PublicEduChain: A Framework for Sharing Student-Owned Educational Data on Public Blockchain Network

Article *in* IEEE Access · January 2024

DOI: 10.1109/ACCESS.2024.3385660

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Received 29 February 2024, accepted 30 March 2024, date of publication 5 April 2024, date of current version 16 April 2024.

Digital Object Identifier 10.1109/ACCESS.2024.3385660

RESEARCH ARTICLE

PublicEduChain: A Framework for Sharing Student-Owned Educational Data on Public Blockchain Network

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ABSTRACT Today, educational data, controlled centrally by educational institutions and administrative units, may be vulnerable to damage caused by natural disasters, political instability, and wars. Simultaneously, challenges arise in accessing this data for educational activities within the framework of exchange programs or lifelong learning. In the literature, there are numerous blockchain-based studies focusing on storing and sharing data in various fields. While several studies exist on blockchain applications for certification, verification, and data sharing in the education sector, a fully decentralized infrastructure has not yet been presented. To address this issue, it is proposed that data control should shift to the hands of students, who are the rightful owners of the data, rather than being solely in the hands of educational institutions. In alignment with the decentralized internet vision, Web3, public blockchain networks are considered the most suitable infrastructure for this purpose. To meet this need, a framework named PublicEduChain has been introduced within the scope of this study. PublicEduChain allows students to store their data in smart contracts created on the public Ethereum network, making it possible to share this information with any educational institution and administrative units. Educational institutions can access student data stored in smart contracts on the public Ethereum network through Learning Management System (LMS) applications and can add data to these contracts. PublicEduChain ensures that data is managed under student ownership within a fully decentralized infrastructure. The practical steps in PublicEduChain, such as creating a smart contract, logging into LMSs with Ethereum IDs, and allowing LMSs to read and write data in the student contract, are explained in detail.

INDEX TERMS Blockchain in education, Ethereum, learning management system sharing educational data, smart contract, student owned data.

I. INTRODUCTION

Globalization, the transition to a digital economy and Industry 4.0, the emergence of new professions and the processes of transition to a digital society have also strongly influenced the field of education. The pandemic period has contributed to the transformation of education, significantly expanded the possibility of online learning, and forced people to change their field of activity, improve their digital skills and receive additional education [1]. In the current information age and globalization context, the support of international organizations like Erasmus+ [2] and DAAD [3], has led to a rise in the number of joint education programs and academic mobility initiatives. In these processes, there has also been a great demand for distance education and students are receiving education from different sources. Students who receive education from different sources within the scope of exchange programs or lifelong learning have difficulty in managing their past course and skill knowledge in different educational environments. Due to natural disasters, political instability and wars in countries, education systems and data can be irretrievably destroyed. Refugee students who have been forced to migrate to other countries due to the recent and still ongoing war between Ukraine and Russia

The associate editor coordinating the review of this manuscript and approving it for publication was Mueen Uddin.

face great difficulties. For example, most of the Ukrainian refugee university students in Poland did not have any documents confirming their educational background and Polish universities had to conduct interviews and special exams to assess their level of knowledge [4]. Currently, the education sector is controlled by educational institutions and administrative bodies. Although the current model offers quality, reliability, and knowledge, it is not flexible in terms of time, money, and distance constraints [5]. In addition, companies that provide lifelong learning and certification services independently of each other and without any standard or quality control continue to grow. All these problems create the need to digitally transform the records of student credits and academic achievements into a flexible, reliable, and decentralized structure. Blockchain is considered the most suitable solution due to its features and services, offering the potential to overcome the aforementioned challenges.

Blockchain technology was first introduced in 2008 in an article published by a person or group with the pseudonym Nakamoto [6]. According to Li et al. [7], blockchain is an emerging technology that covers many computer sciences such as cryptography-based digital signatures and distributed consensus mechanisms. Thanks to its distributed and transparent structure, blockchain technology enables data sharing between peers in an encrypted and secure manner without a central authority. Blockchain, first known as the technology behind digital currencies, has been pioneering innovative solutions in many areas such as finance, supply chain, health, public services, and education in recent years. Blockchain has the potential to provide a connecting infrastructure between formal and informal learning by using it in the field of education, such as storing students' academic records [8] and verifying and validating credits, certificates, and qualifications within the scope of lifelong learning [9]. Alammary et al. [10] presented several potential solutions offered by blockchain in their review study on blockchain applications in education. In their recommendations for future studies, they emphasized the considerable benefits that blockchain could bring to cooperation and partnerships between educational institutions. They stressed the importance of conducting further research to explore how blockchain can facilitate and enhance collaboration in the future. In a review study on the use of blockchain in education, Loukik et al. [11] highlighted application examples and benefits. They specifically addressed the challenge of managing and sharing academic records for future studies. The authors proposed a study investigating how academic institutions could leverage blockchain to record various digital badges and share them across a network of other educational institutions, businesses, and relevant government agencies. According to Bhaskar et al. [12], integration research should be conducted in collaboration with the information technology (IT) sector to further explore the potential use of blockchain technology in education.

Nowadays, there is a problem of trust in data sharing between educational institutions. In this context, many researchers and practitioners propose the establishment of a blockchain-based education network. Although its adoption is still at an early stage, researchers in the field of education believe that blockchain technology can be considered as a resource for learner empowerment and an opportunity to restructure traditional educational institutions [11]. The Joint Research Center (JRC) report emphasizes that blockchain has the potential to grant students ownership of their qualifications, courses, activities, and feedback, rather than placing control solely in the hands of educational institutions or employers [13]. Using this type of infrastructure will increase students' flexibility by allowing them to access the full range of academic programs at all other institutions. It will also help educational institutions reduce operating costs by using common infrastructure, services, and academic programs [5].

Despite all these advantages and opportunities for the application of blockchain in the education sector, there are still various challenges [14], [15], [16]. For example, according to Saberi et al. [17], blockchain is still considered an immature technology as it is still in the early stages of its development. Therefore, it still suffers from various issues related to scalability, interoperability, security, and privacy. There is also the problem of how to integrate blockchain technology into legacy systems [18]. How to integrate blockchain technology in educational systems that collect enormous amounts of data about a large number of students is also an important issue [19]. Upadhyay [20], Khan et al. [18], Gräther et al. [21] addressed the challenges of this integration [22]. Qualified professionals are needed to make these integrations and manage the blockchain network. The fact that the number of these personnel is still very limited and that educational institutions do not have access to this pool is an important factor that makes things difficult [19]. In a qualitative study in which Mohammed and Vargas interviewed 15 experts in the field of academia and management, they stated that factors such as the type of blockchain used (public-private) and the developer community behind it will affect the integration efforts [23]. The experts interviewed by the authors in this study, for example, stated that it may be easier and less costly to develop a distributed application on the Ethereum blockchain, which is a public network and has a large developer community behind it.

The concept of web3 has emerged after bitcoin and Ethereum cryptocurrency applications, introducing the idea of smart contracts and Decentralized Applications (dApps) running on decentralized networks like blockchain or distributed ledger technologies, moving away from traditional centralized servers. Web3 has opened the door to a new era based on decentralized and zero-server architecture that increases users' awareness of privacy about their digital identity and data [24]. With this era, people started to use distributed and transparent applications by eliminating centralized structures and third-party applications and institutions. Web3 architecture allows for the decentralized management of identities, assets, and data. Today, individuals can handle their cryptocurrency accounts, log in to applications, and store their data using smart contracts through their digital identities on the blockchain. Recently, instead of blockchain addresses consisting of very long characters, people can create pseudonyms thanks to namespace applications [25] and use these names in daily life and social media. For example, instead of address information consisting of 35-40 characters, it becomes easier to log in to applications on the internet, exchange cryptocurrencies, manage certificates, etc. with a domain name such as "mustafa.eth". It is anticipated that such decentralized applications will continue to grow and gain popularity in the future, and this infrastructure is planned to be utilized in the method presented in this study.

When the literature is examined, it is understood that there is a need for a secure data sharing infrastructure between educational institutions [10]. It is concluded that this environment can be created with blockchain, but for this purpose, information technologies should be utilized more on issues such as how to integrate blockchain into already working LMS applications [12]. In addition, in all studies in the literature, it is seen that educational data on the blockchain is created and managed by educational institutions. This is thought to be a major obstacle to sharing educational data in a decentralized, secure, and transparent structure. To fill this gap in the literature, a framework called PublicEduChain was presented that allows students to manage their own educational data on the blockchain and integrate it into the LMSs of their choice. Using Web3 architecture, this framework aims to pave the way for enhanced data autonomy for students and create a secure collaboration environment for educational institutions.

The main contributions of this work can be summarized as follows:

- This paper initiates a discussion on the implementation of data ownership on educational data, which is the basis of the Web3 concept that has a great potential for the future.
- The paper introduces a framework called PublicEduChain, which enables students to own their credit records and academic achievements and securely share them with educational institutions in a transparent manner. The development of this framework is demonstrated through an example scenario. Detailed explanations, accompanied by visuals, are provided on technical aspects such as creating smart contracts on the Ethereum network, integrating with LMSs, and monitoring data on the network. It is anticipated that this information will serve as a guide for students and LMS developers.
- In order to manage educational data on public networks without the need for any infrastructure investment, a gas fee is required. This study explains how this fee is calculated for educational data through an example scenario. It is thought that the use of public networks will increase in the future and this information will be enlightening for researchers.

II. LITERATURE REVIEW

A. BLOCKCHAIN

Blockchain was first defined in 2008 by a person or group under the pseudonym Nakamoto as a distributed ledger structure in which each record is stored and shared in a distributed structure by stakeholders in the network [6]. Reyna et al. [26] described the blockchain as a secure data warehouse where data is stored in a distributed, transparent, and unchangeable structure as a result of a consensus reached by stakeholders. According to Glaser [27], blockchain is a database where participants keep their asset records publicly and anonymously, without the need for an intermediary or central authority. Johar et al. [28] defined blockchain as a distributed ledger technology that is secured by cryptography in response to the trust problem that users have been experiencing for a long time. Lewis [29] showed that blockchain differs from traditional databases in that transactions such as adding and verifying records in blockchain are performed by stakeholders through consensus mechanisms on the P2P network. The features that distinguish blockchain technology from other technologies can be listed as follows [30].

- A copy of the data is saved by all participants in the network. By storing the data transparently in this way, data loss and data destruction are prevented.
- It enables the development of distributed and automated applications in different fields thanks to new technologies such as smart contract and digital signature.
- Thanks to digital signature and consensus mechanisms, stakeholders can trust each other without the need for a central authority.
- Since it operates in a distributed structure without a central authority, it cannot be controlled or shut down.

One of the most important services offered by blockchain technology is smart contracts. It is thought that smart contracts can replace classical contracts by working decentralized and within predetermined rules on the blockchain network [26]. In other words, smart contracts are computer codes that take place transparently in the blockchain network, cannot be changed and work in an automated manner. Thanks to smart contracts, banks, notaries and similar third parties are eliminated, thus providing significant advantages in terms of cost, speed, and security. It is thought that smart contracts, which are being used in many areas today, have great potential and will become more popular and widespread in the future [31]. The most notable advantages of blockchain technology are the ease of auditing, authentication, information tracking and authentication (e.g., educational records, appointments, certification and licensing, tuition fee payments, credit transfer, intellectual property, copyrights) [32].

The development of blockchain from its emergence to the present day can be evaluated in three phases [33], [34], [35]. The first of these is the Blockchain 1.0 phase, in which blockchain is recognized as the technology that forms the infrastructure of Bitcoin and other digital currencies. The period in which blockchain is used in financial application areas with smart contracts after digital currencies is called Blockchain 2.0. In recent years, the use of blockchain in many areas such as health, agriculture, education, public administration, IoT is called blockchain 3.0.

Existing blockchain systems are classified into three categories as Public Blockchain, Private Blockchain and Consortium Blockchain [36].

Public Blockchain: Public Blockchain offers an open platform that allows people affiliated or independent of various organizations to participate, add records and mine. This type of blockchain has no restrictions and is therefore also referred to as permissionless blockchains. Public Blockchains are completely open and transparent and do not contain any special validator nodes. The fact that anyone who wants on the blockchain can download all chain data and start mining ensures that there are many active copies of the chain. This increases the security and consistency of the blockchain. In distributed structures that do not have any control mechanism in this way, due to the growth of the data size in the existing network, consensus protocols have a lot of work during a change in the chain.

Private Blockchain: Blockchain structures managed by a person or group that enable sharing and data exchange between people in one or several organizations are called Private Blockchain. It can also be called permissioned blockchain because people without a special permission cannot join the chain. The participation and access of a node to the network is made according to the rules set by the group managing the network. This reduces the decentralized and transparent structure of the blockchain.

Consortium Blockchain: Consortium Blockchain can be defined as a partially private and permissioned blockchain in which a predetermined group of nodes, rather than a single organization, is the decision maker in block verification and reconciliation processes. These nodes decide who can join the network and who can mine. For block verification, a multi-signature scheme is used, where a block is considered valid only if it is signed by authorized nodes. Whether the network is public or restricted, and whether everyone on the network can read and write data, is decided by a consortium.

Although blockchain has great potential as a new technology, there may be some difficulties in its widespread use. Some of these are as follows; In blockchain systems using "proof of work" as a consensus protocol, a lot of electricity is consumed, and a high amount of IT resource investment is required. For example, as of 2021, the Bitcoin blockchain, which works with the "proof of work" protocol, consumed more electricity than many countries [37]. At the same time, as a result of the excessive demand for many computer parts such as the video card used in Bitcoin mining, the prices of these parts have increased significantly. Again, the storage and verification of all data in the blockchain by all participants may cause situations where performance is insufficient under intense transaction load. In blockchain systems, transactions made by users are shared transparently in an encrypted manner. As a result of analyzing this publicly shared data, it is possible to access the relationship between accounts or the real identities of users [38]. In addition to the difficulties encountered in the implemented and widespread applications, new features may also be needed in parallel with new developing technologies. Blockchain continues to develop as a new technology and many studies are being carried out by researchers and companies to overcome these challenges.

B. WEB3

The Internet has undergone several significant transformations since its emergence. From the static web pages of Web 1.0 to the interactive and social media-oriented Web 2.0, the evolution of the Internet has created new opportunities and challenges for individuals and organizations. Web 1.0, or the "Static Web", emerged in the early 1990s and was characterized by static web pages and limited user interaction. During this period, the internet was used as a medium for accessing and sharing information through basic HTML websites. Most of these websites were read-only, had limited interaction, and users could not contribute content. In the mid-2000s, the internet evolved into Web 2.0 and dynamic websites, social media platforms and increased user-generated content emerged [39]. The technological developments of Web 2.0 enabled users to interact with web pages and contribute content in real time. Web 2.0 contributed to the rise of platforms such as Facebook, Twitter, and YouTube, characterized by user-generated content, collaboration and information sharing [40]. However, the centralization of data and control in Web 2.0 has raised concerns about privacy, data ownership and monopolistic practices [41].

Web3 or "Decentralized web" attempts to address the issues of centralization and data control by using blockchain technology and cryptographic techniques [34]. The decentralized web presents a vision of a more secure, transparent, and user-oriented internet where individuals have more control over data and online interactions. Unlike the client-server architecture on which Web 1.0 and 2.0 technologies are based, Web3, which came to life with the emergence of blockchain technology, has opened the door to a new era based on a decentralized and zero-server architecture that increases users' awareness of privacy about their online identity and data [24].

Web3 is a vision of the internet based on decentralized and distributed technologies such as blockchain and aims to provide increased security, transparency, and user control [34]. Web3 aims to overcome the limitations and problems of centralized data storage and control prevalent in the current Web 2.0 era [42]. The core technologies of Web3 include blockchain, smart contracts, decentralized applications (dApps), decentralized autonomous organizations (DAOs) and non-fungible tokens (NFTs) [43]. These technologies enable the emergence of various applications such as decentralized finance (DeFi), digital identity management, data sharing and digital asset ownership [44].

C. BLOCKCHAIN IN EDUCATION

Blockchain-based solutions can ensure that administrative work is carried out quickly and simply when a verification process is needed. With this feature, blockchain can facilitate and simplify student activities associated with the verification of credentials such as degrees, transcripts, and students' qualifications, achievements, and professional abilities [12]. In addition, blockchain solutions retain ownership and control of the credentials obtained on students, thus eliminating the need for an intermediary to verify them [45]. Furthermore, blockchain has the potential to facilitate higher education institutions' activities such as payment, accreditation, and collaboration [11]. Despite this, few educational institutions have started to use blockchain technology, and most of these institutions use it to verify and share academic certificates and/or learning outcomes achieved by their students [22]. However, researchers believe that blockchain technology has more potential and could revolutionize the field [10]. Nespor [46] believes that blockchain can weaken the centralized role of educational institutions as certification intermediaries and provide students with more learning opportunities. In general, blockchain-based solutions have been used in the field of education to eliminate third-party control, ensure data security and immutability, prevent fraud, and make improvements in digitalization and management [1]. Some of these studies are mentioned below.

Thanks to the EduCTX application developed by Turkanovic et al. [47], the course credits completed by higher education students are stored on the blockchain by all institutions in the network in accordance with ECTS (European Credit Transfer and Accumulation System). In this way, students can see the course credits they have completed in different institutions in their accounts on the blockchain. In addition, all participating higher education institutions can manage transactions such as application and document verification via blockchain. Chen et al. [22] conducted a study on keeping diplomas and certificates on the blockchain instead of producing them printed on paper. Thanks to the system presented, the loss, destruction or modification of the document printed on paper is prevented. Thanks to the digital verifications provided by the blockchain, it is possible for job applicants or educational institutions to verify students' documents. Shen and Xiao [48] stated that exams such as midterms and finals should be transparent, fair and cannot be changed later. For this purpose, a solution has been proposed that allows exam questions, student answers and exam results to be kept on the blockchain. It was stated that the exam questions and answers should be kept on the blockchain, and these records should be voted and accepted through the anonymous identities of the students. In this way, the real identity information of the students is kept confidential, and the exam processes are transparent, fair and unchangeable. Kistaubayev et al. [1] developed a web-based application that runs smart contracts developed with solidity language on the public Ethereum network to record and manage student loans and records despite performance problems such as high transaction costs and delay in transaction time in order to prevent document forgery and ensure transparency. The developed application called UniverCert was used experimentally in Republic of Kazakhstan. The presented solution was evaluated as efficient in terms of performance and transaction cost and stated that this solution has strong potential and competitive advantages for the use of blockchain technology for the entire higher education system of the Republic of Kazakhstan at minimal cost. Al-Zoubi et al. [49] also mentioned the importance of remote laboratories in many universities, which provide students with access to devices and experiments around the clock via the internet, giving partner institutions the opportunity to share resources, expensive equipment, and specialized laboratories on a regional and international level. However, it was stated that the data generated and stored in remote laboratories lack transparency, traceability, security features, reliability, and dependability, and are vulnerable to single point failure due to centralization. In response to this problem, the researchers created a blockchain-based infrastructure with smart contracts on the Ethereum network and integrated it with the web-based Moodle learning management system through the MetaMask application. The proposed solution was used for testing purposes in several countries and promising results were obtained. Tariq et al. [50] presented a solution called Cerberus for online and secure verification of academic information. Today, a graduating student is physically issued a diploma at their university. In this solution, this document is digitally uploaded to the blockchain and a QR code is generated. The student and other institutions can then verify the diploma through this QR code. The authors have chosen a private blockchain for the Ceberus solution. Ethereum, Quorum, Hyperledger Fabric can be used as private blockchain systems. Institutions that want to join the Ceberus network as a node are examined by the accreditation unit and if deemed appropriate, a public key and cryptography key pair is created. Abdelsalam et al. [51] highlighted the vulnerability of data to attacks and manipulation in traditional exam systems. They proposed a solution for storing question answers and results on the blockchain. Ethereum network was preferred for the demonstration and necessary integrations were made on Moodle as an LMS application. With this solution, students will be able to log in to the Moodle application via MetaMask, and after completing the exam presented to them, they will be able to save the answers to the blockchain. The demo of the proposed solution was realized on Ethereum installed in the local environment. The study provides a detailed explanation of this demo application, accompanied by screenshots and code fragments.

Looking at these blockchain-based studies in the field of education, it is seen that solutions are offered for the secure storage and verification of data such as certificates, diplomas and exam grades. These solutions vary in terms of the blockchain system used, blockchain type, decentralization, data ownership and transaction costs. The PublicEduChain framework presented in this study is compared with the prominent studies in terms of key features. Table 1 shows the results of this comparison.

TABLE 1. Comparison of the solutions.

Solutions	Blockchain Type	Decentralization/ Transparency	LMS Integration	Data Owner	Cost Detail
Cerberus [50]	Private (Suitable for Ethereum, Quorum, Hyperledger)	Partially	No	Education Institution	No
UniverCert [1]	Public (Ethereum)	Yes	Yes	Education. Institution	Yes
EduCTX [47]	Private (Ark)	Partially	No	Education Institution	No
Proposal for Exam [51]	Private (Ethereum)	Partially	Yes	Education Institution	No
PublicEdu Chain	Public (Ethereum)	Yes	Yes	Student	Yes

In Table 1, Cerberus, Univercert, EduCTX, Proposal for Online Exam and PublicEduChain solutions are compared in terms of blockchain type, decentralization, and transparency, LMS integration, data ownership and cost criteria. When the table is examined, it is seen that the public Ethereum network is used in Univercert and PublicEduChain solutions, while various private blockchain systems are used in other solutions. As it is known, since public networks are open to everyone, there is no need to obtain permission to write and read data on these networks. In this sense, Univercert and PublicEduChain solutions running on the public network can be considered completely decentralized and transparent. In Cerberus, EduCTX, Proposal for Online Exam solutions that use a private network, these solutions are considered partially decentralized and transparent, since tasks such as setting up the network, managing the network, and granting permissions to educational institutions to join the network are managed by a team. In recent years, especially during the COVID-19 pandemic, LMSs have been very effective and useful and have gained significant popularity. Considering that a secure data sharing environment between educational institutions can also be provided through LMSs, whether the solutions offered include LMS integration or not should be considered as an important issue. When the solutions were analyzed, it was seen that Univercert, PublicEduChain and Proposal for Online Exam solutions included integration between the blockchain network and LMS through MetaMask tool, smart contracts, and APIs. The ownership of educational data, which is the main idea of this study, is considered to be an important comparison criterion. In solutions other than PublicEduChain, data is created by educational institutions and transferred to the blockchain. The management, integration, and sharing of this data with other systems are handled by the institutions themselves. In PublicEduChain, in accordance with the Web3 concept, student ownership of data is ensured. In this solution, students can create their own smart contracts. Thanks to these contracts, students can see their data on the public Ethereum network and integrate it with the LMSs of the institutions they wish. It can be said that PublicEduChain differs from all solutions in the literature in this respect and is a pioneer for future studies. Storing data in Public or Private blockchain networks incurs cost. Private blockchains necessitate substantial hardware investment and the employment of IT personnel for network installation and management. In public networks, there is no infrastructure investment or personnel costs, but due to the structure of these networks, a transaction fee called gas fee must be paid for each transaction. In the solutions offered on the private network, the costs related to the hardware infrastructure and the installation and management of the network are not mentioned. In contrast, both Univercert and PublicEduChain solutions, which operate on the public network, provide information about the gas fees required for transactions. PublicEduChain further provides details on calculating gas fee values and the fees needed to create a sample smart contract and write data to a contract. This cost information is critical for real-world implementation of the proposed solutions. In private networks, there are difficulties such as complex cost calculations and difficulties in accessing expert personnel for network installation and management. Therefore, public networks are considered more preferable for real-world applications. In general, when all solutions are compared in terms of the type of network used, it is thought that Cerberus, EduCTX, Proposal for Online Exam solutions may have difficulties in terms of not being fully decentralized, initial cost requirements, and challenges in network and stakeholder management. Univercert and PublicEduChain solutions have similar features in general, but PublicEduChain holds a significant advantage due to its management of data under student ownership rather than academic institutions, as well as the ease of sharing and integration.

III. PublicEduChain

This section outlines the PublicEduChain framework, designed to empower students in managing their data on the public blockchain network independently, without relying on third parties such as educational institutions or companies.

Ethereum, which is widely preferred by researchers [1], [49] and has a large developer community behind it, was preferred as the blockchain network for PublicEduChain. The decision to utilize the public Ethereum network was influenced by the complexities associated with managing private blockchain networks and the difficulty in accessing qualified experts. Rodríguez Bolívar et al. [23] also emphasized the ease and cost-effectiveness of managing public networks compared to private networks in their study, based on expert interviews. One of the reasons why public blockchain was preferred in this study is that all work can be done on the public network without any investment expenditure for works such as hardware, infrastructure, and network management. Another pivotal factor is the potential of the Public Ethereum network to serve as an infrastructure for the increasing proliferation of decentralized applications in the future, aligning with the principles of web3, which we can express as the new version of the Internet, and where people can own the content on the internet. According to data from the Etherscan web application, a platform monitoring all transactions on the Ethereum network, there are currently 245 million active users, with approximately 100 thousand new users creating Ethereum accounts daily [52]. Analyzing transaction density reveals the creation of 1000 verified smart contracts daily on the Ethereum network, with an average of more than 1 million transactions. These statistics underscore the rising prevalence of decentralized web3 applications, with the Ethereum network playing a pivotal role in this ongoing transformation.

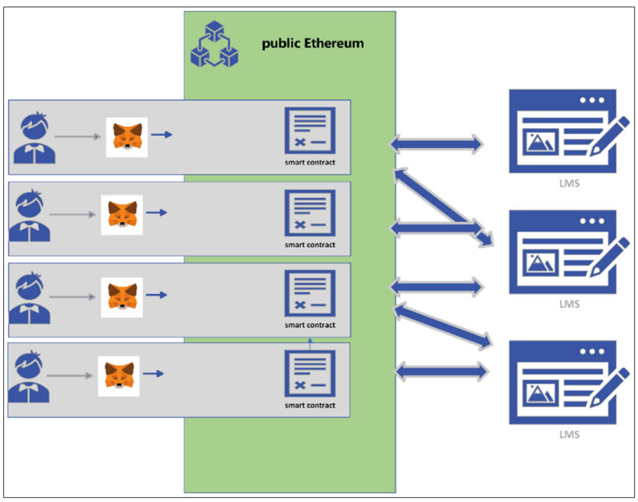

FIGURE 1. **General structure of PublicEduChain framework.**

In the PublicEduChain framework, illustrated in Figure 1, students gain complete control over their data by creating smart contracts through their accounts on the public Ethereum network. Educational institutions can enable students to log in with their Through LMSs, educational institutions can facilitate student access by allowing them to log in with their Ethereum accounts and retrieve educational data stored in their smart contracts. Moreover, educational institutions can establish corporate Ethereum accounts, utilizing them to store data like certificates and grades within individual student smart contracts. In this way, a student can store his educational data in his own smart contract, log in to LMSs with only his Ethereum ID without the need for any other registration process, and these LMSs can read data from the student's contract and write data to the contract. With the PublicEduChain framework, students can store their educational information without the need for any educational institution or third party and participate in educational activities more freely.

In the PublicEduChain framework, there are steps such as creating smart contracts by students, reading data from smart contracts by LMS and writing data to these contracts. In the next section, these steps are explained practically.

A. SMART CONTRACT CREATION BY STUDENTS

With web3, which we can call the new and decentralized version of the Internet, many decentralized applications have emerged and rapidly entered our lives. For example, cryptocurrencies have become widespread and are used for money transfer, shopping, donation, investment, and many other purposes in daily life. Thanks to wallet applications such as MetaMask and TrustWallet, people can create accounts on blockchain networks, easily access these accounts from browsers and mobile devices, and manage their assets and data. Today, in some applications, in addition to options such as e-mail and Google account, the option to log in with a blockchain ID is added. Thanks to these wallet applications, people can use their blockchain addresses as their new identities on the internet. In 2023, there are 21 million monthly active users using the MetaMask wallet application [53]. It is predicted that similar web3 applications and users using these applications will increase in the future. In the method presented in this study, it is stated that students can manage their educational data completely under their own control. The only way to do this in today's technologies is for students to create their own smart contracts. The reason why this way is preferred is that it is believed that the internet will change with web3, people will give importance to ownership and decentralization, and the creation of smart contracts, which requires some technical skills, will become easier with the tools that will emerge in the coming years.

Today, there are various methods available for creating a smart contract, each catering to different user preferences and technical proficiencies. One of the simplest approaches involves connecting to web tools such as MyWish [54] and Dappbuilder [55] through wallet applications. Users can then create a contract by selecting one of the templates offered by these applications. Presently, these templates cover a range of purposes such as token creation, sales, money transfer, and security. The number of available templates is continually expanding, and it is anticipated that templates for storing educational data may be introduced in the near future. Another way to create a smart contract is to use the Remix web application [56]. Users can connect their wallet applications to the Remix application and create their own smart contracts in a few simple steps.

For this in the PublicEduChain project, an account was established on the Ethereum network using the MetaMask tool. Subsequently, a smart contract was created in the Solidity language utilizing the Remix tool. The code for this contract is depicted in Figure 2. It's important to note

```
// SPDX-License-Identifier: MIT
pragma solidity ^0.8.9;
contract MyEduContract {
   Edudata[] public databank;
   struct Edudata {
    address LMSAdress;
    string LMSDescription;
    string Course;
    string DataType;
    string DataDescription;
    uint data_date;
    }
    function write (string memory _LMSDescription, string memory _Course, string memory _DataType,string memory _DataDescription)public{
        databank.push(Edudata(msg.sender, _LMSDescription ,_Course,_DataType,_DataDescription,block.timestamp));
    }
    function read() public view returns(Edudata[] memory ){
        return databank;
    }
}
```

FIGURE 2. Smart contract code created for PublicEduChain.

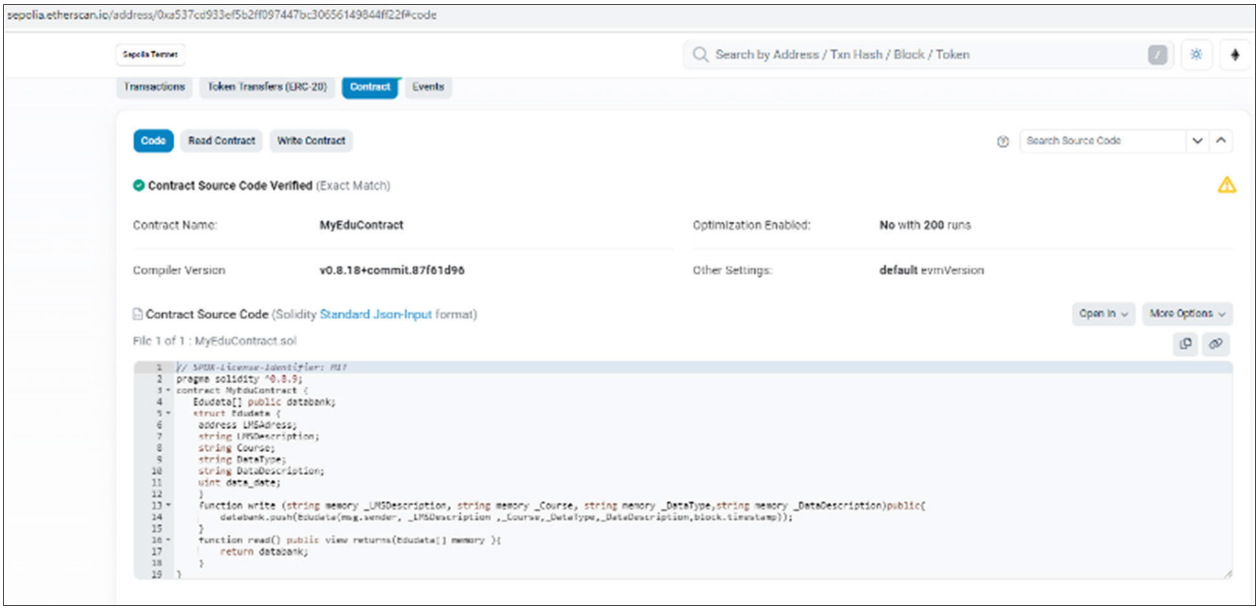

FIGURE 3. Smart contract code created for PublicEduChain.

that this contract operates on the Sepolia Testnet, a testing environment provided by Ethereum for developers.

The smart contract, as depicted in the screenshot in Figure 3, has been successfully uploaded to the Ethereum network and is publicly accessible at "https://sepolia.Etherscan.io/address/0xa537cd933ef5b2ff097447bc30656149844ff22f#code". Through this contract, various training data, including the LMS account, course, data type (certificate, grade, etc.), description, and date information, can be stored.

This contract already contains the basic fields required for an educational data. The blockchain network, LMS, code repositories and APIs for integrations used in these implementation steps of the PublicEduChain framework can be modified by researchers and developers as needed. The structure and content of the smart contract presented here can also be updated.

B. SMART CONTRACT CREATION BY STUDENTS

In this phase, the necessary integration for students to log in to the LMS using their Ethereum accounts, where they can store their identities and educational data, is detailed. For this purpose, the Moodle application was selected as the LMS, aligning with the choice made by Al-Zoubi et al. [49] and numerous other researchers. In the development environment, PHP and MySQL were installed using the XAMMP [57] tool, and the essential plugins for Moodle were incorporated. By default, access to the Moodle application is facilitated through membership creation. To enhance flexibility, the repository provided by Marountas [58] was utilized. Modifications were implemented in the source codes of the Moodle application to login with MetaMask button, providing users with the option to log in using their Ethereum accounts. Figure 4 illustrates the final version of the Moodle application's login screen, showcasing the added MetaMask login option.

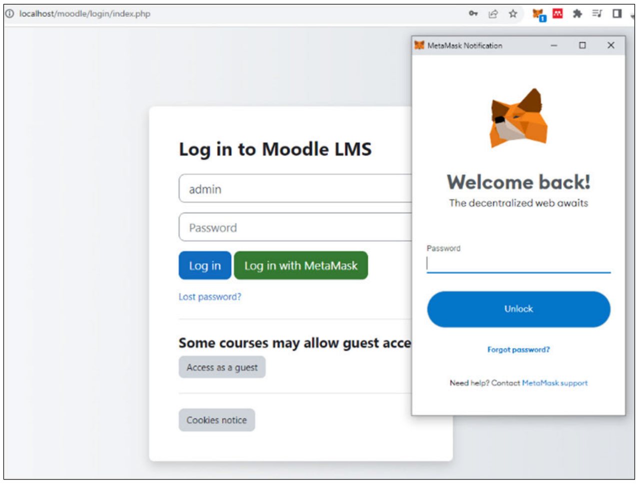

FIGURE 4. Moodle login screen with added MetaMask option.

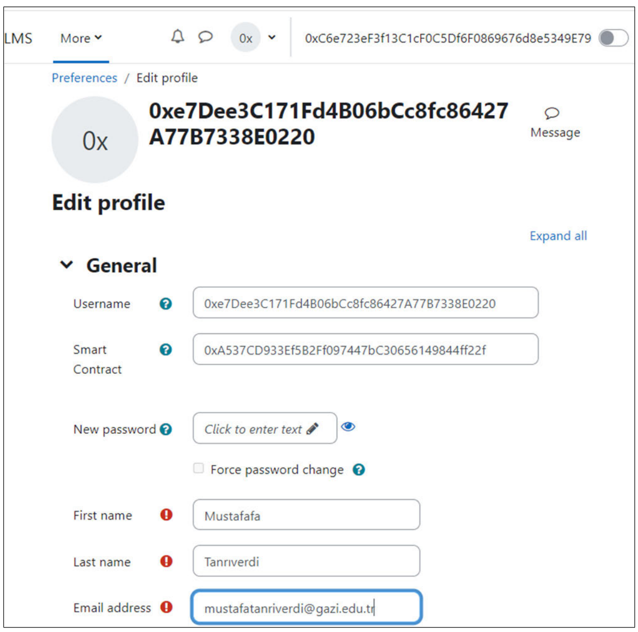

FIGURE 5. Profile edit screen in moodle.

The student who logged into the Moodle application with an Ethereum account was also given the opportunity to edit his profile information as shown in Figure 5.

C. ACCESSING SMART CONTRACT DATA ON THE LMS SIDE

The student logging into the LMS application with their Ethereum account can update the address of the smart contract along with their profile information. The LMS application should have the capability to read the educational data stored in this smart contract and write data to this contract when necessary. To achieve this integration, research was conducted in developer community forums, and it was decided to utilize the repository created by Cabrera [59], which is designed for making transactions in the Ethereum network using PHP language. The libraries and code fragments used in this repository were organized according to the needs and integrated into the source code of the Moodle application. As a result of this integration, the educational data of a student who logged into the LMS with Ethereum and updated the smart contract address from the profile page could be read. As shown in Figure 6, when an authorized user clicks on the "Get Courses" button added to a student's profile page, they can access the data in the smart contract. To test the contract, test data was added to the smart contract with the same Ethereum ID, so the address seen in the LMS address section and the address of the account logging into the LMS appear to be the same.

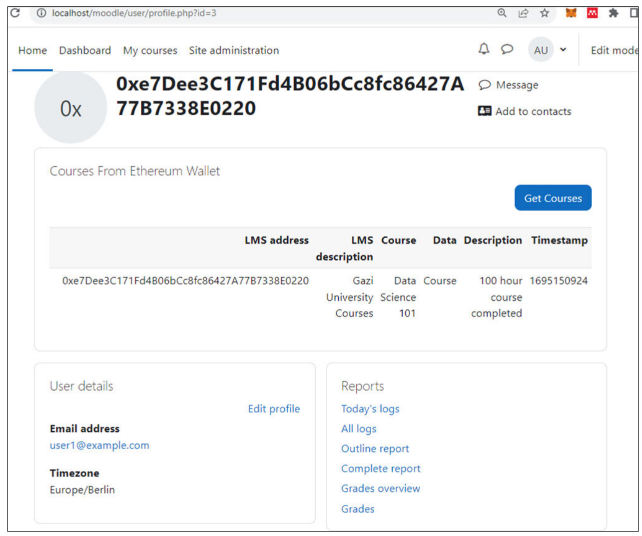

FIGURE 6. Listing the data in the student's contract.

D. ADDING DATA TO THE SMART CONTRACT ON THE LMS SIDE

In addition to being able to read the education data recorded in the student's smart contract on the LMS side, student activities such as completing courses and passing the exam should also be transferred to the smart contract. Thus, this data will now be publicly available on the Ethereum network outside the LMS. For this, the repository provided by Cabrera [59] was utilized, and the necessary integration was made in the Moodle application. Thanks to this integration, the authorized user in the LMS can write the relevant course data to the smart contract of a student taking a course as shown in Figure 7. For this integration, a corporate Ethereum account had to be created for LMS. This address can be seen on the top right side of the screenshot in Figure 7. On this screen, a student who enrolled in the "Data Science 102" course and updated his smart contract from his profile information is listed. An authorized user in the LMS can write course data to the smart contract of the relevant student by clicking on the "Write" link.

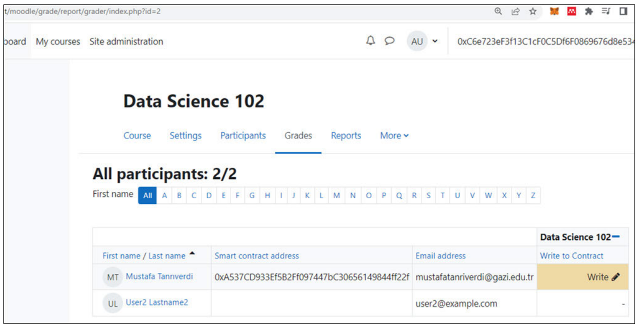

FIGURE 7. LMS screen for writing data to the contract.

Due to the structure of public blockchains, all data transactions made on the network are stored in a transparent and unchangeable way. A transaction value is generated for each transaction made on the Ethereum network and can be monitored via the Etherscan web application. The process of writing the course data to the smart contract with the address ''0xA537CD933Ef5B2Ff097447bC30656149844ff22f'', which the student updated in his profile from the address ''0xC6e723eF3f13C1cF0C5Df6F0869676d8e5349E79'' opened as an institutional account via LMS. This transaction can be seen publicly with the transaction value ''0xbf62513bb938f45b1d3a3a6c566ce30be0453edc3478566a50d6ad0d7368f1f2'' [60].

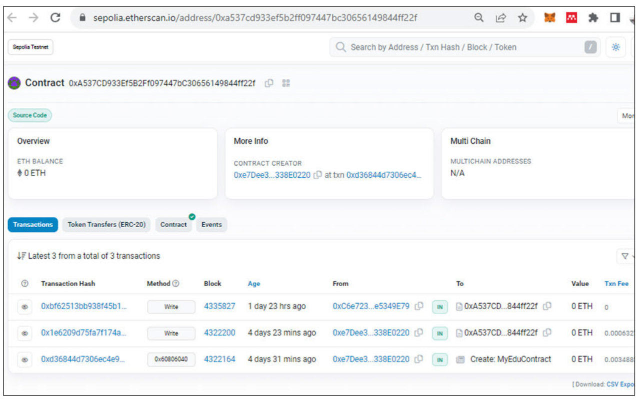

FIGURE 8. Detail of the created smart contract in Etherscan.

In order to better understand and question the main idea of the study, which is that students can store their educational data in decentralized data stores without the need for any third party, it would be useful to explain the transactions made from the Etherscan page in detail. When the smart contract address of the student is entered in the search section at the top of the Etherscan page, the screenshot in Figure 8 is seen. This screen shows the address that creates the smart contract and the data transactions made in this contract. Looking at the movements of this contract, it is seen that the student with the address ''0xe7Dee3C171Fd4B06bCc8fc86427A77B7338E0220'' created this contract and then saved data with the ''Write'' method. Afterwards, it is understood that the ''Write'' method was also executed by LMS, the owner of the address ''0xC6e723eF3f13C1cF0C5Df6F0869676d8e5349E79''. In order to access the details of this last transaction, the screenshot in Figure 9 is seen when clicking on the top of the transaction list. From this page, it can be seen with which smart contract, by whom and when the transaction was made. It is also possible to see the data sent to this contract, for this it is enough to click on the ''click to show more'' link at the bottom of the page shown in Figure 9 and then click on the ''decode input data'' option.

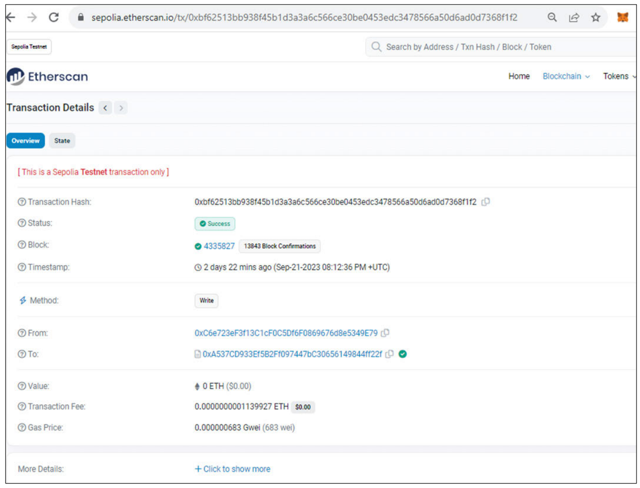

FIGURE 9. Detail of the ''write'' operation performed by LMS in Etherscan.

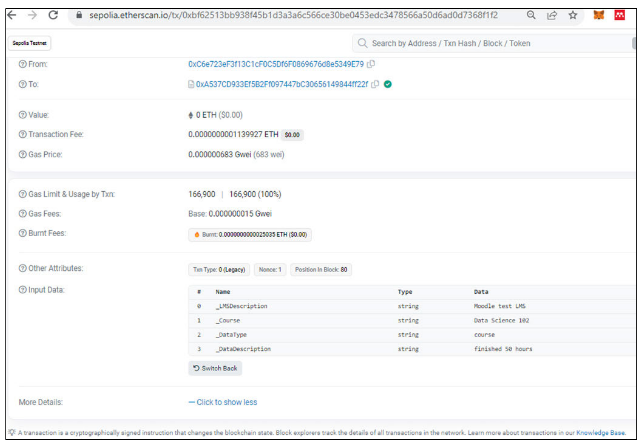

FIGURE 10. Detail of the data written to the smart contract in Etherscan.

The screenshot in Figure 10 shows the data written by the LMS to the student's smart contract. This data transferred to the student's contract is now stored in the Ethereum network independently of the LMS. In the screen shown in Figure 6, there was one test data in the student's smart contract, when the same process is repeated after the data written by the LMS, the information of the ''Data Science 102'' course is now listed as shown in Figure 11. This data in the student's smart contract can be accessed or written to the student's smart contract by other LMSs with the necessary integrations. Thus, independent of educational institutions and administrative units, the student can share his educational data with the LMSs with which he has defined his smart contract.

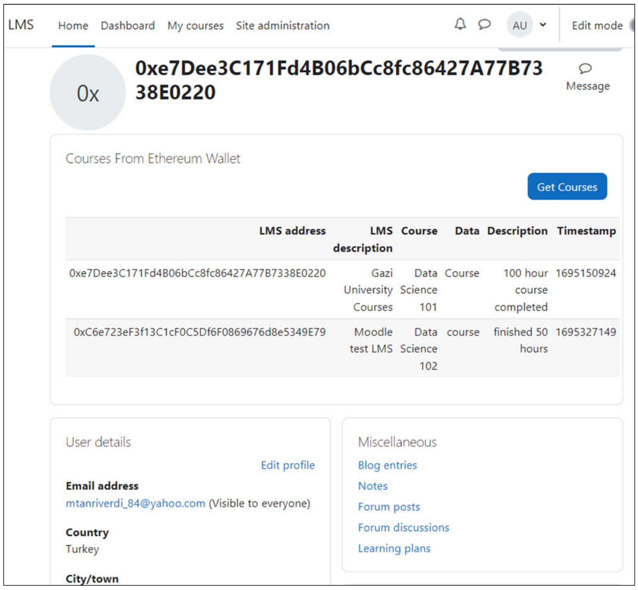

FIGURE 11. Listing of data in the contract after data addition by LMS.

E. FINANCIAL AFFAIRS ON THE PUBLIC BLOCKCHAIN

Blockchain systems are generally operated in two types as public and private. The source codes of all blockchains are publicly available. In private blockchains, these source codes are installed and managed by a group or organization on the servers they own. Private blockchains have costs such as server, infrastructure, and network management, and since these chains are managed by a group or institution, they can be considered as a semi-centralized structure. Public blockchains, on the other hand, are powered by many participants and offer the data stored in their resources publicly. The amount of data stored in public blockchains is increasing rapidly, and the financial resources needed to store and verify this data are provided by the fees charged from the transactions made on the network. A gas fee is paid for each data write job performed on the Ethereum network. This gas fee is calculated based on the amount of gas used by the transaction and the gwei value that varies according to the density of the network [61]. While calculating the cost of the smart contract created in the steps of the PublicEduChain framework, it was seen that the "Gas Limit & Usage by Txn" value seen in the transaction details [62] that created the smart contract was 951970 and the instant calculation value [61] was 9 gwei. According to these values, it is seen that the smart contract cost is 951970*9=8.567.730 gwei, that is, 0,00856773 eth. When the value of Ethereum coin is calculated as 1580 USD at the time of the study, this cost is 13.61 USD. With the same calculation method, the cost of writing data to the student contract by the LMS was calculated as 2.3 USD. According to these costs, it is appropriate in terms of cost and convenience to store and share educational data in this way with only gas fee costs without any investment, without any license, maintenance, backup, network expert for management. Ethereum, which verified transactions with proof-of-work (POW) until September 2022, that is, with computing resources and electrical power, started to verify proof-of-stake (POS) after this date [63]. Thanks to this transition, the computing and electrical power required for the operation of the network has decreased by 99.95%. In this way, it can be said that Ethereum is more sustainable, more performant, and more environmentally friendly. When we look at the USD equivalent of Ethereum coin and the instant calculation (gwei) values that vary according to the density of the network and miner performances, it is seen that these values, which were very fluctuating before, are now moving more horizontally and in a downward trend. This makes it more convenient to develop applications on the Ethereum network.

IV. DISCUSSION

Software skills were necessary to make the required adjustments in the LMS and Ethereum APIs during the implementation of PublicEduChain steps. Throughout this process, documentation, source codes and forum pages were utilized. For the real-life applications of PublicEduChain, only an expert staff with software skills for the necessary integrations may be sufficient without any hardware or license expenditure. Ethereum was preferred as the public blockchain for PublicEduChain due to its advantages, but blockchain systems that offer advanced features such as Neo [64], Qtum [65] can also be considered as options. During the integration stages, it was observed that there are many blockchain systems that offer advanced features, and these systems provide opportunities for developers such as APIs in different software languages, sample projects, forum pages. Moodle was preferred as LMS in the implementation of PublicEduChain steps. Since Moodle is an application written in PHP language, the integrations with Ethereum network were developed with PHP APIs. With the same method, necessary integrations can be made with Python, the language in which it was developed for the widely used and open-source education platform edX [66]. In fact, the education data added to the student smart contract from the Moodle application can also be accessed through the edX application operated by another institution. This can pave the way for transparent and secure data sharing between different systems.

For students to truly own their educational information on the blockchain network, they must be capable of creating their accounts and smart contracts to store their academic data. In the sample application steps, a sample smart contract was created with MetaMask and Remix web tools. Today, students generally do not have the ability to create smart contracts, but it is thought that they may have this skill with the tools and documentation that will emerge with the widespread use of web3 applications over time.

PublicEduChain was run on the Sepolia Testnet provided by Ethereum for developers. In the financial affairs section, the associated costs for actions such as creating a smart contract and writing data to the contract on the Ethereum Mainnet were computed. Due to their structure, public blockchains survive with deductions from transactions. Therefore, for creating smart contracts and writing data to contracts in public blockchains, students and educational institutions will need the cryptocurrency of the relevant blockchain.

V. LIMITATIONS AND FUTURE WORKS

Blockchain networks operate through computer algorithms, providing a decentralized structure resistant to external intervention. Therefore, there is no unit to apply for problems such as "I forgot my password", "there is an error in my smart contract". In PublicEduChain, students need to connect to their Ethereum accounts with wallet tools such as MetaMask. Here, there will be no solution for problems that may arise in password security in wallet applications or in backing up and transferring account information, since there is no contact person in the Ethereum network. Although Public Blockchain networks offer full decentralization, the fact that there is no interlocutor to apply for problems encountered is also a major problem. Technical and legal regulations are needed to solve this problem.

Due to the structure of blockchains, a transaction cannot be deleted or changed. In the presented solution, it is not possible to correct a transaction made by the student or LMS by mistake. To overcome this limitation, another field can be added to the structure in the smart contract and the active/inactive status of the relevant record can be specified and only the records with active status can be taken into account.

In PublicEduChain, students are required to pay a one-time gas fee when creating a smart contract, while the LMS incurs a gas fee with each data addition to these contracts. LMSs can plan to cover these expenses either by passing them on to students or through sponsorship and support. The costs involved may fluctuate based on network density. Therefore, for an LMS intending to write a substantial amount of data to the network, identifying periods of lower costs can significantly reduce overall expenses. Notably, there is a lack of existing studies on these issues in the literature, making it a crucial area for future research.

In PublicEduChain, anyone can create smart contracts to store educational data without any restrictions, and each educational institution can write data to the contracts they want through LMSs. Since a gas fee must be paid for these transactions on the Public Ethereum network, spam or attack attempts are largely prevented. However, there is still a situation open to abuse. To address this issue, educational institutions can make their Ethereum addresses visible on their LMSs and even add them to their corporate information such as e-mail and social media accounts as shown in Figure 7. In this way, necessary verifications can be made with the address information in the "LMSAddress" field of the education records in smart contracts. In future studies, it is thought that in order for this infrastructure presented in the Public blockchain to work more efficiently, there will be a need for studies to be carried out to ensure the control of educational institutions that can write data to smart contracts.

VI. CONCLUSION

Today, there are problems in sharing educational data centrally managed by educational institutions and administrative bodies and ensuring its security in cases such as war and natural disasters. In addition, educational companies providing lifelong learning and certification services, which are increasing in number and attracting interest from students, are also excluded from data sharing. When studies on blockchain and education were examined, no study was found in which students owned their own data and the data was stored in a decentralized structure. To address this gap, this study proposes the PublicEduChain framework, which manages educational data in a distributed architecture under student ownership. This decentralized approach aligns with the growing prevalence of web3, emphasizing decentralization and ownership on the internet. The study employs the public Ethereum network to ensure decentralization in storing and sharing data, eliminating costs related to hardware investment and blockchain network installation and management.

The implementation of PublicEduChain is detailed in the study, providing guidance on integrating blockchain into existing LMSs. The tools and technologies used in the implementation process are thoroughly explained, accompanied by screenshots for clarity. The study highlights the transparency and traceability of every transaction within the public Ethereum network, substantiating these points with illustrative examples. Additionally, in the financial affairs section, enlightening information about the fees to be paid for transactions made in public networks is also included. The study makes a significant contribution to the literature in this respect.

Today, information and communication technologies are developing and spreading very rapidly. Blockchain cryptocurrency, smart contract, NFT and Metaverse applications, which are considered as web3 applications with their distributed and transparent structure, have recently entered our lives rapidly in many areas. In the future, it is predicted that people will prefer web3 applications that adopt trust in information systems instead of third-party intermediaries and applications. In this context, PublicEduChain is considered to have a great potential usage area for the future. It is thought that the difficulties encountered in the implementation of PublicEduChain's steps, such as students' smart contract creation and LMS integrations, will be eliminated with the tools and applications to be developed in the future.

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