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Transforming academic assessment: The metaverse-backed Web 3 secure exam system

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Abstract

Metaverse—a three-dimensional computational environment—combines physical and virtual reality to enable social relationships and immersive experiences by mimicking real-world scenarios. Metaverse is considered the third wave of the internet revolution (exploiting Web 3.0), leveraging upcoming technologies such as extended reality and artificial intelligence shaping a new era of human–-machine interactions. In recent years, increased research and development on educational technologies (EduTech) based on blockchain technology has seen substantial growth of metaverse-based solutions within the higher education context. This research aims to synergize blockchain technology and metaverse environments to conduct online exams (metaExam) in a trustworthy, reliable, and secure way. The synergy between blockchain and the metaverse brings various benefits, such as improved security, cost effectiveness, and increased efficiency in the online examination process. One of the central features of the proposed solution metaExam is to leverage cryptographic protocols via blockchain to control data access, making verification faster and protecting against misuse. Exam scores and grades are stored on a blockchain ledger using a digital signature method to enhance security. We validated the proposed solution by testing a prototype on the Ethereum platform using the Sepolia Testnet network using Microsoft Windows environment. Evaluation results indicate (i) query response time (10–50 ms), (ii) and query execution performance (CPU utilization between 1%–5%) offering computationally feasible solution. This research contributes by integrating blockchain and metaverse technologies to offer a solution metaExam that can offer improved security and immersive user experience for exam management. The proposed solution and its validation can provide insights into transforming online exams, offering a fresh perspective on addressing concerns about exam grade authenticity and verifying academic credentials in EduTech.

KEYWORDS

blockchain, Ethereum, medical exam system, metaverse, online test, smart contract, virtual reality

1 | INTRODUCTION

Blend learning (BL) converses to a combination of several educational methods that facilitate learning both inside and outside the classroom. Virtual instructor-led training (VILT) offers a charming skill in which participants can join with the content and cooperate with both the instructor and other classmates. Due to the pandemic of COVID-19, education faces a significant challenge, because of which the adoption of BL and VILT has increased globally [32]. The traditional classroom activities are flexible, reachable and cost-effective based on these methods and due to integration of technology and educational tools [14]. The COVID pandemic highlighted the importance of online teaching for advancing educational progress, with metaverse technology emerging as an optimistic encouragement for student learning [22]. The universities and academic institutions established the metaverse and its impact on learning in the virtual world that creates a new dimension of education with the combination of virtual and physical [5, 37]. Modern education trusts on e-platforms and mixing e-learning with artificial intelligence to initial STEAM-focused tasks [12, 34].

1.1 | Blockchain systems in education and virtual reality

Blockchain technology in education is still early, with limited adoption in institutions [3]. While some organizations use it to verify students' achievements (certificates, exam grades), there is untapped potential for further exploration. Experts believe blockchain can significantly impact the education industry [28], potentially expanding learning opportunities and challenging the traditional role of educational institutions in certification [35]. The metaverse, originating from Neal Stephenson's 1992 science fiction, refers to a three-dimensional (3D) virtual reality (VR) existing beyond reality [29]. It represents a digitized world expressed through digital media, smartphones, and the internet. Extensive efforts and research have been made to turn the metaverse into a reality [17, 27], with organizations like the Acceleration Studies Foundation providing a roadmap in 2006. The metaverse is defined as a 3D-based VR where daily activities and economic life occur through avatars representing real individuals [20, 21]. As the metaverse is rapidly introduced into everyday life, some applications are already being used in education, emphasizing the need to understand its concept, types, and educational applications.

1.2 | Research challenges and objectives

The metaverse has emerged as an advanced form of VR or augmented reality (AR), providing students with immersive and interactive learning experiences and transforming the learning environment [2, 19, 20]. Acting as a shared, persistent, decentralized space, the metaverse emphasizes social, simulated, and collaborative experiences, separating from traditional AR/VR applications [2]. Devices like the Oculus Quest headset represent the metaverse with a VR interface [23]. During the COVID-19 pandemic, metaverse applications have been introduced in medical training, employing it for thoracic surgeons' hands-on practice and real-time discussions and integrated the metaverse into architect education, utilizing blockchain technology for certifying digital artwork as nonfungible tokens (NFTs), resulting in significant improvements in imaginative perception among students.

A comprehensive overview of the proposed system is depicted in Figure 2, illustrating the architectural principles employed in designing and implementing the blockchain system within a metaverse environment supported by complementary tools for automated system development. The figure presents a layered view of the system, delineating its components and connectors, aiding system developers in maintaining separation of concerns. This layering approach organizes various operational aspects at different layers of the system, facilitating modularization for algorithm specifications. The objective of this study is to develop and validate a blockchain-based approach for conducting online exams in a metaverse environment. This involves implementing digital signature techniques to secure student exam scores and grades. The study aims to evaluate the proposed model's functionality, performance, and gas consumption through a series of trials and analyses. Our main contributions to this article are as follows:

- Architecting a VR-based exam system that synergizes blockchain technology (infrastructure to secure exam storage and retrieval of exam data) and metaverse (visual environment as VR for the exam).
- Implementation of algorithms to automate the process and give a proof-of-concept (PoC) for a blockchain-driven secure exam system in metaverse environment. By using the algorithms, we are able to develop a PoC and a foundation for evaluating the metaExam prototype for the Ethereum student exam system.
- Validating the functionality of smart contracts on Ether TESTNET, we implemented a case study with a set of trials and evaluated the proposed model's major

capabilities: scalability, computational efficiency, and energy efficiency.

The organization of this article is structured as follows:

Section 2 deals with metaverse impact and applications. Section 3 Related Work Overview—investigates the existing research and contextualizes the current work. Section 4 Research context and methodology—provides insights into the research methodology and the broader context in which this study was conducted. Section 5 deals with empowering solutions: Case study—offers a detailed account of algorithm implementation, the technologies employed, architectural insights, and the executed model. Section 6: Results and evaluation—outlines the outcomes and evaluations of the proposed system, including a comprehensive cost and security analysis. Section 7 summarizing the key findings and contributions of the research.

2 | RESEARCH CONTEXT: METAVERSE IMPACT AND ITS APPLICATIONS

In this section, we discuss the impact of metaverse in the context of education and discuss its applications of metaverse. Section 2.1 discusses the metaverse and education environment of metaverse. Section 2.2 presents the applications of metaverse which are using the environment of metaverse with virtual reality and other technologies combinations.

2.1 | Metaverse impact on education

In the evolving Metaverse, students can experience fully immersive multimedia learning environments that blend the real and virtual worlds. For example, a geometry class might involve students interacting with geometric shapes in a VR setting while receiving guidance from a math expert. This trend drives the emergence of metaverse programs and schools, challenging traditional educational structures. Gamification, incorporating game mechanics into learning, is gaining popularity in virtual environments, enhancing engagement [10]. The demand for gamified learning is expected to rise alongside the increasing use of AR, VR, and AI in education, with the global game-based learning market projected to grow [26]. Various VR and AR platforms are currently available, especially in countries at the forefront of the Metaverse. The concept of a "Metaversity" has emerged, where higher education institutions are digitally associated using XR technologies. Distinguished players like Virbela and VictoryXR are pioneering immersive learning experiences, creating international virtual campuses that prioritize physical proximity and real-time collaboration [15].

2.2 | Metaverse applications

With the movement of the metaverse, countries China, United States, and certain European nations are actively developing VR and AR platforms. The Virbela Open Campus one of them is the most famous, which expanded importance during the peak of the pandemic as a major platform for hosting international conferences. Authors, having experienced these platforms in teaching and conferencing, highlight the significant impact of immersive technologies on education. Platforms like Virbela facilitate multifunctional campuses for research, conferencing, and teaching. Integrating XR technologies in the metaverse enhances learning motivation, allowing students to interact with teachers and classmates through avatars. Important studies include Siyaev and Jo's exploration of MR in aircraft maintenance, according to Gonzalez Crespo et al. [11] analysis of educational virtual environments in the metaverse, and Saundarajan et al. [31] research on AR mobile learning apps improving mathematics outcomes.

In the metaverse, users can practice or learn in situations mirroring the real world. Applications include:

- Virtual 3D classrooms: Metaverse's development of 3D virtual classrooms allows students to interact virtually with classmates and teachers, bridging the gap between physical and online education [9].
- Virtual campus activities: Students engage in extracurricular activities like sports and the arts in a virtual setting, participating in music or math clubs and campus activities [25].
- Simulating real-life conditions: Subject-specific 3D spaces are created to captivate students by simulating real-world scenarios, enabling them to conduct experiments and participate in activities like creating documentaries [16].
- Virtual tours: The metaverse facilitates virtual travel worldwide, expanding students' horizons and worldviews by enabling them to visit any place of their choice in minutes [36, 38].
- Gamification: Metaverse incorporates gamification, enhancing student engagement and encouraging students to actively participate in learning and submit assignments on time [8].

TABLE 1 Comparative overview of centralized versus decentralized (blockchain-based) digital identity management.

Feature	Central identity management	Blockchain-based distributed identity management
Governance Mechanism	Central Governance	Decentral Governance
Identity Change	Change Management on Central Server	Change Management with Individual Consent
Key Management	Reset the password to recover lost identity/key	Digital assets are vanished if key is lost.
Storage	Server is Central	Distributed Nodes.
Freedom	Risk of stolenIdentities	User to reclaim stolen/lost Identities

Table 1 provides a complete overview and presents a detailed analysis in the context of centralized and decentralized identity management systems. Assessments of student is essential for adopting a blockchain-based approach in creating student valuations which could be a paradigm shift in this domain. This approach influences the support of decentralized storage while presenting users with suitability of access. The decentralized storage mechanism has far-reaching implications, mostly around the fundamental principles of security and transparency. Academic institutions can ensure the data of assessment is secure and transparent after implementing a blockchain-based student assessment system. In column of "Feature" discusses the number of features that are used to compare centralized and decentralized digital identity.

3 | EXISTING WORK

This section presents an overview of the most relevant related work, which allows for the analysis of existing solutions, the techniques that support their operation, and their limitations, which justifies the scope of the proposed solution and the contributions it makes. According to Table 1, the centralized and decentralized are compared and summarized objectively, allowing the proposal to be objectively evaluated and compared.

3.1 | Briefing and considerations in designing examination systems

Blockchain development has evolved significantly, progressing through three phases: Blockchain 1.0, 2.0, and 3.0. In its initial stage, Blockchain 1.0 primarily facilitated straightforward cryptocurrency transactions, laying the foundation for decentralized digital currencies. The subsequent phase, Blockchain 2.0, shifted focus towards broader applications, notably in real estate and the introduction of smart contracts. These contracts enabled automated and secure transactions, eliminating the need for intermediaries in the processes of registration [21].

The latest stage, Blockchain 3.0, represents a paradigm shift with diverse applications spanning various sectors such as government, education, healthcare, and science. Blockchain has emerged as a transformative platform for managing digital certificates in education, offering a secure alternative to traditional paper documents. This technology securely stores certified identities and employs smart contracts and certification authorities for efficient management. Pioneering educational institutions like Nicosia University have taken bold steps by depositing academic credentials directly on the Bitcoin blockchain, showcasing a forward-thinking approach and embracing the vast potential that Blockchain 3.0 brings to the educational landscape [13]. This advancement ensures the security and integrity of academic credentials and heralds a new era in how educational records are managed and verified.

AR integrates virtual objects seamlessly into the real world, appearing to coexist in the same space [6]. AR combines real and virtual elements interactively and in real-time, potentially engaging multiple sensory modalities. Unlike VR, where the virtual world is entirely immersive and isolated from the real environment, AR enhances the real-world experience by adding virtual objects to the existing surroundings. Conversely, VR creates fully immersive environments without considering the real world, utilizing headsets and sensory input for a realistic experience [33]. In AR, the real world is observed directly, and computer-generated elements enhance the existing reality, distinguishing it from the immersive nature of VR [7].

3.2 | Previous studies and comparative analysis

The metaverse's key advantage lies in erasing geographical constraints, providing a neutral space for global interactions, and fostering connections based on shared interests. It represents a 3D evolution of traditional internet use, offering an immersive experience and impacting social and economic. Nearly 60% of users embrace technology for its closeness and the opportunity to explore digital worlds. Business executives foresee a positive metaverse impact on their sectors, with an anticipated economic value of $5 trillion by 2030, potentially influencing global GDP by 2.8% by 2031. The metaverse's immersive nature enhances focus, unlocking new potential for personal and professional endeavors. It eliminates physical classroom constraints in education, allowing global collaboration and facilitating visual learning for a more engaging educational experience, enabling students to witness historical events firsthand [24].

The concept of the metaverse, originating from Neal Stephenson's science fiction, refers to a 3D virtual world, including applications in education. Described as a technological expression of culture, the metaverse offers immersive, multi-user online environments for social and economic interactions. However, its educational implications lack empirical and theoretical clarity, with scholars globally exploring its applications in education and its potential impact on the future of learning. Technologically, the metaverse represents the third wave of the internet, incorporating emerging technologies like extended reality (XR), 5G, artificial intelligence (AI), and data processing. Within this expansive metaverse, incarnations play a crucial role in enhancing interaction and navigation. Developing technologies are suggested for a more reachable and appealing experience. Whereas AR and VR have designed the metaverse, there's theory about the potential role of brain–computer interfaces (BCI) in advancing its adoption. Despite being early, BCIs potential to read the brain signals into actionable commands and escalating accessibility in the metaverse. The implication of student's inspiration in AR and VR learning environments is emphasized. However, there is a breach in research in understanding students' various perceptions of the metaverse in higher education, particularly considering fluctuating levels of learning inspiration. A study employs an innovative technique to explore how students distinguish and interact with the metaverse in higher education for addressing this gap [18].

Conclusive summary: Table 2 systematically illustrates how the proposed solution outperforms or aligns with existing methods. These efforts focus on understanding the associated costs, comparing the security robustness of decentralized versus centralized storage in defending against potential cyberattacks, and evaluating the absence of third-party authentication within the system. By omitting third-party authentication, the system can be designed and evaluated seamlessly, enabling real-time data collection and analysis during exams.

4 | RESEARCH METHODOLOGY AND TOOLS FOR SOLUTION

This section presents an overview of the research. It explains how the study was done and gives the important ideas that are desirable. It sets the base for the whole research. It discusses theories, methods, and the technologies used to make the solution work. It shows the tools and frameworks for software and engineers to put the research into practice. In short, it's a guide that conceals the ideas and practical stuff to help to understand the research better.

4.1 | Research method

Figure 1 provides a detailed visual representation of our research methodology, breaking the entire research process into well-defined steps. This figure acts as a

TABLE 2 Comparative analysis: Existing versus proposed research on secure metaExam systems.

Security mechanisms	[30]	[4]	[1]	Proposed study
Data encryption	✓	✗	✗	✓
Data storage	Blockchain node	Traditional	Traditional	Blockchain node
Attack resistance on the server	✓	✗	✗	✓
No third-party authentication	✓	✗	✗	✓
Metaverse environment	✗	✗	✗	✓

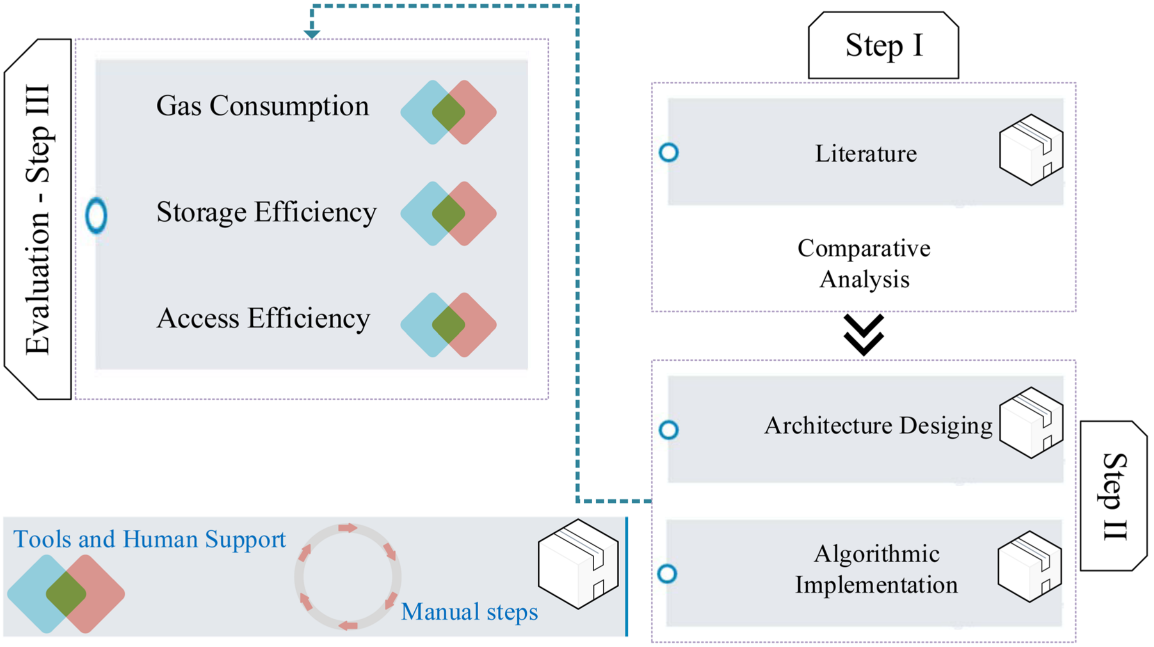

FIGURE 1 An overview of research methodology.

guide, leading readers through the systematic approach adopted for this research. To effectively achieve our research objectives, we employed a combination of quantitative and qualitative research methodologies. Research methods, focused on data collection and analysis, designed the foundation, as depicted in the first step of Figure 1. The following phases, represented as Steps II and III in the figure, involved qualitative research methods, allowing for a deeper exploration of design aspects and empirical evaluations. This combination of quantitative rigor and qualitative depth is at the core of our research strategy, highlighting the complicated approach used to address the research objectives.

Step I—Literature review and analysis: This first phase is the foundation of our research method. It's where we excavate deep into what others have already studied and written about. We look at all the existing knowledge to understand what's already out there. It helps to circumnavigate concluded our research. The detailed discussion of this part is in Section 4, where we systematically study past work, finding the gaps and opportunities that inspire our research.

Step II—Architecture and algorithm design: In this important step, we passage from theory to practical planning. We create a design and the architecture of our solution. This architecture is presented in Section 4 (Sub-Section 4.1), showing how our research is structured. We also break down the step-by-step plan for turning our theoretical ideas into real, practical phases.

Step III—Solution evaluation: The last step in our research is the examination of how well our solution works. We carefully test and measure its efficiency, ensuring it solves the problem we set out to address. It presents all the details about how we evaluate our solution in Section 4 (Sub-Section 4.3), where we explain the tests and measurements, we use to ensure our solution do well. We check the gas consumption and apply the number of tests.

This research methodology follows a systematic step, commencing with an exhaustive literature review and analysis in Step I, advancing to Step II's architectural and algorithm design, and concluding with the rigorous evaluation of our proposed solution in Step III. Each step plays an essential role in advancing the overall route of the research, leading us from a conceptual grasp to the practical implementation and assessment of our innovative approach.

4.2 | Solution overview

This section gives an overview of the solution by presenting Figure 2. The design shows the connected parts of the proposed solution in Figure 2.

In this research, we develop the experimental blockchain-based system with a metaverse environment and design particular algorithms with custom modes based on the requirements. The implemented algorithms are the core of the proposed solution, which enables efficiency and secure data processing within a dynamic metaverse environment. By leveraging smart tools and techniques, we engineered algorithms capable of swiftly

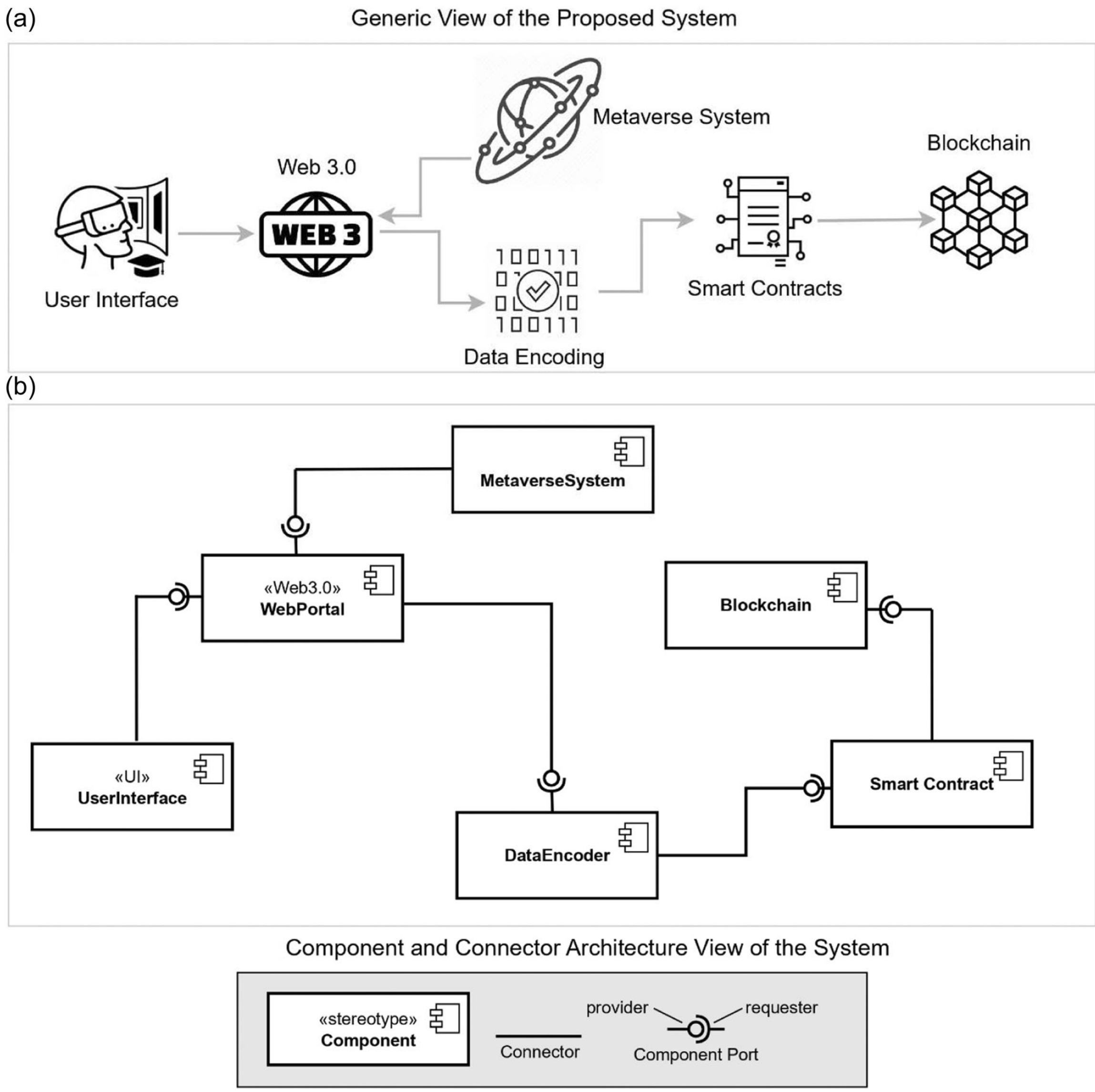

FIGURE 2 Architectural overview of the proposed solution.

locating and verifying data, thus ensuring seamless operation and minimal disruptions. We designed and implemented these algorithms to improve system security, performance, and effectiveness. Each algorithm was precisely tuned to improve its functionality and ensure compatibility with the inclusive system architecture. This development approach of the algorithm is presented in Figure 2 which describes the integration of the system.

A significant attention of algorithmic design was on data efficiency and security. The innovative cryptographic techniques are used to secure delicate data and streamline data processing operations. By prioritizing efficiency and security, the algorithms contribute to the overall strength and reliability of the developed system. During this research, we conducted in-depth testing and validation procedures to assess the performance and effectiveness of the algorithms. These evaluations encompassed various trials including resource utilization, and resistance to possible security threats. The results of assessments specified the usefulness of algorithms. The algorithms designed as part of research represent a fundamental component of the proposed solution.

4.3 | Tools for solution implementation

Tools and blockchain technologies including metaverse: To effectively bring our proposed solution to real-time practices, and a comprehensive set of blockchain-related technologies and metaverse programming libraries. These resources are requisite for the seamless execution of our innovative approach, encompassing:

- o Our blockchain-based metaverse exam system (MES) includes innovative technologies, primarily relying on blockchain technology for its robust foundation. Ethereum, a widely recognized blockchain platform is the basis for our smart contracts and the entire Metaverse exam system. These smart contracts, executed automatically, play a crucial role in streamlining processes related to accessing and storing exam scores and grades.
- o We integrated nonfungible tokens (NFTs) in the blockchain and metaverse development. To incorporate virtual reality assets into the blockchain, we utilized Solidity contract libraries from OpenZeppelin, an open-source platform. The NFTs enable the creation of distinguishing and indivisible digital assets within the metaverse which contributes to the immersive experience of the virtual environment.
  - *ERC721 library:* is essential to create NFTs in our Metaverse system. Each NFT signifies a unique digital asset that cannot be divided. Its straight links to a user's account address and ensures ownership. The ERC721 standard potentials that each asset maintains its unique value.
  - *Ownable library:* This library provides exclusive ownership rights to a single account holder of the contract. The owner has the authority to accomplish important administrative tasks, managing the entire contract for smooth operations. The present owner can also transfer ownership if needed adding flexibility in managing the system.
  - *Counters library:* The Counters library is key in system implementation, allowing for the increment or decrement of numerical values. The functionality is vivacious for generating unique token IDs in bytecode. It ensures that assets within metaverse receive diverse identifiers and preserve their uniqueness and individuality.
- o *Data security:* Ensuring the security of the developed system is domineering. We have implemented progressive encryption mechanisms to secure information, conspicuously featuring the Rivest–Shamir–Adleman (RSA) algorithm. These procedures are applied to secure data and ensure the privacy and integrity of stored data during transmission.
- o *Development and testing frameworks:* Our development and testing processes were improved by utilizing robust frameworks. Smart contract development was carried out using the Solidity programming language, algorithm implementation was implemented through the NodeJS framework, and Ethereum contract testing was conducted using Truffle. We used ThreeJS to expertise the virtual reality elements of Metaverse, creating an immersive and engaging student experience.
- o *System validation:* Initial tests were conducted online using the Remix Ethereum IDE to validate the system. The Sepolia testnet, a cutting-edge Proof of Stake (PoS) platform, was chosen to deploy smart contracts seamlessly. This environment facilitated the execution of Metaverse transactions and secure storage of student grades on the blockchain, affirming the robustness and reliability of our system. The involved interplay of these technologies and tools brings our Blockchain-based Metaverse Test System to real-time environment (see Figure 3).

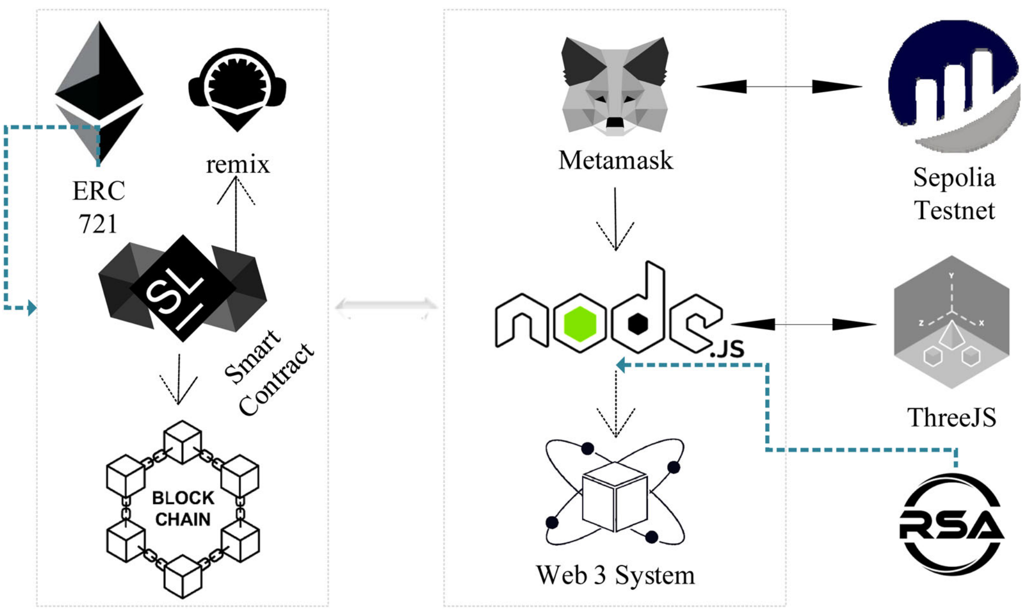

FIGURE 3 Examination of the technological and tool components for system realization.

Our integration of advanced technologies serves a dual purpose: to simplify the implementation process for software and system engineers while ensuring the highest security, reliability, and functionality standards within virtual reality. These technologies collectively serve as the foundation of our system, ensuring its efficient operation and adherence to rigorous standards in data security, robustness, and student experience. In the following sections, we complicatedly examine our system, offering a comprehensive overview of its architectural framework and investigating the core structure supporting our solution. We elucidate the algorithms propelling our system, providing insight into the modularized implementations that drive the Metaverse Test System. Lastly, we thoroughly evaluate our solution, shedding light on its efficiency, effectiveness, and suitability in the broader educational landscape. These sections deliver a holistic understanding of the pioneering system and its transformative potential in VR and education.

5 | EMPOWERING SOLUTIONS: CASE STUDY AND ALGORITHMS

This section discusses the architectural perspectives of the system. We break down the processes into sub-processes. By offering an inclusive architectural perspective, our goal is to deliver a comprehensive understanding of the system and how it works. We systematically explore the algorithms that initiate the system, intelligently explaining their functions and implementation. These algorithms serve as the foundation of our solution, and understanding their details is key to acquiring how the system achieves its goals.

5.1 | Architectural overview of solution: Implementation of processes

The architecture of software-intensive systems is vital in guiding the successful implementation process. It assists as a detailed strategy for designing the solution. The architectural view of the proposed solution is described in Figure 4, providing an explanation of the system's design. This system utilizes Ethereum smart contracts, ensuring records' immutability and reliability. The architectural design validates that our system effectively manages test grades while keeping the principles of data security. In this design, test results are securely saved in the blockchain ledger to facilitate creative problem-solving in a dynamic educational setting. Figure 4 visually represents the step-by-step process of archiving grades within our system and the particular steps taken to ensure a comprehensive, reliable, and innovative online exam approach enhanced with virtual reality elements.

The exam results securing process in the proposed solution is described in Figure 5. The exam takes place in a communicating metaverse environment which makes learning more interesting. The exam results are kept securely in the blockchain. Ensuring data security and confidentiality is a top priority of our system. After completing the exam by student, the system uses the RSA algorithm to generate the digital signature key public and private key. The private key is displayed on the user's screen, who is prompted to save it. The system encrypts the exam score with the user's public key and saves it in the blockchain. When the student wants to view the results, the system asks for the private key to decrypt the result and present it in a readable format.

5.2 | Algorithmizing overview: Implementation of algorithms

In this section, we use algorithms, and step-by-step instructions, a key part of this study. We describe three main algorithms, each showing a specific process and its working. The algorithms are the core of this research which establishing the support for the solution. We break down each algorithm to help to understand the importance in our research. This discussion is strong basis we have created for our study, ensuring everything is clear and easy to understand as we work towards.

Context of algorithms: We have carefully designed these algorithms to deal with specific aspects of our new approach. The main work is ensuring that important information, exam results, and grades, are kept secure on blockchain and the important thing these algorithms do is handle the encryption and decryption of data. The proposed solution based on algorithms is strong protection, making sure that exam scores and grades as they move through our metaverse system are based on blockchain. With these advanced encryption techniques, we enhance the security of our system, giving users confidence that their data is secure from attackers and unauthorized access or breaches.

Input parameters: Our blockchain system has key things it needs to work. These are the administration ID, student ID, and metaverse values. The basic pieces that control how our system in the blockchain metaverse works.

Processing: Algorithm 1 plays an important role in proposed system, focusing on saving metaverse virtual

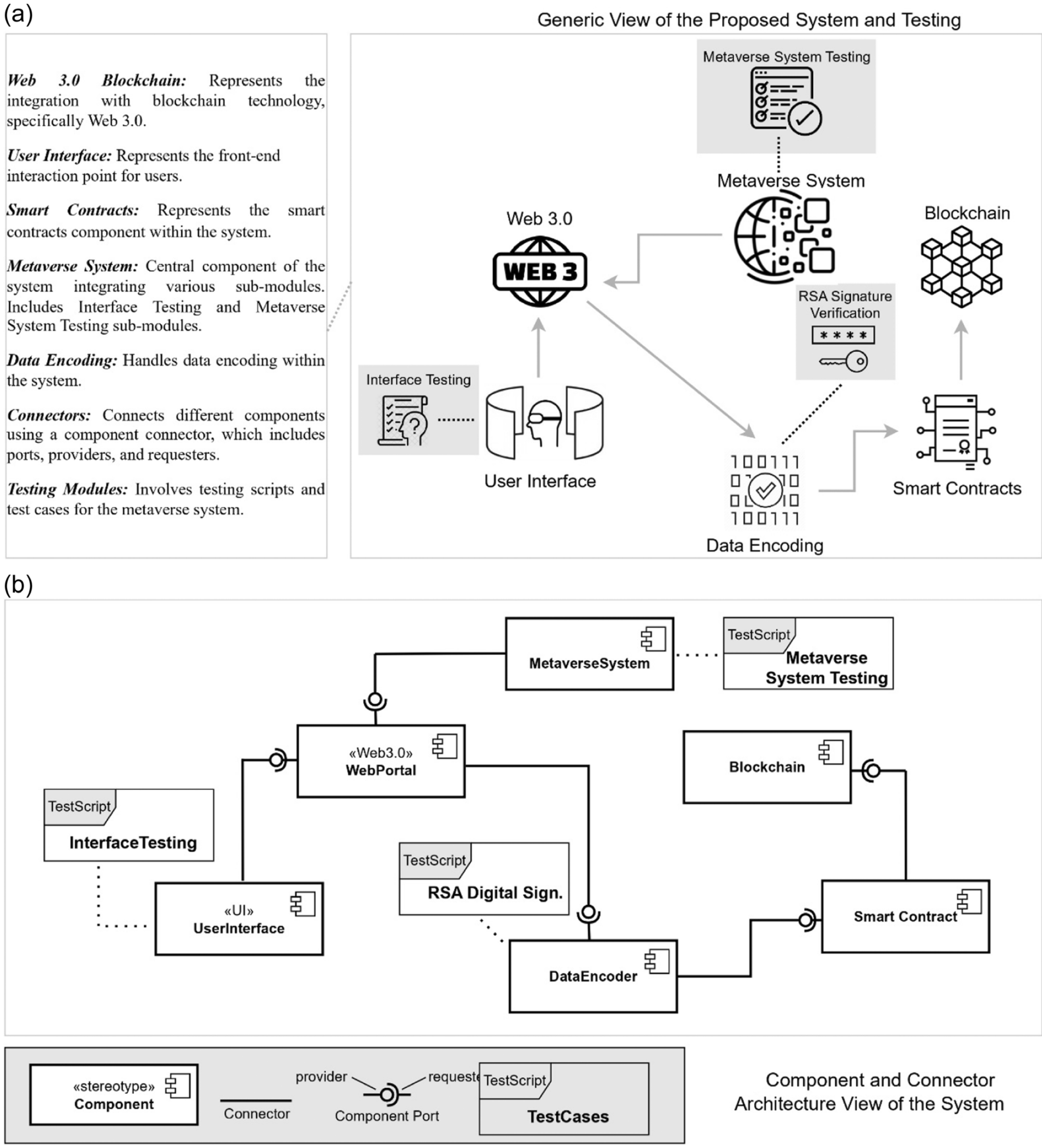

FIGURE 4 An in-depth insight overview into the elaborate solution.

reality values. It manages the mapping of tests, including communications between the administration responsible for creating tests in the metaverse and the users engaging with these virtual reality challenges. The algorithm has a dual function, serving two main purposes. In first, it produces metaverse tests, creating immersive experiences for users. Secondly, it facilitates student access and use of these tests which ensure a smooth and user-friendly collaboration.

Algorithm 1. *Creating Metaverse*

Data: adminId, userId, metaverseData
Result: Metaverse
initialization;
if *Is Metaverse* **then**
    if *adminId is Valid* **then**
        SaveDataToLedger(metaverseData);
    else
        unauthorized;
    end

```
else
    Type is Access;
    if userId is Valid then
        GetValues ← GetMetaverseData();
        while GetValues_i do
            GenerateMetaverseTest ←
              SetDataInMetaverseEnvironment(GetValues[i]);
        end
    else
        unauthorized;
    end
end
unauthorized;
```

Output parameters: the security layer is for storing metaverse tests securly, which are valuable results of our system. It secures the metaverse tests in the blockchain ledger. This ensures their integrity and trustworthiness, preventing unauthorized access or tampering in our blockchain-based metaverse system.

Input parameters: this proposed system includes a set of key input parameters to its operation. The input parameters are student ID, test grade, the blockchain address, and a secret key. These parameters serve as the elements that govern the processes executed by our system.

Processing: Algorithm 2 is a key part of this system, and it executes securely for the user's exam results. the student completes the exam, algorithm ensures that the result is kept secure and saved in the blockchain ledger. The main thing is that it uses a method called digital signature, which is a secret code to ensure the user's result is unpretentious and can be trusted. This code method is known as RSA. This algorithm creates two keys, having two types of keys for securing the data. After finishing the exam, the system shows a student one of these keys (the private key). Then, the other key (the public key) is used to secure the exam's score and save it in the ledger.

Algorithm 2. *Securing Data*

```
Data: userId, uGrade, uAddress, pubKey
Result:
initialization;
if uAddress is Valid then
    while examTest_i > 0 do
        List_i← TestResponse(Ques_id, Ans_id);
    end
    Result ← CheckCalculate(List_i);
    uGrade ← Result;
    if uGrade is not NULL then
        u_publicKey← NodeRSA('public');
        u_privateKey← NodeRSA('private');  popup to User only
        publicKey ← NodeRSA(u_publicKey);
```

(Continues)

```
        encryptedResult ← publicKey.encrypt(uGrade,'base');
        SaveToLedger(userId, uAddress, uGrade, status);
    else
        NULL
    end
else
    unauthorized;
end
```

Output: the output of this algorithm function stores test outcomes in the blockchain. It ensures that the results are accurately recorded within the blockchain, whether a student passes or fails a test.

Input parameters: This system trusts on significant input details to work. These details include the student ID, the user's blockchain address, and a public key.

Processing: Algorithm 3 is the interface that validates student address and updates their dashboards according to roles and blockchain address. If a student passes or fails the exam, the score is encrypted and stored in the blockchain using the user's public key. Upon authentication using the user's private key decrypts the result score and allow the student to access it. This algorithm is retrieving and displaying information which is stored in the blockchain, facilitating student interaction and retrieval of relevant data.

Algorithm 3. *Interface Layer*

```
Data: uAddress, u_pvtKey
Result:
initialization;
if uAddress is Valid then
    if encryptedResult is not NULL then
        Decoding Processes;
        parampvtKey ← u_pvtKey
        if parampvtKey is not NULL then
            pvtKey ← NodeRSA(parampvtKey)
            decryptedResult ← pvtKey.decrypt(encryptedResult)
        else
            not Valid;
        end
    else
        incorrect;
    end
else
    unauthorized;
end
```

Output: The output produced by this algorithm is mapped data securely stored within the blockchain and gives access securely to the user.

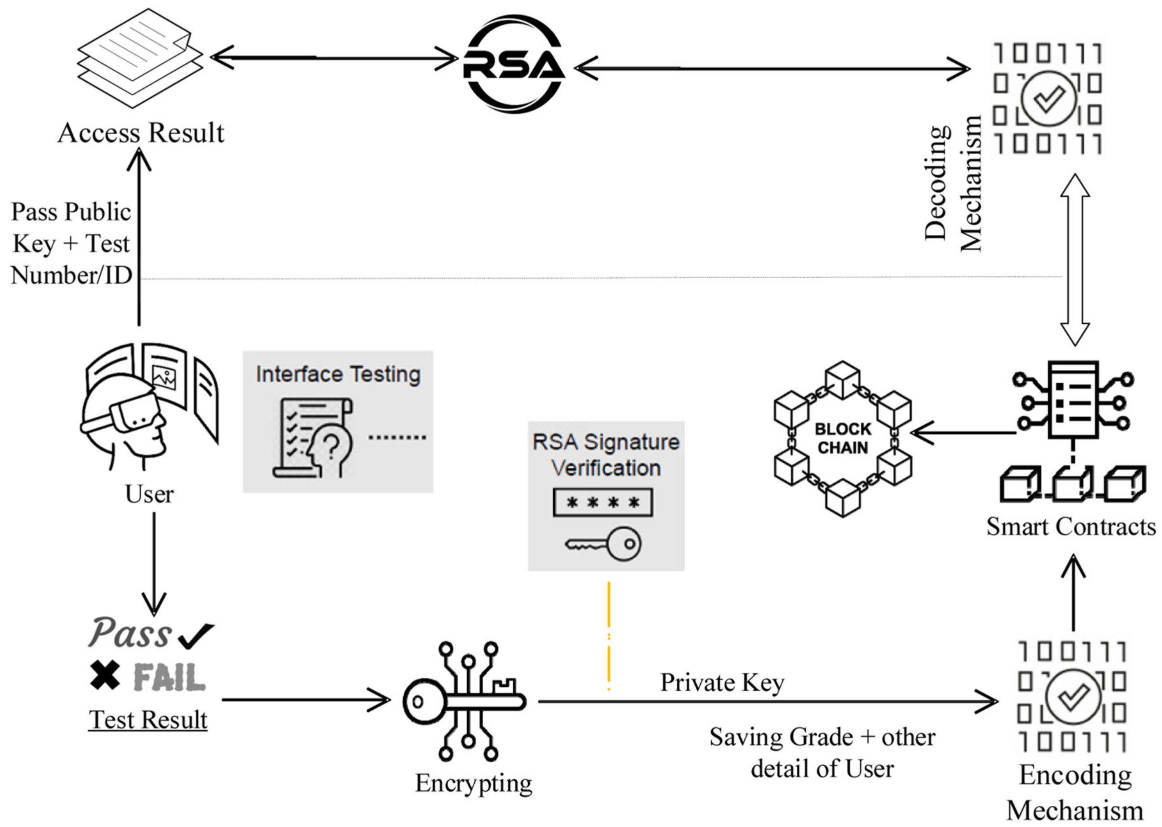

FIGURE 5 An examination test process for saving and accessing.

$$SecureM = \sum_{i=1}^{n} (Exm_{grade} + Pub_{key} + Pvt_{key}) \tag{1}$$

Equation (1) of the secure model presents the security sequence that applies to exam results to secure the student's grade. It simply shows the main parameters that are being used in the model to secure it. The parameters are graded after attempting the exam based on the scores and the student's public key including private key.

6 | RESULTS AND EVALUATIONS

This part thoroughly studies the extensive results obtained from applying our proposed method. We provide a detailed account of the experimental conditions, giving a view of the study's findings. Our emphasis is on exploring the practical results of our approach, offering valuable insights into how the solution works in real-world circumstances. We discuss the setup experiments designed for thorough evaluations, ensuring the trustworthiness and credibility of the results obtained.

6.1 | Metaverse online exam: A case study

In this case study, we show the strength of our solution by analyzing numerous test transactions performed by different student accounts in a Metaverse setting. Users interact with the system by taking tests presented visually through VR. After completing a test, the system calculates grades, and for those who pass/fail, the result is encrypted with the user's public key, generated by the system, and stored in the blockchain ledger. We used the Sepolia testnet as our ledger for storing transactions. An example of attempted tests is also presented in Table 3. Figure 8 indicates a test in the Metaverse, giving insight into the exam example. These case study examples highlight how effective our approach is in safeguarding sensitive result scores.

6.2 | Results

In this section, we discuss the results of implementing a case study.

The depiction of transactions on the Sepolia Testnet platform is visually presented in Figure 6, providing a

TABLE 3 The main parameters of implementing one example are presented.

Public Key	MFwwDQYJKoZIhvcNAQEBBQADSwAwSAJBAKNhVLEPk+DsevvHthjeHQ7pe/ grdXEO4aGTfKuEoGR3nKwgSGmeqJN2vock3SHU9F4gEM+JAE7pHp9gnR6BHWsCAwEAAQ = =
Private Key	MIIBUwIBADANBgkqhkiG9w0BAQEFAASCAT0wggE5AgEAAkEAo2FUsQ + T4Ox6+8e2GN4dDul7+Ct1cQ7hoZN8q4SgZHecrCBIa-Z6ok3a+hyTdIdT0XiAQz4kATuken2CdHoEdawIDAQABAkBHCLRX31v+ORMnkSc9HKUprJ43wj1nkH7NT2Cu +hT6WM0r1diuZcp0t50Bs7xh0sv + /CwwkhnfHbZVmHSVv5HxAiEAz6v3t/ hmn5vlvVraUasjvvTUDatrwtqQnM + 8Ta1WaPcCIQDJZrJX8k0/llrr2a6zl3l4q4vFyg1xDLS+zZYYcCQmLQIgNbHgFfgrCJ +1chU4l58pWelRnsswzKvYckMgC/GCgxcCIBwgxK21wIYt + JrR9y1L7YIl60p/ cqskTCYNznWxS8stAiBKsmBDn4t2C7vnfucpq6P5rYitU6p1NJ5EzERTT+qhUw = =
Result Score	91% (A+)
Encoded with Public Key	eOia4fOvFeflOFgGxuxmtASOsByB61juwpNmCO48RcLGEcQmHgbZfN6l8A/QwaofqtcUJ8egQJIf2E5fQGwtLg = =

comprehensive overview of all student transactions from when they took the test. This visual representation offers a detailed insight into the complete transaction history of the student within the platform. Moving on to Figure 7, it investigates further by illustrating complicated details concerning the specific transaction block of interest. Each block in Figure 7 corresponds to a unique transaction and encapsulates pertinent information about that specific transaction. This detailed breakdown ensures a thorough understanding of the individual transactions, fostering transparency and clarity in evaluating the user's interaction with the blockchain ledger.

Figure 8 provides a detailed illustration of the test-taking process within a metaverse environment. In this example, the student gains authorization to take a test, allowing them to engage with the system. Data is extracted from the blockchain ledger during the test, acting as the metaverse environment for the test, while the questions are sourced from a centralized database. As the student proceeds through the test, their answers are securely stored in the blockchain ledger and associated with their unique address, ensuring accessibility for future reference. Whether the student successfully passes or fails the test, the outcome is recorded in the blockchain ledger, serving as a permanent test result record. This integrated approach ensures the transparency, security, and accessibility of test-related data within the metaverse environment.

6.3 | Evaluation

In our assessment experiments, we focused on both hardware and software components; we aimed to create an environment that is robust and optimized for efficient interactions with blockchain technology.

- Hardware configuration
  - We conducted our experiments primarily on the Windows Platform.
  - Exam scores were calculated and saved into the blockchain ledger, and these operations were performed on hardware equipped with a core i7 processor and 16 GB of runtime memory.
  - This hardware configuration was chosen to ensure sufficient resources for the smooth execution of processes related to saving the records on the blockchain ledger.
- Software tools and environment
  - Specialized evaluation scripts were employed for conducting thorough assessments, which were automated systems.

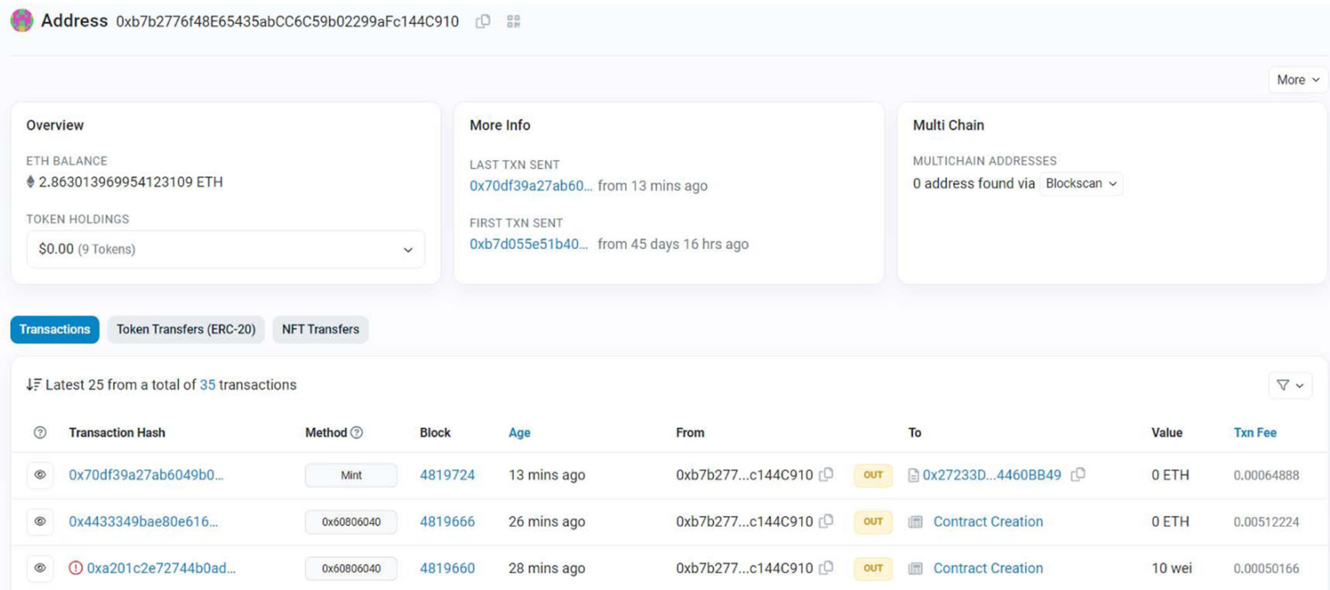

FIGURE 6 Smart contract deployed and tested.

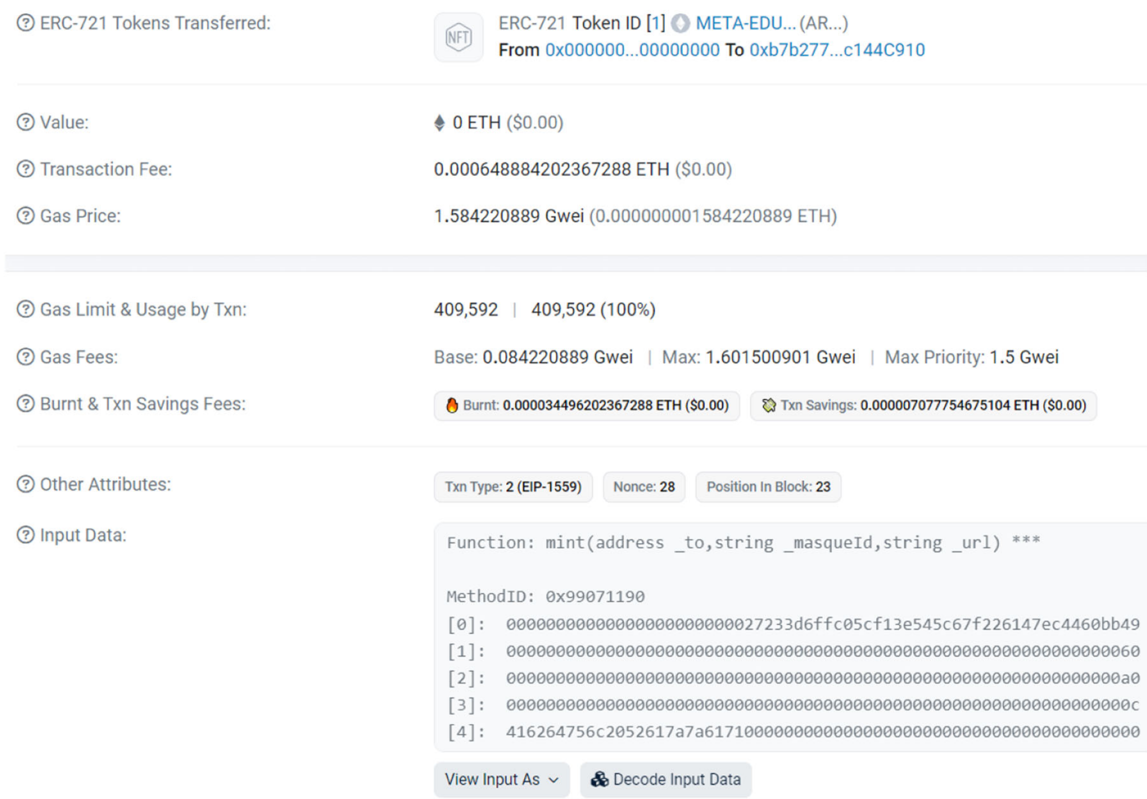

FIGURE 7 Executed smart contract of metaverse online exam score to save the record.

- The scripts were predominantly written in NodeJS, a versatile JavaScript runtime environment.
- The Visual Studio Code development environment was used to execute the evaluation scripts, and the ReactJS programming language was utilized to enhance their functionality.
- NodeJS was the foundational platform for system development, facilitating seamless communication

with the blockchain ledger accessible through the Sepolia testnet.

- Development process
  - NodeJS played a crucial role in simplifying the development process and ensuring efficient interaction with the blockchain.
  - The integrative approach allowed for coding, testing, and debugging of evaluation scripts with precision, ensuring their smooth and accurate operation.
- Evaluation phase and libraries
  - The evaluation phase leveraged relevant libraries, including a JavaScript performance library script.
  - This script was essential for tracking CPU usage during data upload and storage processes, providing valuable insights into system efficiency and resource consumption.

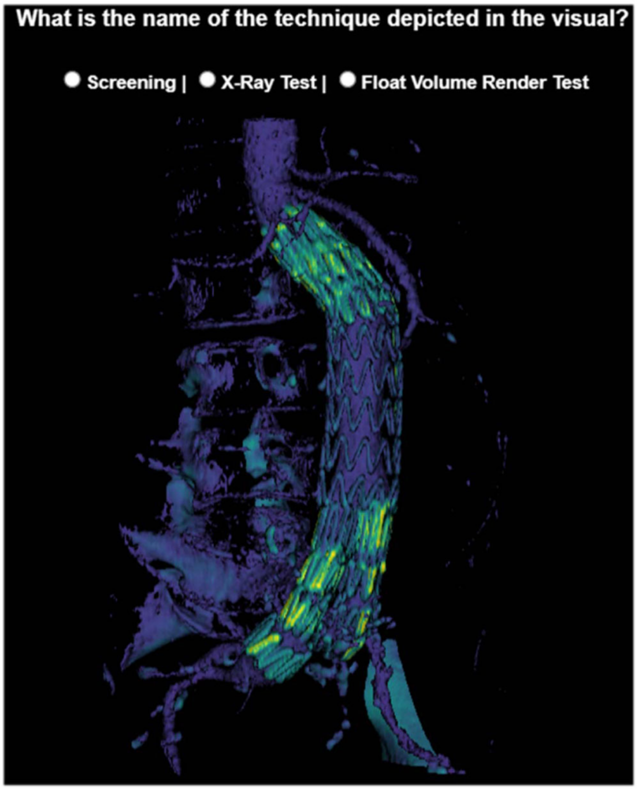

FIGURE 8 Metaverse visual example as a question for the test.

Our experiment focused on a crucial task: saving exam scores and grades to the blockchain ledger. We examined important performance measures, the time it takes to upload educational resources (answers to questions), retrieve data, and analyze information. The total time, including uploading and accessing data, was a central aspect of our investigation. We used a standard data size, as shown in Figure 9.

The results highlighted a clear connection between data size and resource usage. Specifically, when uploading educational resources larger than 1000 bytes, the average fuel usage was about 1,476,230 gases. Similarly, storing data of 350+ bytes consumed an average of 322,839 gases. These findings reveal an important pattern: gas consumption also rises as the data size increases. This indicates that resource usage is directly linked to data size. In essence, this emphasizes the strength and scalability of our system, showing that it consistently manages fuel efficiently, regardless of the data size. This is crucial for maintaining smooth and dependable performance in blockchain.

To store exam scores and grades while keeping blockchain records, we use labels like AR (Accessing Result) and SR (Saving Result) to entirely record information on the blockchain when users pass or fail their tests. We focus on query response time to measure how well our system executes. This metric reproduces the system's ability to store and retrieve data within the blockchain environment. To validate the effectiveness of our approach, we conducted a series of experiments, and the results are presented in Figure 10. The vertical axis of the figure shows the response time in milliseconds. In contrast, the horizontal axis outlines two separate functions: accessing results from the blockchain ledger and storing record information on the

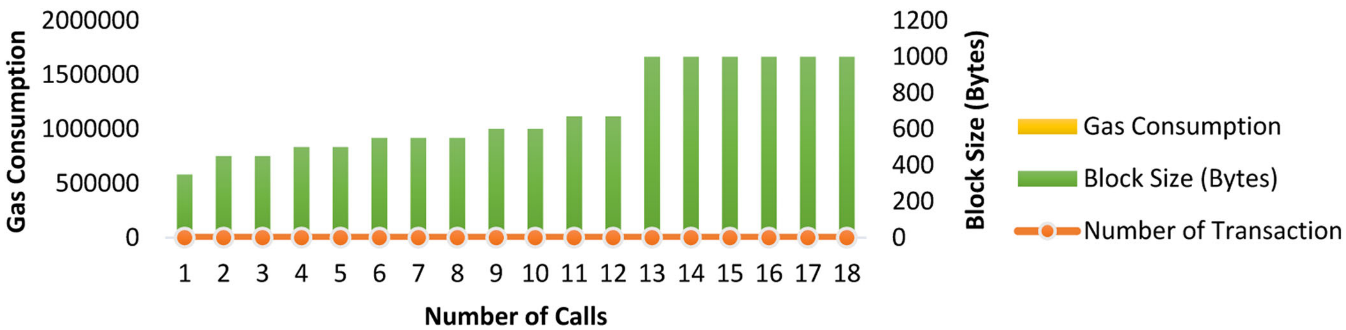

FIGURE 9 The block size and transaction count are determining factors affecting gas consumption.

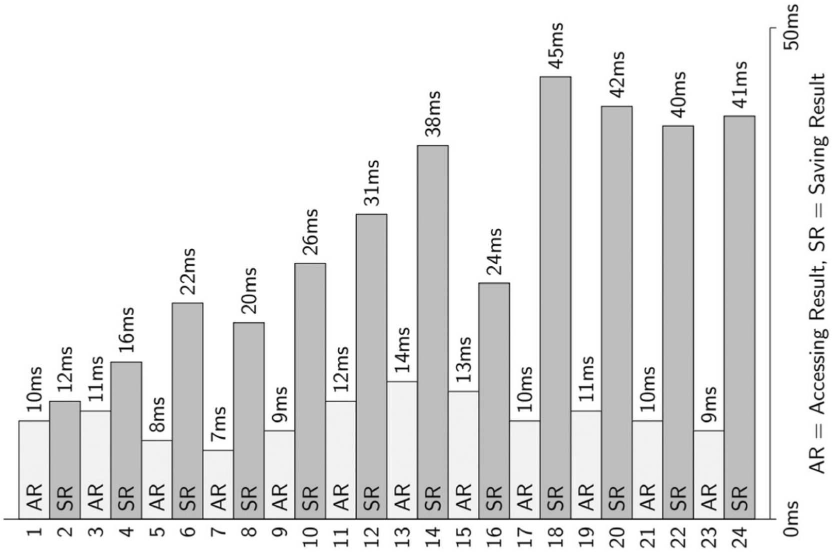

FIGURE 10 The computational time for decentralizing the exam score and grades saving record to the blockchain ledger.

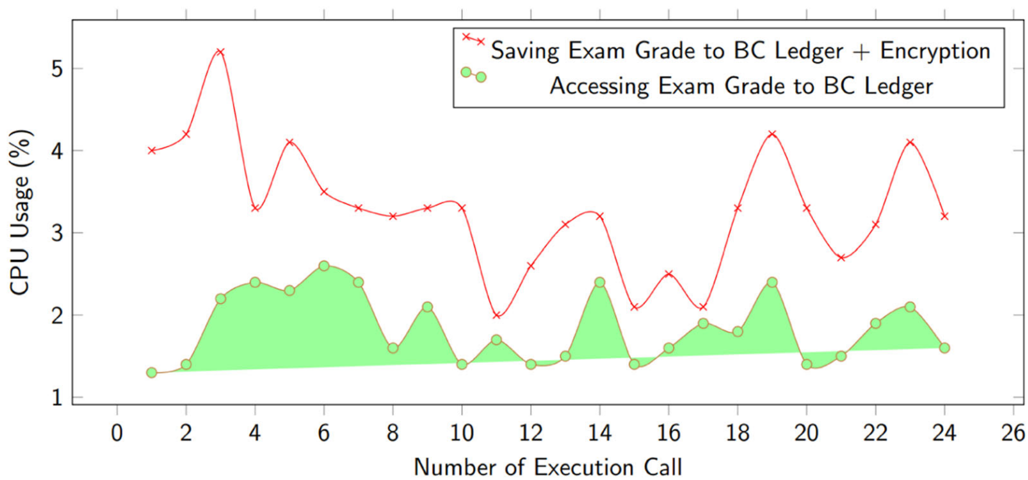

FIGURE 11 Computational time of CPU usage for accessing and saving data.

blockchain. By comparing query response times and execution functions, we gain valuable insights into system performance and the potential impact of Smart Contract execution on response time.

In Figure 11, a visual representation of CPU usage provides valuable insights into the performance of data access execution. There are two types of data processes: storing data in the blockchain ledger after encryption by the user's public key and accessing the score and grade after decryption by the user's private key. It's important to note that the initial execution stages show relatively longer durations for the first and second numbers within the execution sequence. These initial delays may be due to network latency, resource allocation, and system initialization. Addressing these initial delays is crucial to optimizing system performance, reducing them, and enhancing the overall student experience.

6.3.1 | Threats to validity

Here we briefly elaborate on a few possible risks that may affect the validity of the research. Future efforts must focus on reducing vulnerabilities to validity as part of the process of improving the solution and its ramifications.

- Internal validity: With smart contracts and blockchain-based storage, decentralizing the metaverse and evaluating the solution may result in internal validity. The Ethereum platform can produce different results in the evaluation. Researchers should consider different platforms in their future work instead of Ethereum, which can minimize internal validity.

- External validity: We implemented controlled experiments based on our case study approach to present the system and validate the solution. Due to controlled experiments with a limited number of trials of a case study may limit rationalizing the generalization of the solution and the accuracy of its validation. More case studies and different systems are required that can minimize the impacts of external validity.

7 | CONCLUSIONS AND FUTURE WORK

This research provides a synergy between blockchain technology and the metaverse environment to provide an innovative solution for improving online exam systems and securing student's grades in EduTech. The proposed solution relies on Ethereum and smart contracts to ensure secure and tamper-proof exam scores and grades within the Sepolia Testnet framework. Each participant in our system has a unique blockchain address, providing self-sovereign identity, re-encryption capabilities, and secure data storage. As part of solution validation, we analyzed the efficiency of the algorithms supporting our solution through a cost analysis and experimental implementations. This investigation highlights the system's ability to establish secure connections to save the grades for online exams within the metaverse, improving productivity, data origin tracking, and audit effectiveness by utilizing decentralized data storage and eliminating the need for intermediary administrative bodies. Despite the benefits of Ethereum integration, it's crucial to acknowledge Ether fees associated with each transaction and data transmission. These fees are inherent to Ethereum's network functionality, serving as necessary costs for transaction execution and validation. Therefore, when designing and implementing the system, these fees must be considered in financial planning and the overall cost structure.

Needs for future research: we aim to extend the scope of our evaluations using diverse datasets and include more case studies within the educational metaverse context. This extension will provide a more comprehensive assessment of the proposed framework's performance and effectiveness, making it more applicable to modern educational practices in various scenarios and contexts. We will upgrade to a secure certification system.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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APPENDIX

[block:4819666 txIndex:10] from: 0xb7b...4c910 **to:** MetaEdu.(constructor) **value:** 0 wei **data:** 0x608...00033 **logs:** 1 **hash:** 0x2e7...bbcda

status	0x1 Transaction mined and execution succeed
transaction hash	0x4433349bae80e6161a18996be46c609ae4dc8ab75494f5a713e24bf983368ec6
block hash	0x2e77a8b83f58d41c8e3642e075c989c356161f4e708531475e16ae4411fbbcda
block number	4819666
contract address	0x27233d6ffc05cf13e545c67f226147ec4460bb49
from	0xb7b2776f48e65435abcc6c59b02299afc144c910
to	MetaEdu.(constructor)
gas	gas
transaction cost	3189697 gas
input	0x608...00033
decoded input	{}
decoded output	-

logs


```
[
	{
		"from": "0x27233d6ffc05cf13e545c67f226147ec4460bb49",
		"topic": "0x8be0079c531659141344cd1fd0a4f28419497f9722a3daafe3b4186f6b6457e0",
		"event": "OwnershipTransferred",
		"args": {
			"0": "0x0000000000000000000000000000000000000000",
			"1": "0xb7b2776f48E65435abCC6C59b02299aFc144C910",
			"previousOwner": "0x0000000000000000000000000000000000000000",
			"newOwner": "0xb7b2776f48E65435abCC6C59b02299aFc144C910"
		}
	}
]
```


[block:4819724 txIndex:23] from: 0xb7b...4c910 **to:** MetaEdu.mint(address,string,string) 0x272...0bb49 **value:** 0 wei **data:** 0x990...00000 **logs:** 1 **hash:** 0x6f8...57e5f

status	0x1 Transaction mined and execution succeed
transaction hash	0x70df39a27ab6049b0815bacef57b35ba7a50d21897114f065a0594ea5ebc9767
block hash	0x6f80b12ff2e784155bfe7304658714566c0f0b2c07213a01b1e9a5e4f9757e5f
block number	4819724
from	0xb7b2776f48e65435abcc6c59b02299afc144c910
to	MetaEdu.mint(address,string,string) 0x27233d6ffc05cf13e545c67f226147ec4460bb49
gas	gas
transaction cost	409592 gas
input	0x990...00000

decoded input


```
{
	"address _userAddress": "0x27233D6ffC05cf13E545C67f226147EC4460BB49",
	"string _name": "Abdul Razzaq",
	"string _grade": "eOia4fOvFeflOFgGxuxmtASOsByB61juwpNmCO48RcLGEcQmHgbZfN6l8A/QwaofqtcUJ8egQJIf2E5fQGwtLg=="
}
```


decoded output -

logs


```
[
	{
		"from": "0x27233d6ffc05cf13e545c67f226147ec4460bb49",
		"topic": "0xddf252ad1be2c89b69c2b068fc378daa952ba7f163c4a11628f55a4df523b3ef",
		"event": "Transfer",
		"args": {
			"0": "0x0000000000000000000000000000000000000000",
			"1": "0xb7b2776f48E65435abCC6C59b02299aFc144C910",
			"2": "1",
			"from": "0x0000000000000000000000000000000000000000",
			"to": "0xb7b2776f48E65435abCC6C59b02299aFc144C910",
			"tokenId": "1"
		}
	}
]
```

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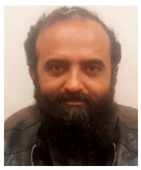

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