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Strengthening data integrity in academic document recording with blockchain and InterPlanetary file system

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ABSTRACT

A diploma is a certificate or official document given by a school or college that is useful for continuing education, applying for jobs, and assessing student intelligence. The main problem with diplomas and other academic documents is that many are forged. This study aims to develop a prototype for recording student academic data using blockchain and blockchain and InterPlanetary file system (IPFS). The research stages were conducted with system conceptualization, data modeling, smart contract development, IPFS integration, data transaction development, user interface/user experience (UI/UX) development, and system testing. A blockchain is a permanent information structure formed by data blocks that are interconnected with transaction data blocks before and after it. The transaction data for each block are encrypted using asymmetric cryptography. IPFS is a peer-to-peer network protocol for storing and sharing data in a distributed file system applying the concept of decentralization to make the manipulation more difficult. The results show that student academic data and documents were successfully stored in a blockchain network using smart contracts and IPFS. Blockchain technology, smart contracts, and IPFS strengthen the value of these documents into documents that are safe, difficult to counterfeit, and easy to trace, such that authentication and integration are better preserved.

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1. INTRODUCTION

Recording and processing data using computers is considered insecure due to the vulnerability of digitally stored data to manipulation and hacker attacks, prompting increased awareness of the digital storage of important information, including academic documents such as transcripts and diplomas. This increased awareness underscores the importance of implementing robust security measures to protect sensitive data [1]. Cases of unauthorized access and data manipulation have become more common, requiring proactive strategies to ensure the integrity and confidentiality of academic records [2].

The problem of forgery of diplomas and other academic documents is still common in Indonesia. The fake diploma documents are used to find jobs and other things. The lack of validation and verification mechanisms for these academic documents makes diploma forgery rampant. This proves that the company still has difficulty verifying its diploma [3]. Therefore, every school or university requires a system of issuing transcripts, diplomas, and other important academic documents to make it easier for companies to verify the

authenticity and maintain the data integrity of academic documents, such as diplomas, transcripts, or certificates, during the education period [4], [5].

Blockchain technology has emerged as a promising innovation with vast potential in various fields including education [6], [7]. Blockchain ensures transparency, security, and data integrity through cryptographic technology, strong encryption, and consensus mechanisms, making it a reliable solution for a wide range of applications across industries [8]–[10]. In education, blockchain can be used for a range of purposes such as validating academic certificates and transcripts [11], verifying the authenticity of educational certificates [12], building a decentralized education record management system [13], automating and increasing transparency in educational assessment [14], [15], supporting lifelong learning [16], decentralizing the storage and sharing of learning materials [17], verifying teacher's qualifications, constructing a secure and transparent electronic voting system for educational decision-making [18], establishing a digital identity infrastructure in education [19], and supporting education funding through the use of blockchain [20]. These applications demonstrate the versatility and potential of blockchain technology in the field of education. Using blockchain technology, educational institutions can eliminate the risk of certificate forgery and reduce excessive bureaucracy. Students can access and share learning content securely, without third-party involvement. Principal elections or collective decisions can be made with high integrity. Blockchain technology has the potential to revolutionize the field of education by providing transparency, security, and data integrity in all aspects of the educational process.

Blockchain technology is currently under development. With the use of this technology, data storage will transition from centralized to decentralized [21]. Because the stored data will be scattered across each node and the data that have been stored cannot be edited or deleted, the concept of decentralization will increase the reliability of the data in terms of authenticity and security from hacker attacks or server outages [22], [23]. Data stored on the blockchain will also increase trust in the authenticity of the data because if the stored data are manipulated, it will damage the data chain on the blockchain [24]. By decentralizing data, the InterPlanetary file system (IPFS) enables the peer-to-peer distribution of internet content [25], [26]. The files stored on IPFS will be divided into smaller parts using IPFS technology, and the files stored will be more secure [27], [28]. The file will then receive a content identification (CID) and be cryptographically hashed [29]. Previous research applied IPFS and blockchain technology to secure important documents such as medical record data [30], freelance marketplaces [31], job training certificates [32], vehicle data recording [33], and data from internet of thing (IoT) devices for the needs of smart cities [34]. The results are proven to be efficient and secure compared to systems that still implement the concept of centralized data storage.

Therefore, this study aims to implement and develop a blockchain-based E-transcript/diploma system design in previous research [35]–[38] where the research is still a concept model, as well as the design of the e-transcript/diploma system. The novelty of this study provided a recording of student academic data as well as diploma and certificate documents stored on the blockchain network and IPFS. This research aims to create a system that minimizes the prevalence of fake diplomas, simplifies access to genuine academic documents, and benefits stakeholders such as companies, agencies, and students. The integration of blockchain and IPFS facilitates decentralized data storage, leveraging the advantages of increased security, accessibility, and decentralized computing power for an efficient academic document record system.

2. METHOD

The development methodology of the blockchain-based academic records system is described and shown in Figure 1, which is divided into 7 stages. This structured approach ensures a comprehensive understanding of system construction, starting with system conceptualization and continuing with data modeling, smart contract development, IPFS integration, transaction data design, user interface development, and system testing. An explanation of each stage is as follows.

a. The first part is system conceptualization by building a system architecture model.
b. The second stage is the development of the data model used in the system. This stage includes the creation of DBMS, as well as data models stored on Blockchain and IPFS.
c. The next stage is the development of smart contracts that are used to validate and verify data transactions stored in the blockchain network.
d. Integration with IPFS is done by developing the interaction of data transactions stored on IPFS and hash data stored on the blockchain smart contract.
e. Stage five is the development of transactions carried out in the system, where the application of smart contracts is carried out to validate transactions carried out in the system.
f. The next stage is the development of the front-end interface as a medium for accessing data transactions in the system.

g. The final stage is the functional testing of the system along with transaction testing and data storage on the blockchain network and IPFS.

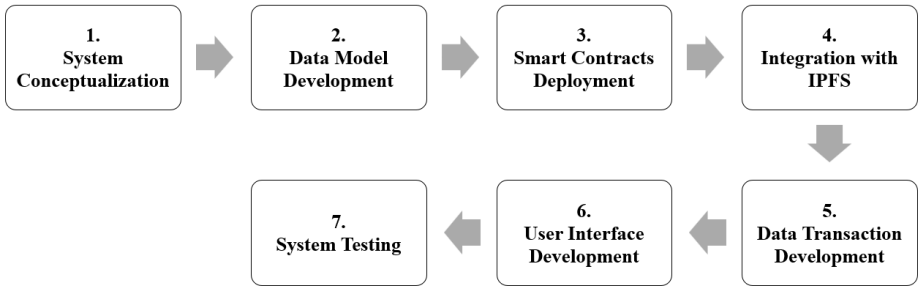


Figure 1. The stages of research

3. RESULTS AND DISCUSSION

3.1. System architecture

An overview of the system developed is shown in Figure 2. There are 3 main users in this system, namely teachers, administration staff/admins, and students. The three users played an important role in the assessment process of the printing of report cards and the issuance of original documents to the public network of the Ethereum blockchain. The system uses IPFS as a medium for storing files before they are published or recorded on the blockchain's public network. In addition, this system has a visitor interface that can be accessed by anyone to check students' academic documents on the blockchain.

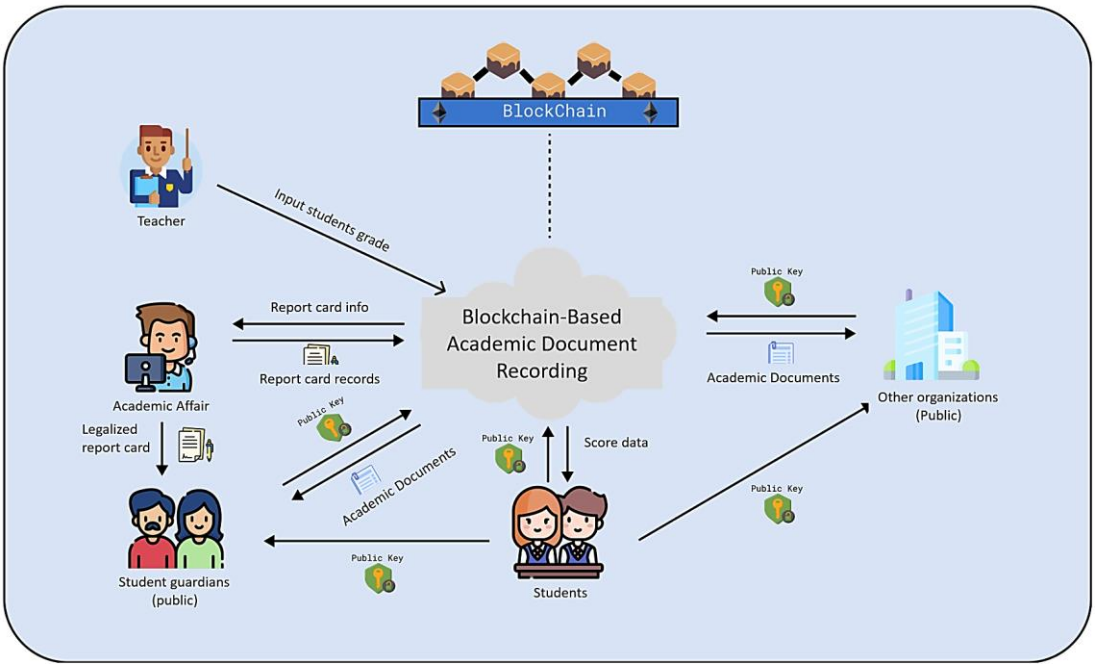


Figure 2. The architecture of document academics recording system using blockchain and IPFS

3.2. Database analysis

The database management system (DBMS) used in the blockchain and IPFS-based document academics recording system is MySQL. The database contained in this system aims to store off-chain transaction data, namely data that is not stored in the blockchain network, which includes academic data such as subject data, teachers, classes, students, and user data. The database schema used in this system is to describe relationships in existing tables and their fields and attributes can be seen in Figure 3.

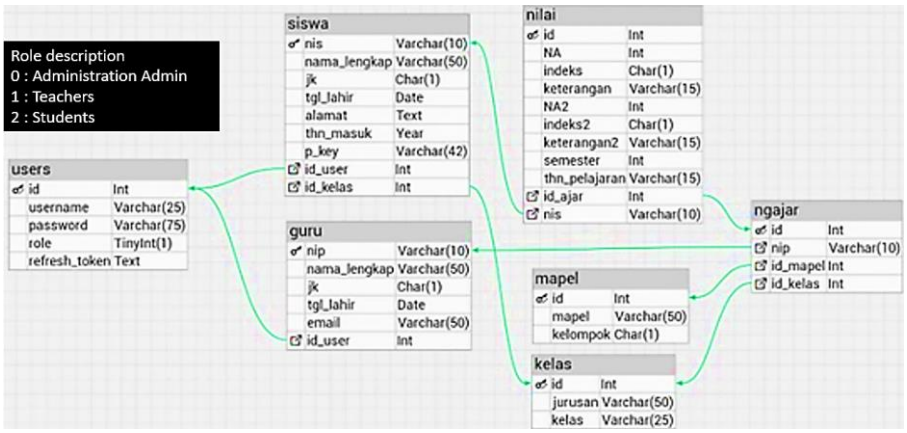


Figure 3. Database scheme of document academics recording system using blockchain and IPFS

3.3. Smart contract analysis

The smart contract used to build this system uses solidity language. This system requires two smart contracts i.e. DTranscript.sol and Migrations.sol. The data storage format on smart contract DTranscript.sol can be seen in Table 1. The implementation of the smart contract is used to handle transactions in the academic document recording system, in student data upload transactions, upload academic documents, and in academic document download transactions. The use of IPFS is applied when the transaction requires the storage of student academic documents, and the IPFS data will be stored in the blockchain network in the form of hash documents. The application of the designed smart contract can be seen in Figure 4.

Table 1. Data storage format on dtranscript.sol smart contract

Struct	Data type	Variable name
Student	Uint	NISN
	String	Name
	String	Department
	Uint	Year
	Uint	uploadTime
	Uint	Size
	Address payable	Uploader
	Document	docs
Document	String	fileHash
	String	fileName
	String	fileType

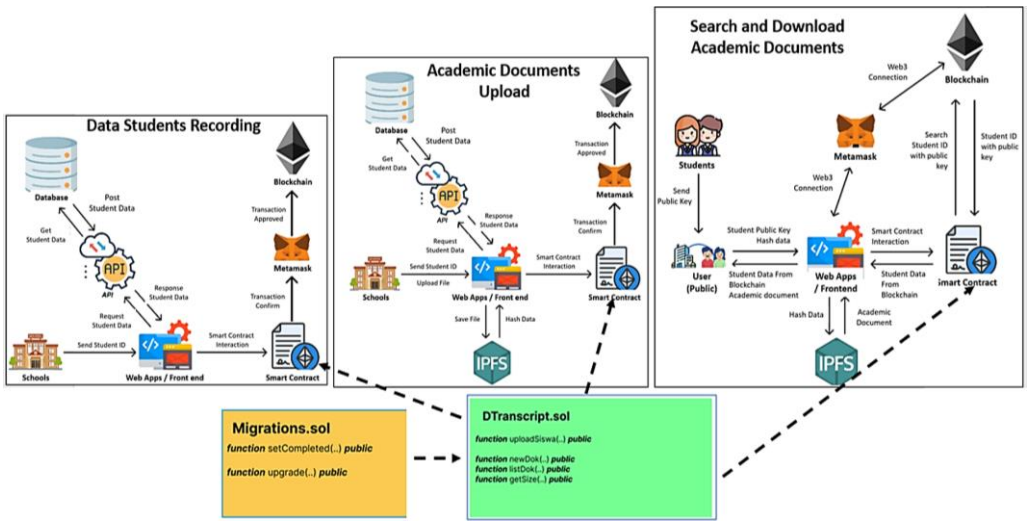


Figure 4. Implementation of smart contract model

3.4. IPFS analysis

The application of IPFS in this system occurs during the process of adding student academic documents to the blockchain network. When uploading documents to the system, the system will extract files into 3, namely buffer files, file names, and file extensions. After the admin uploads a document, the system will send the buffer file in the form of an array to the IPFS server. If successful, the IPFS server will return a value in the form of a file hash result. Then the file hash results along with other file attributes will be sent to the smart contract to store data on the blockchain network. Then the transaction will be confirmed by a MetaMask before the data enters the blockchain network. The mechanism for implementing IPFS in the developed system can be seen in Figure 5.

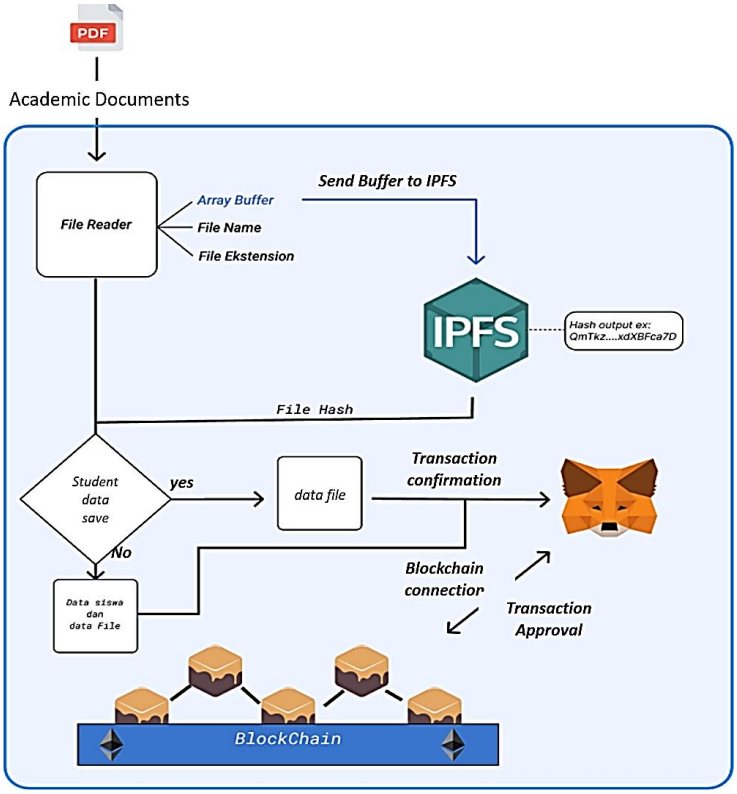


Figure 5. IPFS mechanism in academic document storage

3.5. Analysis of transactions implementing blockchain and IPFS

3 sub-systems carry out the transaction process by applying blockchain and/or IPFS. The sub-systems include the student data upload sub-system, the academic document upload sub-system, and the student data search sub-system along with academic documents on the Ethereum blockchain network. These sub-systems are developed so that transaction data can be stored on the blockchain network and IPFS as well as ease of data search.

Figure 6 shows the mechanism of uploading student data into the blockchain network, as well as the algorithm used in the smart contract. The student data check is performed on the system database. Student data is stored in the form of a student object by including student parameters and upload time into the blockchain network as shown in Algorithm 1. If the data is found, then data storage can continue on the blockchain network can be done through smart contracts.

Before entering the process of the document upload, the system will first save the buffer file to the IPFS server which will return a hash value of the buffer file which can be seen in Algorithm 2. The hash file will later be stored when running. The document upload subsystem can be seen in Figure 7. The last sub-system that implements blockchain and IPFS technology is a visitor or public view on this application which functions to search student data along with a list of academic documents and download documents from the IPFS server using hash files stored on the blockchain shown in Figure 8. Algorithm 3 shows the mechanics of student data on the blockchain network will be searched, and data will appear along with supporting documents located on IPFS.

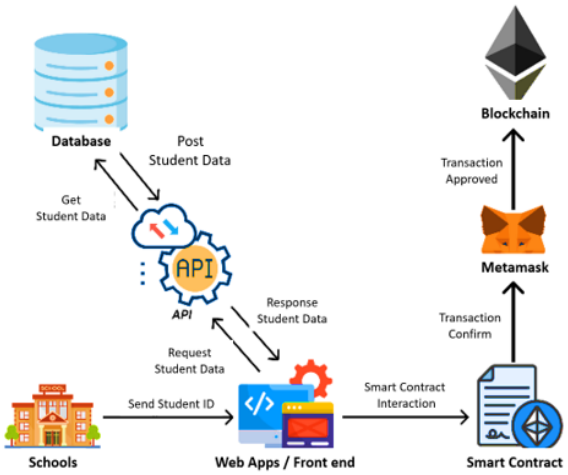


Figure 6. Uploading student data to the blockchain network

Algorithm 1. Upload student data to blockchain

```
Input: publicKeyStudent, NISStudent, StudentName, StudentMajor, StudentClass
1. Student.NewStudent ← StructStudent
2. NewStudent.NIS ← NISStudent
3. NewStudent.Name ← StudentName
4. NewStudent.Major ← StudentMajor
5. StudentMajor.Class ← StudentClass
6. NewStudent.Size ← 0
7. NewStudent.Uploader ← Get SenderAddress
8. NewStudent.UploadTime ← Date(Now)
```

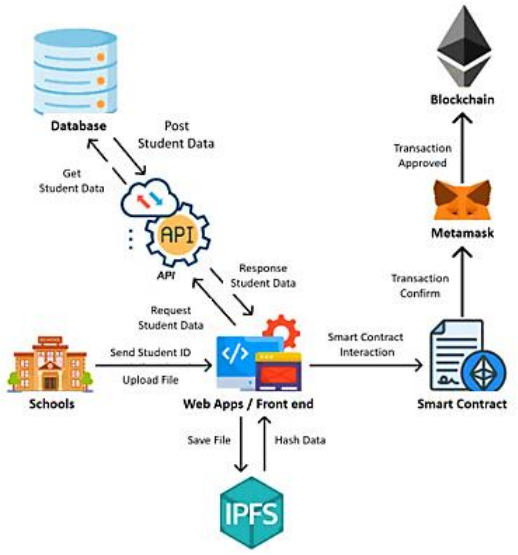


Figure 7. Uploading student documents to the blockchain network and IPFS

Algorithm 2. Upload student documents to blockchain and IPFS

```
Input: publicKeyStudent, HashFile, FileName, FileType, Size
1. Student.Students ← StructStudent(StudentPublicKey)
2. Students.Docs[Size].FileHash ← FileHash
3. Students.Docs[Size].FileName ← FileName
4. Students.Docs[Size].FileType ← FileType
5. Students.Docs[Size].UploadTime ← Date(Now)
6. Students.Docs[Size].Uploader ← Get SenderAddress
7. Students.Size ← Size+1
```

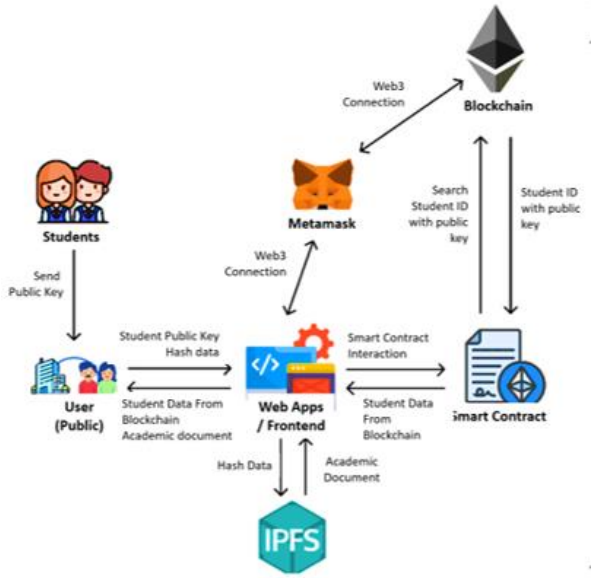


Figure 8. Student academic documents search subsystem in the blockchain network and IPFS

Algorithm 3. Student documents search in blockchain and IPFS

```
Input: publicKeyStudent
1. Student.Students ← StructStudent(StudentPublicKey)
2. Students.Data ← GetStudentData
3. Students.Docs ← GetStudentDocs
4. i ← 0
5. While (i<Students.Size) do
6. Students.ListDocs ← Get Smartcontract(SenderAddress)
7. i ← i+1
```

3.6. User interface implementation

Figure 9 shows the mechanism for uploading academic documents into the blockchain environment. This activity is carried out by the student affairs user, using his MetaMask wallet ID. Every transaction stored on the blockchain needs to use a wallet to identify the user who made the transaction. MetaMask is used to get the identity credentials of each user.

Further interface for searching student data and student academic documents can be accessed by visitors or public users and traced to when and who entered the document. It can be seen in Figure 10. Figure 10(a) shows the search page when it was initially opened or before performing a data search. Figure 10(b) is a search page where data is found on the blockchain network.

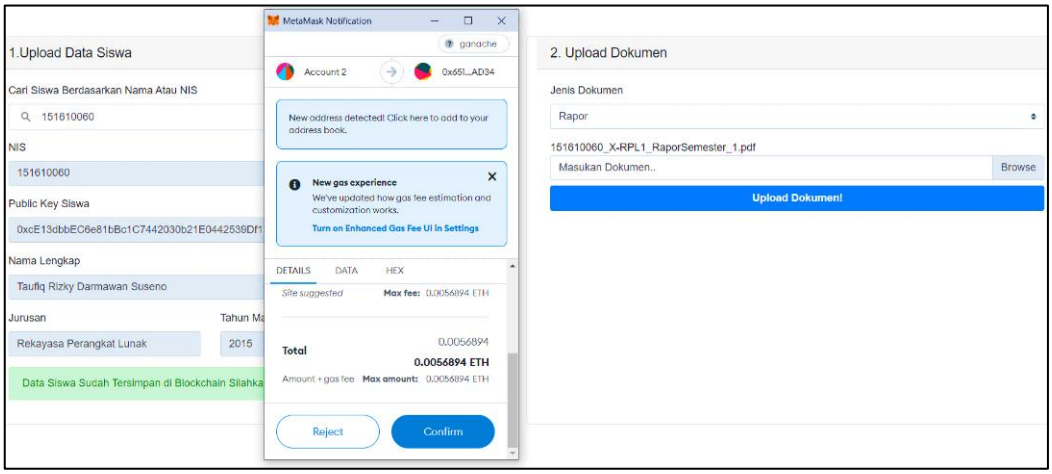
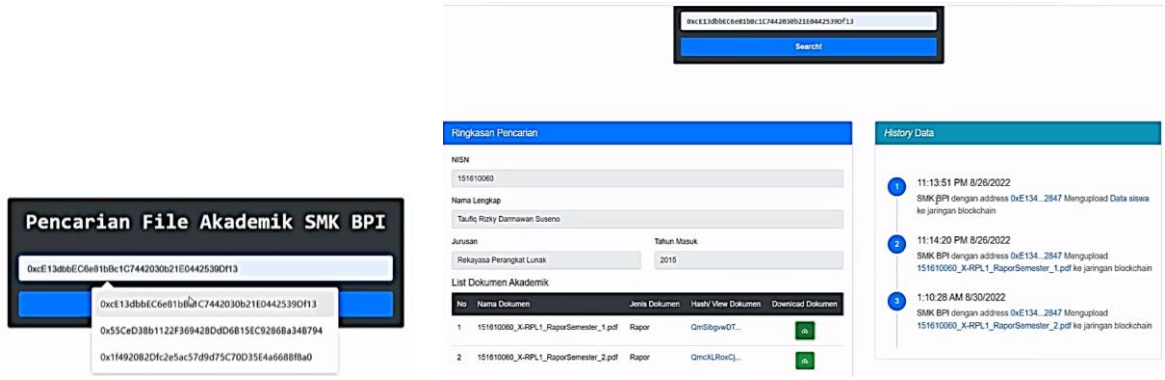


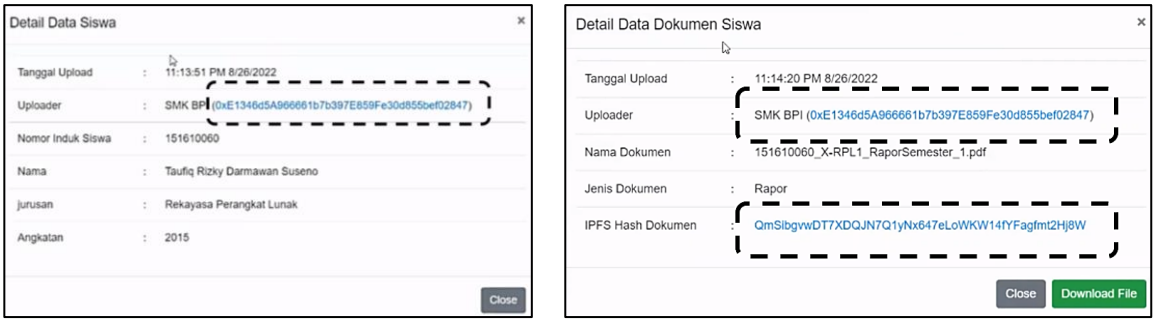
Figure 9. The user interface for uploading student data and student academic documents



(a) (b)

Figure 10. The user interface for searching and tracing student academic data and documents

Figure 11(a) shows the details of the student data that has been stored on the blockchain along with the upload time and the uploader's address. Figure 11(b) shows the details of student documents that have been stored on the blockchain. It shows that the user has obtained the credential identity through MetaMask and the academic document has obtained the metadata hash from IPFS.



(a) (b)

Figure 11. The user interface for detailed student academic data and documents

3.7. System testing

The testing system is performed by testing each function on the system and possible errors that occur for each function [39]. This test is carried out in a black box, which is carried out by paying attention to the input to the system and the output of the system. The test results are shown in Table 2.

Table 2. Blackbox test results on system functionality

No	Test menu	Testing points	Test results
1	Login	Empty data input	Accepted
		Incorrect data input	Accepted
		Correct data input	Accepted
2	Student Dashboard	Update public key	Accepted
		Share public keys using WhatsApp	Accepted
		Generate report cards according to classes and semesters	Accepted
		Download the report card as a pdf	Accepted
3	Teacher Dashboard	Display a list of student data	Accepted
		View student grade data	Accepted
		Student grade input	Accepted
		Remove student grades	Accepted
4	Admin dashboard	Display nis and student names on *autocomplete*	Accepted
		View student data details	Accepted
		Display student report card scores	Accepted

Table 3 shows the results of testing the functionality of smart contracts for data storage mechanisms on blockchain networks and IPFS using black box testing. The testing of smart contracts and IPFS was carried out at several testing points. The test results show that the implementation of smart contracts on functional data upload and data search has successfully referred to the testing points carried out.

Testing was also carried out by entering 2 student data which can be seen in Table 4. The purpose of this test is to ensure that the student data smart contract successfully stores data in the blockchain network. This test aims to find out the average gas fee required to store student data and academic documents on the blockchain network using the developed smart contract The results obtained show that the smart contract successfully stores data in the blockchain, which is indicated by the existence of a public key and gas fee on the transaction.

Table 5 shows the testing of the smart contract function for uploading student academic documents. Testing is performed to ensure that the smart contract design has run properly. The test results show that student academic documents can be stored on the blockchain network and IPFS.

The test results in Tables 4 and 5 show that the design of the smart contract for student data upload and student document upload has been successfully carried out. The appearance of the public key, gas, and fees is evidence that the data has been successfully stored in the blockchain network. While the hash file indicates that academic documents have been successfully stored in IPFS.

Table 3. Blackbox test results on smart contract functionality

No	Test menu	Testing points	Test result
1	Upload data	Student data input in the blockchain network	Accepted
		Document data input in the blockchain network	Accepted
		Document data input in IPFS	Accepted
2	Searching Data	Empty data input in the blockchain network	Accepted
		Correct data input in the blockchain network	Accepted
		Open the student document link in IPFS	Accepted

Table 4. Student data upload test using smart contract

No	Information	Student1	Student2
1	Student number	151610060	151610061
2	Full name	Taufiq Rizky	Muhammad Rizky
3	Department	Software Engineering	Computer and Network Engineering
4	Year	2015	2015
5	Public key	0xcE13dbbEC6e81bBc1C7442030 b21E0442539Df13	0x55CeD38b1122F369428DdD6B15EC9 286Ba34B794
6	Used gas	152873	152753
7	Cost	0.00458618 ETH	0.00458258 ETH

Table 5. Student document upload test using smart contract

No	Information	Document 1	Document 2	Document 3
1	File name	Diploma-TaufiqRizky.pdf	151610060_X-RPL1_RaporSemester_1.pdf	151610060_X-RPL1_RaporSemester_2.pdf
2	File size	42.6 KB	77.2 KB	63.7 KB
3	File type	Diploma	transcript	certificate
4	File hash	QmdpecwP6wsjdQXPNgV tFrXzYtzndxCPsqrYibeah E3iWM	QmSibgvwDT7XDQJN7Q1yNx64 7eLoWKW14fYFagfmt2Hj8W	QmcXLRoxCjRXZvLQp7tA6 XhCBz2k9WswmrRkHEDY MipA41
5	Public key	0xcE13dbbEC6e81bBc1C7 442030b21E0442539Df13	0xcE13dbbEC6e81bBc1C7442030b 21E0442539Df13	0xcE13dbbEC6e81bBc1C744 2030b21E0442539Df13
6	Used gas	134196	189647	174659
7	Cost	0.00558618 ETH	0.00582581 ETH	0.00588852 ETH

4. CONCLUSION

This research successfully developed a blockchain and IPFS-based academic record system to ensure data integrity, prevent manipulation or forgery of diplomas, and provide permanent storage for academic documents. The system demonstrates proper functionality and error-free performance through smart contracts running on the blockchain and secure storage of academic support documents on IPFS. This enhances data security, transparency, and trust, thereby reducing the risk of fraud in the academic environment and increasing confidence in the authenticity of academic documents. Future research will explore the potential integration of blockchain and IPFS with intelligent systems to further support school activities, fostering a technologically advanced and resilient education ecosystem.

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