions per block, as evidenced by a block height of 5,653,759 where CourseFactory processes three addSection operations simultaneously. Of the 59 unique blocks recorded, 21 blocks (35.6%) process multiple transactions simultaneously, indicating good concurrent processing capabilities. Gas efficiency per transaction category shows controlled variance with a coefficient of variation of 0.18 for similar transaction categories, indicating consistent computational costs that facilitate budget planning for adopting institutions.

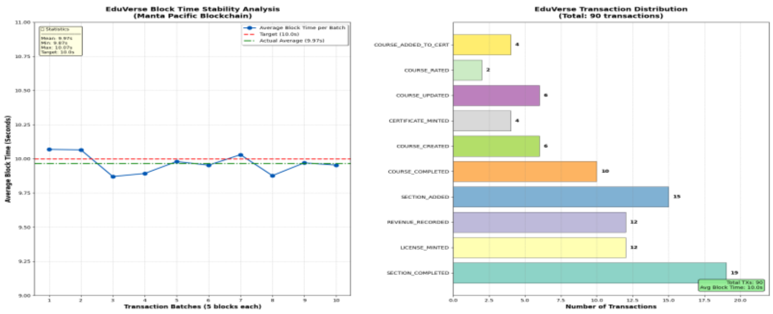


Figure 17. LMS Transaction Data Visualization

The system's economic model implements revenue distribution executed deterministically by smart contracts without the possibility of manual intervention, a fundamental characteristic of blockchain that eliminates the trust requirement for intermediaries. The total revenue of 0.013 ETH is automatically distributed into 0.01242 ETH or 95.5% for creator payouts and 0.00058 ETH or 4.5% for platform fees according to a 90/10 split logic hardcoded in the contract bytecode and publicly auditable. This mechanism eliminates hidden fees or arbitrary deductions common in centralized learning platforms that take 30-50% margins without transparent fee breakdowns, addressing the lack of financial transparency in conventional LMSs that disadvantage creators. Each course payment transaction triggers an atomic dual transfer that is publicly auditable through a block explorer, where split payments are executed in a single transaction without the need for escrow or third-party payment processors that add complexity and counterparty risk.

Table 3. Income Distribution and Platform Economic Metrics

Economic Metric	Value (ETH)	Percentage	Execution Mechanism
Total Revenue (All Sources)	0.013	100%	Smart contract revenue aggregation
License Revenue	0.006000	46.2%	ERC-1155 token minting fees
Certificate Revenue	0.007000	53.8%	ERC-721 NFT minting fees

Creator Payout (90%)	0.01242	95.5%	Automatic split dengan hardcoded ratio
Platform Fee (10%)	0.00058	4.5%	Protocol sustainability fund

Data integrity was validated through triangulation of three independent sources that cryptographically verified the consistency of the learning log using immutable hash functions and merkle proofs. An internal system notification recorded a SectionCompleted event at block height 5,653,514 with a timestamp of 16:49:44 WIB, while the public block explorer Manta Pacific confirmed the existence of transaction hash 0x8b1f755747903038dc2524dfc0fcbedbf8f33b20aca1b3b2f522e6c0a4a2b61 on an identical block with verified status. The decoded transaction log revealed the courseId 2, sectionId 4, student address 0xb5075eB5734bc8A6a9bbC1Ca299Fd8C0bd4Cff58, and Unix timestamp 1764668984 parameters, which perfectly matched the system's internal records without a single byte discrepancy. This cryptographic hash match represents a mathematical proof of immutability that allows successor institutions to validate the authenticity of credentials by directly querying the public blockchain without the need for proprietary APIs or centralized databases that administrators can tamper with, addressing the problem of credential fraud that plagues educational institutions globally. This mechanism eliminates the reliance on credential verification intermediaries that charge per-query verification, creating significant cost savings for institutions with high verification volumes.

Table 4. Cross Validation of Internal Data with Public Blockchain

Validation Source	Verified Key Data	Consistency Status
Internal System Log	Block: 5,653,514 - Timestamp: 16:49:44 WIB - Event: SectionCompleted	Recorded in the application database
Block Explorer (Public)	Tx hash: 0x8b1f...2b61 - Contract: 0x6eA7Fe...6778 - Gas used: 260,899	Confirmed on a public blockchain
Transaction Decode	Student: 0xb5075e - courseId: 2 - sectionId: 4 - timestamp: 1764668984	Match 100% with system log
Cross-Reference	Block height, address parameters, function signatures	Zero discrepancy detected

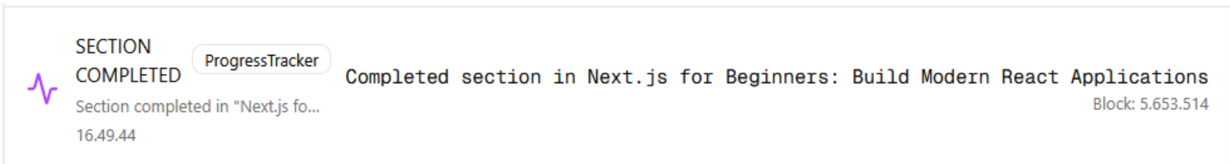


Figure 18. Transaction Block

D. Systemic Risk and Limitation Analysis

Although the consensus mechanism and data storage are decentralized, the data access layer for query operations still relies on third-party RPC indexer providers like Goldsky or Thirdweb, which can become a single point of failure if service disruptions or API rate limiting hinder the user experience. Validation was limited to a controlled transaction simulation with a total of 97 transactions from four active learners. It did not include load testing on a scale of thousands of concurrent users that could uncover hidden bottlenecks in the architecture, such as mempool congestion or database read/write contention on RPC endpoints. Reliance on the Manta Pacific Testnet environment carries inherent risks related to testnet stability, such as periodic resets that can erase historical data, faucet limitations that limit testing capacity, or breaking changes in protocol upgrades that are not backward compatible with deployed smart contracts. Migrating from testnet to mainnet deployment requires a comprehensive security audit to ensure compatibility with the mainnet execution environment, which has different gas economics, as well as the procurement of gas reserves for operational costs, which must be factored into the total cost of ownership analysis, given that mainnet gas prices can be volatile depending on network congestion. Dependencies on external oracle services for off-chain data, such as course content metadata stored in IPFS, also require redundancy mechanisms to prevent data unavailability if the IPFS gateway experiences downtime. Data pinning strategies should also be considered to ensure long-term content persistence.

Testing identified three categories of failure scenarios that require additional handling mechanisms in production deployments. First, a transaction revert occurs when the same student address attempts to complete a section that has been previously marked complete, resulting in a revert message with a gas consumption of 21,000 wei without any state change indicating proper guard clause implementation. Second, a race condition can potentially arise in concurrent course enrollment where two transactions from different addresses attempt to enroll in the last available slot, requiring nonce-based ordering at the mempool level for deterministic resolution. Third, orphaned license tokens can occur if a renewal transaction fails due to an insufficient balance in the student wallet, requiring a grace period mechanism or notification system to prevent service disruption. Testing also revealed limitations on batch operations where CourseFactory.addMultipleSections with an array size of more than 10 elements approached the block gas limit of 30,000,000 wei on the testnet, necessitating a strategy solution for courses with complex structures containing dozens of sections.

5. Conclusions

This study demonstrates that the integration of the Manta Pacific Sepolia network, the ERC-1155 standard, Goldsky, and the Livepeer protocol successfully creates a decentralized LMS architecture that overcomes the cost and latency trilemma in blockchain education, achieving 10-second block confirmation stability and an average gas cost efficiency of 260,899 wei per transaction. The study's key innovation lies in the development of an end-to-end mechanism that goes beyond certificate validation and encompasses the entire lifecycle, from licensing to autonomous content distribution. This shifts the educational governance paradigm from institutional trust to transparent cryptographic verification, where data integrity and revenue distribution (90/10) are recorded immutably and anti-manipulation. While technically sound, this study suffers from limitations such as reliance on a third-party RPC indexer provider, which could potentially create a single point of failure, and the block gas limit for large-scale batch operations in a testnet environment. Therefore, the continuation of this research should focus on the implementation of decentralized oracles to ensure redundancy of metadata data access, as well as the implementation of comprehensive security audits on the mainnet network to validate the system's resilience to cost volatility and network attacks at a real operational scale.

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