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Implementation of blockchain-based document management system for higher education organizations

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Abstract

Blockchain is revolutionizing various industries, from healthcare to real estate, by making existing systems and processes transparent, secure, and efficient. New application scenarios include adopting smart contracts and decentralized frameworks in education and healthcare, which are seen as promising answers to longstanding problems such as security, credibility, and operational inefficiency. Blockchain's decentralized and transparent nature offers a significant improvement in the handling of educational documents. Traditional verification methods for academic qualifications or credentials are cumbersome, slow, and often fraud-prone. To ensure the authenticity of academic records, blockchain provides unalterable records that are recorded on 'the chain' once and cannot be amended. Therefore, each transaction or update of a student's academic history can be found and verified, thereby providing transparency and dependability throughout all stages of the verification process.

Several blockchain-based educational projects have already revealed their potential. Initiatives focused on building decentralized knowledge platforms and secure digital student identity cards or resume and credentials verification networks offer hope. These platforms prevent fraud and handiness for students: all grade details are kept permanently in their hands. With blockchain, students have a comprehensive and portable record of their education, job skills, and qualifications that can be downloaded this second to potential employers or hearings. The same documents provide students with independence and mobility since their certificates are not tied to a single institution or territory.

Blockchain further promotes cooperation between all stakeholders in education, like teachers making decisions, policymakers, or executives who run businesses. Through a wholly transparent and open system to all parties, Blockchain reduces the dependence on intermediaries often found in traditional process management methods, with speed and cost savings benefits. Moreover, in handling crucial information such as that held on student grades and personal details, blockchain's secure data management provides a very real protection against unauthorized access or breaches.

Keywords

smart contracts, academic credentials, blockchain, consensus mechanism, digital identityKeywords

I. Introduction

In contributing to social development, education enables people to feel better themselves academically, skillfully, and value-oriented from a multifaceted perspective, with ethics included. An individual's educational background is a milestone representing the education an individual has received. The degree certificate of students after graduation shows off their knowledge and skills to society at large, especially their future employers. Employers often determine hiring through credentials. The credibility of qualifications then directly impacts the quality of the workforce. However, there have been reports about fake degrees from unlicensed universities in the past, for example, in the United States. This is especially worrisome since there are currently 300 unaccredited universities and an estimated 2 million counterfeit degree certificates in circulation. Without any intended wrongdoing, corporations may employ personnel who have been supplied with a set of false credentials. This results in decreased efficiency, legal entanglements, and a general lessening of the work environment for other employees. Moreover, using fake credentials to enter educational programs or find a job can result in unqualified people occupying critical positions, particularly in industries, such as healthcare, that rely heavily on aptitudes. About 10% of all job applications that corporate employers read contain fraudulent credentials. The cost of academic certificate fraud to businesses runs about $600 billion annually. To protect the credibility of academic credentials and safeguard employers from false information, educational institutions must implement strict verification techniques for academic credentials. Technology can play a pivotal role in improving the authentication and verification of documents, reducing the risk of fraud. This is especially important in fields like medicine, where reload and expertise are essential to public health safety. In Bangladesh, for example, fraudulent practices resulted in staff being thrown into jail and bogus doctors selling illegal drugs and preparing counterfeit medical reports. Similarly, non-medically qualified staff work in pseudo-clinics in Mexico, where surgeries have led to several complications and patient harm. The demand for a reliable way to check digital academic documents is evident here. Many technologies are currently under review, but blockchain holds a lot of promise. Blockchain ensures the secure storage and unalterable retention of digital academic credentials. It can reduce the manual repetition of standard verification procedures, ensuring the integrity of academic verification processes. In addition, blockchain technology can protect the authenticity of academic credentials. Blockchain is a decentralized database that stores data securely linked chronologically in a chain of blocks. Once data have been stored in the blockchain, it cannot be altered or eliminated without the consent of the network, that is, it is immutable. This quality enables the creation of a durable, transparent, and non-membership ledger capable of following academic progress, descendants' payments, and transactions. Furthermore, with built-in mechanisms to prevent unauthorized transactions, blockchain technology provides a secure and efficient method for verifying and storing academic credentials. This dramatically reduces the risks involved with fraud and increases trust in the system.

In short, blockchain technology for education will eliminate traditional human-trusted academic credentials and student records, creating a safer and more efficient learning environment. Its capacity for automating work through smart contracts, increasing data security, and preventing adulteration can change educational institutions' relationships with employers and students. Today's blockchain technology, consolidated and widely used more than ever, brings a new road to academic efficiency. This benefits higher learning institutions, students, and companies alike. The continued development of blockchain-based educational projects will continue to demonstrate its potential and lay a foundation for a future in which educational undertakings are more transparent, credible, and secure.

a. Blocks in blockchain

Blockchain is a collection of blocks. Each block consists of a header and transactions. The first block of the blockchain is called the "genesis block." Every block has metadata like version, previous block hash, Markle root hash, time stamp, nonce, and difficulty target. The hash address of the final block is used to calculate the address of the current block to add a newly formed block to the existing blockchain using consensus mechanisms like Proof of Wrok (POW) and Proof of Stake (POS).

As shown in Figure 1, blocks have a specified storage capacity, say 500 transactions per block; once filled, the block is linked to the existing blockchain [25].

b. Types of blockchain

There are several types of blockchains, categorized based on their permission model and access control. The types of blockchains are presented in Table 1.

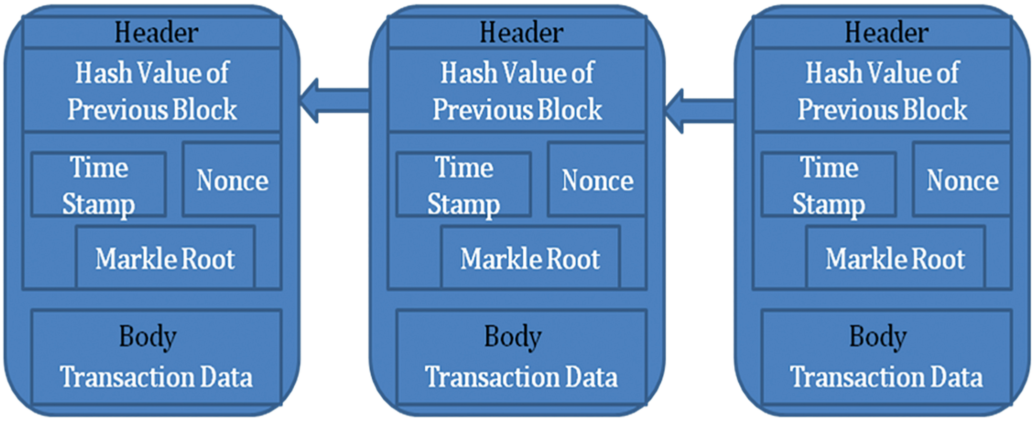

Figure 1: Structure of blocks in blockchain.

Table 1: Comparison of different blockchain platforms

Parameters	Public blockchain	Private blockchain	Consortium blockchain
Network type	Public decentralized	Partially decentralized	Partially decentralized
Access	Anyone	Single organization	Multiple selected organizations
Efficiency	Low	High	High
Centralized	No	Yes	Partial
No. of users	More	Less	Less
Speed	Slow	Fast	Fast
Scalability	Harder to scale	Easier to scale	Easier to scale
Example	Bitcoin, Ethereum, Litecoin	Ripple, Hyperledger	Quorum, Corda

Each type of blockchain has strengths and weaknesses, making them suitable for different uses. Public blockchains excel in decentralized applications and open ecosystems, while private blockchains offer more control and privacy for enterprise or sensitive data applications. Consortium blockchains bridge the gap between these two models, offering a balance of transparency and confidentiality for collaborative projects involving multiple parties.

Applying blockchain technology in the classroom could change our approach to learning and education. Blockchain technology can be used to build a transparent, safe platform for tracking and validating student credentials, certifications, and academic accomplishments. In addition to making it more straightforward for students to demonstrate their abilities and knowledge to prospective employers, this technology can significantly increase the effectiveness and dependability of the educational system [4]. Producing a safe and tamper-proof digital transcript is one of the main advantages of blockchain technology in education. A student's academic record, including grades, certificates, and other accomplishments, can be secure, decentralized, and stored on this transcript. This may replace the need for conventional transcripts printed on paper, which are readily misplaced, destroyed, or altered [5]. Establishing a centralized platform for issuing and verifying digital credentials is another possible advantage of blockchain technology in education. As intermediaries are no longer needed to validate academic credentials, this can significantly streamline obtaining and verifying them. Additionally, since blockchain technology offers a trustworthy and unchangeable record of student accomplishments, its transparency and security can aid in the fight against fraud [6]. The efficiency, security, and legitimacy of the educational process could all be enhanced by incorporating blockchain technology. Blockchain technology can contribute to developing a more transparent and safe education system, making it easier for students to track and validate their academic progress.

c. Literature review

Technology has the power to transform education and learning thoroughly, as well as to make education more accessible and equitable for people all over the world if it keeps developing. More projects or initiatives still need to be used for better performance. For the present technology initiatives in the selected domain, see Refs. [13–15].

c.i Credentials and certification

This technology streamlines the issuing and managing of educational credentials. Digital certificates and badges can be securely issued and shared with learners, employers, or other institutions, reducing administrative burdens and ensuring efficient verification of student credentials.

c.ii Record-keeping

It provides a decentralized and secure ledger where educational records, like diplomas, certificates, and transcripts, can be stored. Records are secured once recorded on the chain, ensuring their integrity and preventing fraud or unauthorized modifications.

c.iii Document verification

This emerging technology enables transparent verification of educational credentials. Any network participant can verify a record's originality without relying on a centralized authority. This grows trust and eliminates the need for time-consuming manual verification processes.

c.iv Data security and privacy

It employs advanced cryptographic techniques to secure data. Personal information and educational records stored on the chain are encrypted, ensuring privacy and protection against unauthorized access. Users can control their data and grant selective access to relevant parties.

c.v Smart contract

A digital agreement document deployed on the blockchain. Contracts are executed when certain conditions are satisfied. It simplifies automated enrollment, fee payments, course completion validation and transfer of credits, reducing manual intervention and enhancing efficiency.

c.vi Portability and interoperability

It promotes the portability and interoperability of educational credentials across institutions and platforms. Students can maintain a digital record of their achievements, quickly shared and verified by different educational stakeholders, and eliminate repetitive documentation.

A study [16] presents a literature review on blockchain technology's use in education. Another study [17] discusses the pros and cons of technology in education. The main applications that lie in education are decentralization and digitization of processes. Their research delves into several important issues, including scalability issues brought on by slow-moving blockchain transactions, the Scaling Trilemma, and data protection laws that hinder application developers. Additionally, they emphasized the difficulties associated with market adoption.

Three critical findings are worth mentioning based on searching and screening reference papers. First, chatbots are the most common Artificial Intelligence (AI) learning technology, which provides personalized, scalable, and cost-effective learning. Second, with a focus on meta-teaching and meta-learning, robotics applications are typically exploratory. Third, real-time contracting, time-stamping of education, digital certification, digital credential verification, and digital grading are a few of the uses of blockchain. The rigorous process of verifying medical school diplomas, internship completion, and board certification is known as physician and practitioner credentials. Getting hospital privileges and a medical board license can be costly and time-consuming processes that frequently call for a high degree of blind faith in the doctor's or other practitioner's qualifications. The credential verification process gets more brutal as non-medical professionals broaden their areas of practice and loosen up telemedicine regulations. In medicine, ultrasound is a specialized procedure requiring practice to become proficient. In the past, operators with different backgrounds in the medical field use have shown a wide range of skill levels. Blockchain technology maintains a public ledger for tracking various ultrasound records. Moreover, it streamlines the credential verification procedure, increasing its effectiveness and requiring a higher standard of integrity from each provider [14].

Key Management Infrastructure (KMI) has pioneered blockchain for online reputation management, badges, and certificates. KMI has developed a blockchain prototype for micro-credential issuance and is using Ethereum to make badges into smart contracts. The main goals of KMI's activities are to lead blockchain initiatives in higher education and develop blockchain technology for use in UK higher education qualifications. KMI is working on blockchain projects with the University of Texas and the University of Ghent. OU's initiative, however, does not prioritize the end-user and is not offered to satisfy employers, other parties, or third parties. KMI concentrates on the layers of applications, and users can manage their data and private vital wallets, in theory.

To give recipients more control over the certificates they have earned, the MIT Media Lab employs Blockcerts to certify groups of students digitally. The recipients of this initiative might be independent of an outside party to store, validate, and verify credentials. The issuer digitally signs the certificate, and its hash is stored in the blockchain transaction using MIT's certification architecture. Every recipient has a separate hash value for their certificate. This initiative had an ownership problem since MIT had to roll out certificates using a pair of graduation and workshop participation. Furthermore, a great degree of trust in this system is necessary. Since everyone can access data and certificates of their ownership, privacy is another crucial consideration. The issue is that although the certificate can be shared with one employer, the recipient cannot keep it a secret from another employer. Hashing is employed when an employer requires verification of the authenticity of a certificate and discloses the certificate and its hash value. The privacy issue must still be fully addressed [20–23].

Another blockchain-based method for confirming academic credentials is called "RecordsKeeper." Educational institutions can use RecordsKeeper to issue certificates and give users a receipt which they can share with the employer to verify the certificate. The employer will use the receipt to verify the certificate in RecordsKeeper. This mechanism is simple, but ownership rights must be with the parties who want to view the certificate in the proposed blockchain. This is equivalent to giving ownership to a third party, which could result in manipulation. To guarantee the certificate's security, this might function effectively on a private blockchain [24–26]. Table 2 discusses various International Universities using blockchain for record keeping.

d. Comparison between traditional record-keeping systems and blockchain technology

The benefits of blockchain technology over conventional record management systems are displayed in Table 3. The comparison shows how blockchain technology can transform data storage, security, transparency, and traceability. It also offers important insights into how blockchain technology can increase the effectiveness and dependability of managing educational records.

Table 2: Different universities using blockchain [19]

S. No.	University and country	Findings
1	ASU, USA	• Used for credential verification • Secured storage • Reduces administrative burden • Improves transparency
2	UNIC, Cyprus	• Fast and effective payments
3	University of Malta, Malta	• Secure research data sharing • Collaborations with universities
4	Imperial College London, UK	• Improves transparency and traceability • Ethical procurement of goods and services
5	ETH Zurich, Switzerland	• Decentralized decision-making • Participation and transparency for stakeholders in a university community

Source: Amr Koshiry et al., 2023.

Table 3: Comparison between traditional record-keeping systems and blockchain technology

S. No.	Parameters	Traditional record-keeping	Blockchain technology
1.	Type of system	Centralized	Decentralized
2.	Transparency	Low	High
3.	Security	Less secure	Highly secure
4	Auditing	Difficult	Easy

e. Challenges of blockchain in education

e.i Scalability

Block sizes have increased due to educational systems gathering vast amounts of data on numerous students. Transactions on the blockchain take longer as there are more blocks and each transaction requires peer-to-peer verification [34]. The network's technical scalability is thus a significant technological challenge of blockchain, particularly for public blockchains, which may prevent its widespread adoption, as is the case with the education sector [28]. Blockchains are slow compared to other systems. They typically have lengthy transaction times and little storage capacity [35], which could be a significant drawback in some educational environments. It is common knowledge that legacy networks can handle thousands of transactions per second. For example, Visa has a processing speed of about 1,667 transactions per second. However, the two most widely used blockchain networks, Ethereum and Bitcoin, are still far behind in transaction speeds. Ethereum can process about 20 transactions per second, compared to 3–4 transactions on the Bitcoin blockchain [36]. However, the kind of educational application created will determine how to handle the scalability issue of the speed of blockchain transactions [34].

e.ii Student data privacy and general data protection regulation (GDPR)

Since privacy in the blockchain is difficult to achieve, it is a challenge in several academic usage scenarios that deal with sensitive data. The fact that transactions on the blockchain are visible to all users could jeopardize privacy because this information could be gathered and made public elsewhere [37]. In the present days, a lot of educational institutions follow stringent privacy laws. Students have faith in the people who handle their data. Nevertheless, these data will lose their privacy if stored in a public ledger. In this case, public blockchains are ineffective for storing these data, even when they are encrypted [35]; therefore, a private blockchain or consortium could be helpful, where the students will have restricted access and all their personal information will be kept private, as it should be. Nevertheless, several national and international regulations for protecting personal data should be considered. For instance, the European General Data Protection Regulation (GDPR) [38] is a significant European limitation. It prohibits the storage of personal data in an unaltered storage system, like a blockchain, and requires that the data be anonymized. As such, this is a contentious issue that needs to be resolved before blockchain can be used to register students' and educators' personal information in the educational space. Moreover, the blockchain's inability to be altered presents challenges when trying to delete data, even when required for legal compliance, which contradicts the GDPR's "right to be forgotten." Nevertheless, a study focusing on blockchains in the education sector sought to utilize blockchain technology and its unchangeable properties to safeguard the distribution of academic certificates for students, providing a method to cancel digital certificates that have been incorrectly issued [39]. Various privacy-preserving solutions, like Secure MultiParty Computation (SMPC) techniques, commitment schemes, Zero Knowledge Proof (ZKP), ring signatures, Zero-Knowledge Succinct Non-Interactive Argument of Knowledge (zkSNARK), and homomorphic hiding, are being developed to tackle privacy concerns in the blockchain, enabling users to stay anonymous and maintain data control during transactions [40].

e.iii Implementation cost

Proof-of-work, the popular consensus technique for validating new blocks, consumes significant electrical energy and presents another possible scalability concern [12]. The Bitcoin proof-of-work, for instance, is well known to squander enough electricity annually to power a nation of the size of Switzerland [11]. In this regard, Park [8] contends that the education industry's most complex problem is proof-of-work. As a result, the proof-of-work blockchain in education has a higher carbon footprint and increases the danger of climate change because of its high power consumption.

It was suggested that the decline in educational applications was due to proof-of-work difficulty, which would only worsen as the number of blockchain nodes increased. On the contrary, no standard example of an extensive global education blockchain compared to the millions of cryptocurrencies exists [8]. There is no strong enough incentive or reason to carry out its proof-of-work, but this might change when Ethereum 1.0 and 2.0 join shortly and use a new verification method called "proof-of-stake" [8].

Nonetheless, there are a few intriguing solutions to the scalability issue. To speed up transactions, the Lightning Network, for instance, adds a new layer to the primary blockchain system [58]. Another approach is termed "sharding," which divides node subgroups into smaller networks called "shards," each of which is in charge of a distinct set of transactions [59]. Different blockchain systems, such as Multichain, Ethereum, and Hyperledger, offer unique characteristics and capabilities that might not be suitable for all applications. Blockchain systems, for instance, provide many consensus techniques, affecting the applications that may utilize them.

II. Methodology, Tools, and Techniques

This section describes the proposed educational document verification and authentication model, as shown in Figure 2. The hybrid blockchain will be used in an education system because authorities and responsibilities will be granted per stakeholders' roles. Interplanetary File System (IPFS) is a peer-to-peer, decentralized, distributed file system. It uses a distributed hash table and a Markle-directed acyclic graph. IPFS deals with content addressing instead of location addressing like HTTP. All stakeholders will interact with the system using a distributed application. Blockchain cannot store large files directly, so it uses an IPFS system. A user uploads an audio, video,

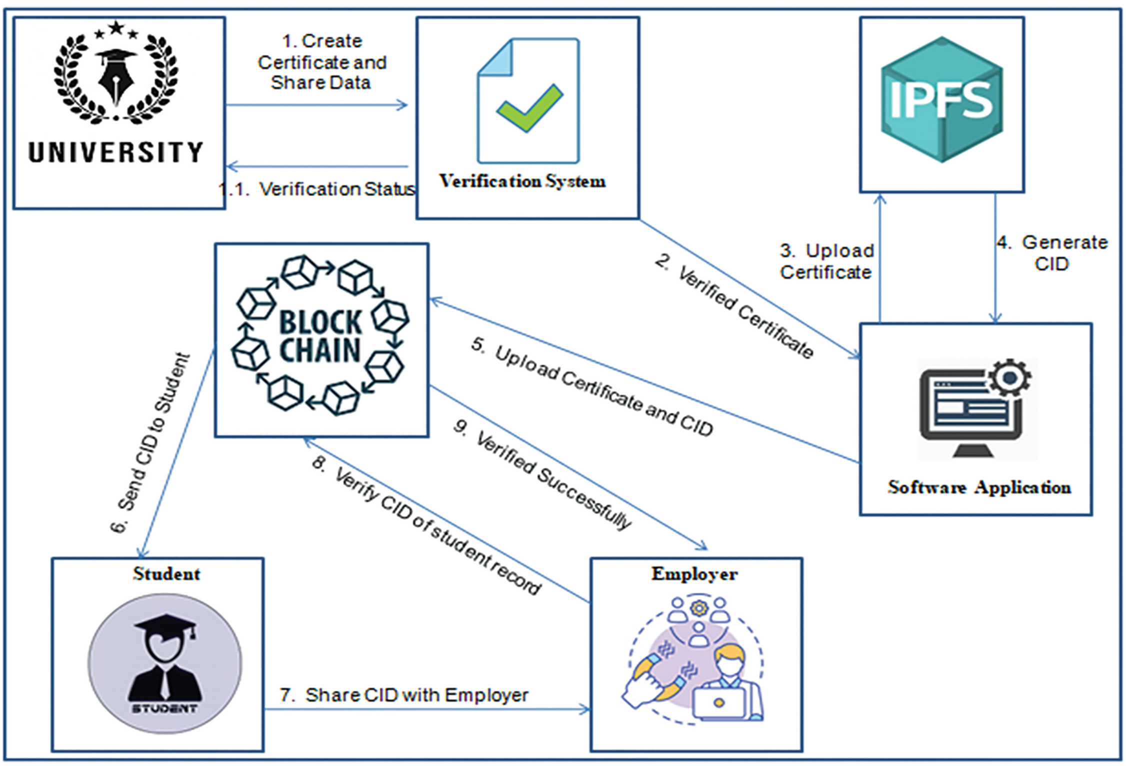

Figure 2: Proposed model.

or document on IPFS, generating a unique hash value called Content Identifier ("CID") using SHA256.

CID is used to access the document on the blockchain. A smart contract is a self-executing agreement with terms encoded directly into code. When specific criteria are satisfied, it automatically executes and enforces the terms of a contract. It runs on a blockchain, a distributed and decentralized ledger technology.

a. Framework for implementing blockchain in the education sector

Implementing Ethereum-based blockchain for Digital Certificates & Credentials in the education sector can significantly enhance the trust, security, and accessibility of academic credentials. Institutions can issue verifiable, tamper-proof certificates directly on the blockchain by leveraging smart contracts, non-fungible tokens (NFTs), and decentralized storage like IPFS. The various steps involved in creating a blockchain based digital signature is shown in Figure 3.

b. Key components of the Ethereum-based framework

1. **Smart contracts (solidity):** Smart contracts automate certificate issuing, verification, and revocation. These contracts will handle certificate creation, ownership, and access control.
2. **ERC-721 or ERC-1155 tokens:** ERC-721 is a standard for NFTs, ideal for creating unique certificates. ERC-1155 allows for both fungible and NFTs, giving the flexibility to issue course credits

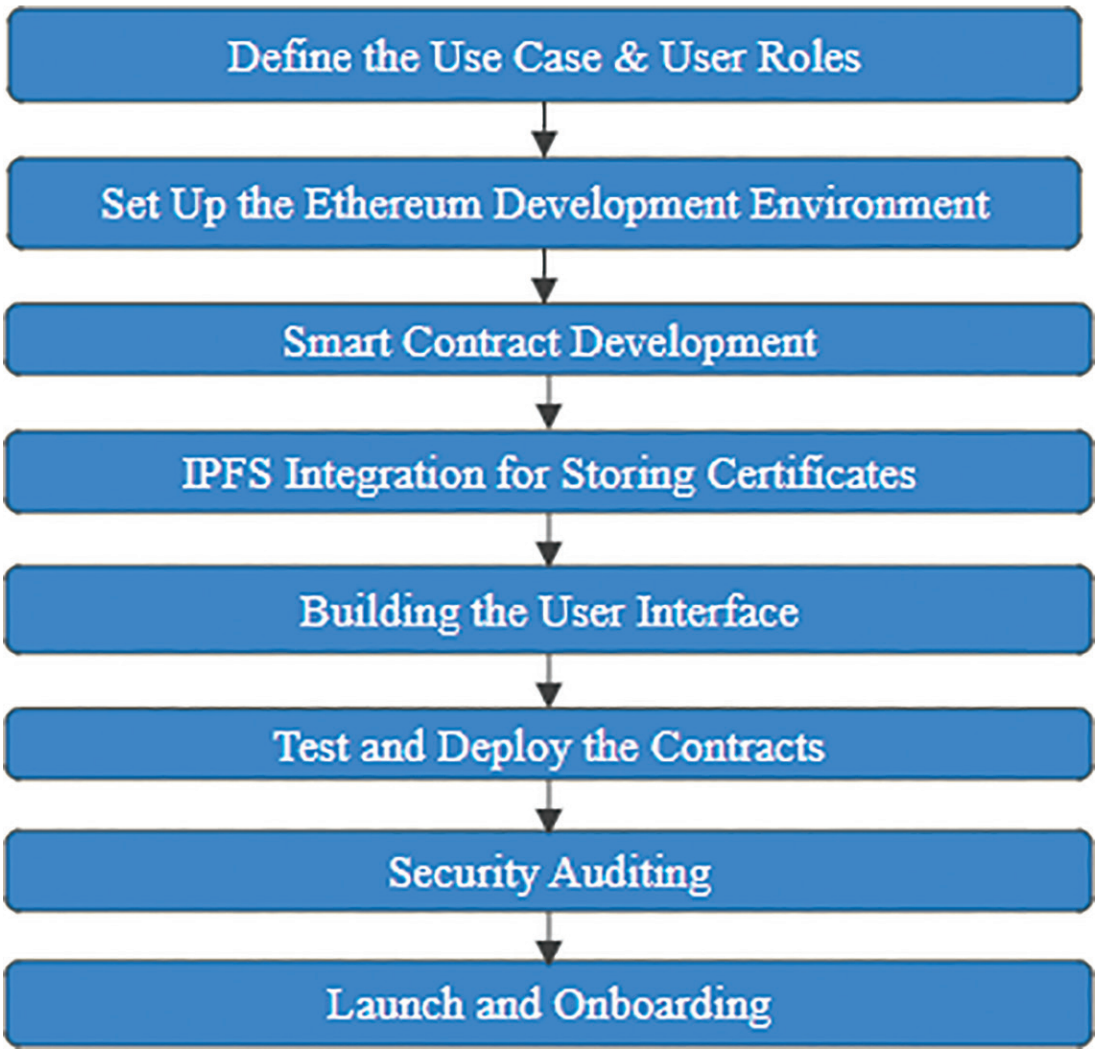

Figure 3: Steps for implementing digital certificates on Ethereum.

as fungible tokens and unique degrees/certificates as NFTs.

3. **IPFS:** Certificates or diplomas can be stored on IPFS for off-chain storage. IPFS will return a hash, which can be stored on the Ethereum blockchain to verify the certificate's authenticity without storing large files directly on-chain.
4. **Ethereum layer 2 solutions (optional but recommended):** To reduce transaction fees and increase scalability, consider deploying the system on layer 2 solutions like Polygon or Optimism. These networks inherit Ethereum's security but offer lower costs and faster transactions.
5. **Frontend interface:** A user-friendly web interface where institutions can issue credentials, and students can access, manage, and share their certificates.

III. Discussion

Blockchain technology has the great potential to revolutionize education. Thanks to its secure storage and analysis of large volumes of data, improved learning analytics and personalized learning experiences are only around the corner. Moreover, the decentralized architecture gives educational institutions a relief valve for learner behavior, preferences, and performance data. Their student information is not just kept out of sight under lock and key; it is safely shielded well outside the reach of authorities, professional associations, or others who might seek to misuse it. Blockchain can also smooth the flow of credits between different institutions—nationally and internationally. For employers, blockchain offers an opportunity to conduct background checks on employment candidates who have verified their academic credentials digitally and securely, thus simplifying the hiring process. Finally, blockchain's immutability and transparency protect people's intellectual property. Using this technology, professors can verify that they have written works under their names; students and other researchers will not be tempted to copy someone else's material verbatim without giving credit where it is due. By fixing these two problems and eliminating the third—bribery, equitable access to resources is thus assured through smart contracts that function as master keys for the disbursement of funds while demanding accountability and efficiency. However, obstacles remain in blockchain's potential use for education, such as scalability and desirable links between different systems or regulatory issues. Active work and cooperation from schools, government leaders, and information specialists are required to exploit blockchain fully in the realm of learning.

a. Benefits of using Ethereum for digital certificates

1. **Tamper-proof and immutable:** Certificates cannot be altered or faked once issued. They remain verifiable and traceable on the Ethereum blockchain.
2. **Verification without third parties:** Employers or other educational institutions can verify credentials without relying on intermediaries, using the Ethereum blockchain to check the certificate's authenticity.
3. **Ownership and control:** Students have complete control over their credentials. They can share them with others via public links, providing easy, self-sovereign access to their academic achievements.
4. **Global access:** The blockchain is decentralized and accessible globally, allowing international verification without centralized authorities.
5. **Cost and efficiency:** Although Ethereum mainnet fees can be high, using layer 2 solutions or side chains like Polygon significantly reduces costs while maintaining the security of Ethereum.

IV. Conclusion

Blockchain has the potential to revolutionize education through its higher transparency, security, and efficiency (for more details on this, see the articles by Bernard Golden published in *Harvard Business Review*). Immutability and decentralized data management, intrinsic to the technology, will enable academic institutions to build trust on a grander scale. Blockchain secures educational records, so credentials and certification processes become tamper-proof and fraud-resistant. Individuals can keep a comprehensive, portable lifelong learning record on the blockchain, bringing together all their achievements or skills with certificates acquired from school. Additionally, blockchain allows decentralized learning platforms to emerge, connecting students directly with teachers and fostering personalized study practices. It can enhance the learning experience by shortening the links between learners and those instructing them. By reducing intermediaries, it also improves the quality of learning. Blockchain has already streamlined many administrative tasks and transactions, saving time and resources. Beyond this, secure data sharing through blockchain also brings about enhanced collaborations among educational stakeholders. Ultimately, blockchain makes education more efficient, available, and safe.

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