A solution for integrating virtual learning environments with Blockchain

Uma solução para integração de ambientes virtuais de aprendizagem com Blockchain

Una solución para integrar entornos de aprendizaje virtual con Blockchain

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Abstract
Education generates a considerable amount of data and information, it is necessary to manage this data securely, avoiding problems of falsification and tampering with diplomas, certificates, and other important student documents. In addition, distance learning is becoming more popular due to the Covid-19 pandemic period, where courses are offered in virtual learning environments such as Moodle. Blockchain technology can be used as a tool to ensure the security of data managed by Moodle. However, there is a gap in current state-of-the-art solutions for integrating these data with Blockchain platforms. This work proposes BlockMoodle, a solution developed to integrate Moodle with Blockchain Ethereum. This work also performs an analysis of the financial cost of using the tool. In addition, a performance evaluation of the proposed solution is also carried out considering different usage scenarios. Finally, the conclusions and future work to be developed are presented.
Keywords: Blockchain technologies; Education; Information security.

Resumo
A educação gera uma quantidade considerável de dados e informações, é necessário gerenciar esses dados com segurança, evitando problemas de falsificação e adulteração de diplomas, certificados e outros documentos importantes do aluno. Além disso, a modalidade de ensino a distância está se tornando mais popular devido ao período pandêmico de Covid-19, onde os cursos são oferecidos em ambientes virtuais de aprendizagem, como o Moodle. A tecnologia Blockchain pode ser utilizada como ferramenta para garantir a segurança dos dados gerenciados pelo Moodle. No entanto, existe uma lacuna de soluções, no estado da arte atual, para integração desses dados com plataformas Blockchain. Este trabalho propõe o BlockMoodle, uma solução desenvolvida para integrar o Moodle com a Blockchain Ethereum. Este trabalho também realiza uma análise do custo financeiro de utilização da ferramenta. Além disso, uma avaliação de desempenho da solução proposta também é realizada considerando diferentes cenários de uso. Por fim, são apresentadas as conclusões e trabalhos futuros a serem desenvolvidos.
Palavras-chave: Tecnologia blockchain; Educação; Segurança da informação.

Resumen
La educación genera una cantidad considerable de datos e información, es necesario gestionar estos datos de forma segura, evitando problemas de falsificación y adulteración de diplomas, certificados y otros documentos importantes del estudiante. Además, el aprendizaje a distancia se está volviendo más popular debido al período de la pandemia de Covid-19, donde los cursos se ofrecen en entornos de aprendizaje virtual como Moodle. La tecnología Blockchain se puede utilizar como una herramienta para garantizar la seguridad de los datos administrados por Moodle. Sin embargo, existe una brecha en las soluciones de vanguardia actuales para integrar estos datos con las plataformas Blockchain. Este trabajo propone BlockMoodle, una solución desarrollada para integrar Moodle con Blockchain Ethereum. Este trabajo también realiza un análisis del costo financiero de usar la herramienta. Además, también se

lleva a cabo una evaluación del desempeño de la solución propuesta considerando diferentes escenarios de uso. Finalmente, se presentan las conclusiones y trabajos futuros a desarrollar.
Palabras clave: Tecnologías blockchain; Educación; Seguridad de información.

1. Introduction

Blockchain has emerged to provide security and reliability in the financial negotiations that took place on the Internet (Nakamoto, 2008). However, it was possible to realize that this technology can be used to record another type of information in a secure and decentralized approach (Ferreira, Pinto & dos Santos, 2017). Thus, interest began to emerge in its use in other relevant areas.

In the education area, a well-known problem refers to security in the management of students' school records, such as grades history and certificates. In addition, the student, when trying to enter a new job or another educational institution, needs to provide proof of the training received and the skills acquired, which in many cases is not easily verifiable (Al Harthy, Al Shuhaimi & Al Ismaily, 2019).

In addition, with the popularization of the Internet, the distance learning modality has become increasingly accessible to a considerable number of students. Currently, Distance Learning uses Virtual Learning Environments (VLE) to make course content available to students and to support interaction between students and teachers. One of the most used VLEs in current days is Moodle, open-source software that offers a wide variety of features. Moodle supports, for example, the creation and management of courses, activities, and questionnaires. Moodle also facilitates communication between students and teachers through forums and messages.

In this context, it is important to adopt security measures to ensure the integrity, availability, and immutability of academic data recorded in a VLE (Chicarino, Jesus, Albuquerque & Aragão Rocha, 2017). It is possible to use Blockchain technologies and platforms for this purpose. However, currently, it is not possible to find in the literature proposals that support the integration of Blockchain technologies to VLEs. To support this goal, the main objective of this work is the proposition of a solution, named BlockMoodle, to support the integration of the Moodle Virtual Learning Environment with the Ethereum Blockchain. Through this integration, it is possible to achieve a higher security level in the management and validation of educational data.

This paper is organized as follows. Section II describes the research methodology of this work. Section III presents basic concepts that are important for better understanding this article. Section IV presents relevant research work related to the use of Blockchain in educational contexts. Section V presents the main contribution of this article, BlockMoodle. Section VI describes the evaluation of the proposed solution. Finally, Section VII presents the conclusions of this paper and describes the future work.

2. Methodology

The methodology of this work is classified as applied research, which generates new knowledge for practical application and solution of specific problems. As for the scientific method used, it is classified as inductive research. This method starts with the observation of phenomena that one wants to know. Research begins on a specific issue and then explores broader issues, based on studies that identify the relationship between observed objects (Prodanov & Freitas, 2013).

A bibliographic search was carried out considering references such as books and papers published in scientific journals and conferences. To carry out this bibliographic research, the search criteria were defined, through the elaboration of a bibliographical review protocol that is detailed as follows.

- Research question: how to guarantee confidentiality, integrity, and availability of Distance Learning data and documents?

- Scientific bases adopted: IEEE Xplore Digital Library; Springer Link; ACM Digital Library; Scielo; Google Scholar.
- Keywords: “Blockchain”, “education”, “data security”.
- Inclusion criteria: articles published after 2015 and containing material directly related to the research question.
- Exclusion criteria: papers published before 2015 or that contain material unrelated to the research question.
- Search strings: “Blockchain AND Education”, “data security AND education”, “Blockchain AND Education AND data security”.

After the definition of the research question, the bibliographic review started. It was possible to identify four main areas: diplomas registration, the authenticity of academic documents, use of Smart Contracts in educational contexts, and Blockchain knowledge record. After this bibliographic review, the development of the BlockMoodle solution was carried out. The solution is based on a Smart Contract that records educational information collected from the Moodle database, such as data related to courses, activities, grades, and so on.

3. Basic Concepts

This section presents the main concepts necessary for understanding this work.

3.1 Blockchain

Blockchain was proposed to create a new approach to carry out financial transactions using the digital currency Bitcoin (Nakamoto, 2008). This technology seeks to ensure security through data decentralization. In other words, Blockchain operates as distributed and shared record bases that store information about transactions that occur on a given network (Al Harthy et al., 2019). All transactions that occur between the network users are grouped into data structures called blocks, which are distributed among the various computers connected to the network (also called nodes). If a new block is inserted, all other Blockchain nodes are updated to receive the new data (Chen, Xu, Lu & Chen, 2018).

Each block has a header, which stores relevant block identification information such as the hash[1] of the previous block, the block identification hash, and the timestamp, which records the moment when the block was created. The contents of the transactions are contained in the block body. Each block saves a reference to its previous one. Due to that, the information stored in a block cannot be changed without impacting other blocks. The chain itself is one of the factors that makes Blockchain networks more secure and virtually unalterable. The first block of the chain, commonly called the genesis block, is encoded at the time that the network is created and serves as the initial state of the system.

3.2 Mining

Before inserting the block in the Blockchain, it is necessary to validate it. This is necessary to be able to ensure that it complies with the requirements defined by the network. This validation, popularly known as mining, consists of a costly computational procedure that seeks to find a valid hash for the block.

Each node connected to the Blockchain network stores a copy of the "Ledger Book", which stores a record of all transactions. There are some mining protocols currently used, the best known being Proof-of-Work (PoW) and Proof-of-Stake (PoS), which use the processing power of machines to solve mathematical calculations. This process is computationally expensive, as these calculations demand a high consumption of resources, especially processing (Chicarino et al., 2017).

[1] The hash is a numeric code that guarantees that the transaction is valid. Once found, the block can finally be added to the network. (Nakamoto, 2008).

3.3 Smart Contract

Smart Contracts are computer codes created to facilitate the execution and fulfillment of an agreement automatically and securely (Szabo, 1996). These contracts offer an interesting degree of security because they allow two or more parties to enter into agreements with each other without the need for a centralized entity as an intermediary. Smart Contracts receive as input several conditions that will be monitored, and when these conditions are satisfied the contract is executed. The whole process takes place automatically, having its security guaranteed by the Blockchain. The operation of Smart Contracts is divided into three steps (Stallings, 2006):

- **Encoding**. The contract is coded in a programming language, and at this moment the instructions that the contract must execute are defined accurately.
- **Submission to Blockchain**. After the encoding process, the contract is compiled and sent to the Blockchain. This submission occurs in a similar approach to what is carried out in cryptocurrency transactions.
- **Execution**. The Blockchain receives the code and processes it in one of its nodes. The Blockchain network then updates the records, and all nodes are updated considering the results of the contract processing. The contract is then monitored by the network.

One of the largest existing Blockchain-based platforms currently is Ethereum, which aims to allow the programming of decentralized applications (DApps) and Smart Contracts (Gencer, Basu, Eyal, Van Renesse & Sirer, 2018). The Ethereum platform seeks to be a great computer in the world with its processing power distributed in its various nodes. In this context, Ether is used as currency for the creation and management of Smart Contracts and the purchase of computing power.

4. Related Work

This section presents research initiatives related to Blockchain usage in educational contexts.

4.1 Diplomas registration

According to Karataş (2018), a considerable number of individuals join a technical or higher-level course through distance education. However, the author highlights the importance of being able to verify the authenticity of the digital certificates issued to students. The paper presents a case study where a series of activities were made available to students through a Moodle environment. A Smart Contract was created, and this contract is used to verify the authenticity in the Moodle environment for control purposes.

Similarly, Mouromtsev, Gosudarev & Sivinskiy (2020) addresses the need to create a mechanism for verifying the authenticity of diplomas issued by universities. The authors propose the creation of a Blockchain network shared between universities. Each institution would be a node on the network and this network could provide a common authentication service. Two APIs were proposed, one to create the decentralized Blockchain network and the other for other functionalities available to users, such as registration.

4.2 Registration of academic documents

Srivastava, Bhattacharya, Singh, Mathur, Prakash & Pradhan (2019) suggests the creation of a Blockchain-based data recording platform that records all credits acquired by the student throughout their academic trajectory. These credits are recorded through tokens. Each university has a node on the Blockchain and will be responsible for generating identification credentials for its students by verifying the authenticity of their documents. The work describes the implementation of the Blockchain and details the proposed algorithms and functions, such as registering the student, registering the educational institution data, and so on.

4.3 Use of Smart Contracts in Education

In this topic, Cheng, Lee, Chi & Chen (2018) propose the use of Smart Contracts registered in Blockchain for diplomas issuance and validation. The contract will define the necessary conditions for the conclusion of the course and other related information. When the student meets all conditions, the contract is self-executed and the diploma can be issued. The work describes the modeling and implementation of a system developed for the Ethereum platform using the Solidity language. An example of certificate generation on the Ethereum network is presented by creating a Smart Contract containing the needed information.

It is also possible to use Smart Contracts for performing payments. Rooksby & Dimitrov (2017) propose the creation of an Ethereum Blockchain-based platform for University environments. This proposal supports the student's registration and the recording of their respective grades in the courses. On the platform, there is a cryptocurrency, called Kelvin Coin, which the student receives as a reward for good performance in academic activities. With this currency, the student will be able to pay for new courses through Smart Contracts.

4.4 Knowledge Record

Han, Li, He, Wu, Xie & Baba (2018) propose the creation of an Ethereum-based platform that allows the educational institution to record the students and their academic trajectories, as well as the knowledge produced by each student. This platform also supports diplomas and certificates registration. This process can be validated whenever necessary by any interested party, such as another educational institution or potential employers.

Mikroyannidis, Domingue, Bachler & Quick (2019) propose the creation of a decentralized architecture for online education, where students will be able to enroll in various courses in VLEs such as Moodle. According to the authors, data such as student rating and activities feedbacks is stored in a specific structure that can be verified through Blockchain. The authors present a decentralized approach using Blockchain, which allows students to plan their entire learning more efficiently. The solution allows the student to have full control and ownership over data and documents generated in the learning process.

The solution proposed in this paper differs from the other previously described ones as it proposes integration capabilities between VLEs (more specifically, Moodle) and Blockchain platforms (more specifically, Ethereum). This feature is considered a gap in the current state of the art.

5. BlockMoodle: A Solution for Integrating the Moodle VLE with the Ethereum Blockchain

This section describes the BlockMoodle solution, which aims to integrate the Moodle VLE with the Ethereum Blockchain. This solution collects the main information related to the students and their respective data and records them on the Blockchain through a Smart Contract.

5.1 Adopted Tools

The following tools were used for the BlockMoodle development.

- **Solidity**. An object-oriented programming language that supports the development of Smart Contracts for various Blockchain platforms, in particular Ethereum. This tool was used to create the BlockMoodle Smart Contract code.
- **React**. Open-source JavaScript library that supports the creation of user interfaces on Web pages. It was used to create the visual interface, which enables access to the BlockMoodle features.
- **Web3.js.** JavaScript API that facilitates the connection to the Ethereum platform using the JSON specification. With this library, it was possible to communicate the front end of the application and an Ethereum Blockchain.
- **Metamask**. Cryptocurrency wallet that can be used as an extension in Chrome, Firefox and Brave browsers. This tool

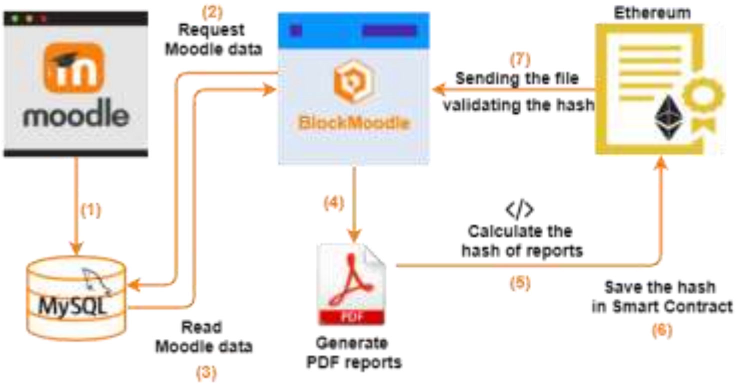
acts as a bridge between Web browsers and the Ethereum Blockchain.

- **Infura**. This API provides instant access over HTTPS and Web Sockets to Ethereum networks. It was used to support the communication between the BlockMoodle solution and the Ethereum Blockchain.

5.2 Solution Overview

Figure 1 presents an overview of the proposed solution BlockMoodle.

Figure 1 - Overview of the proposed solution.



Source: Authors.

Moodle records data in a MySql relational database (1). In this database, it is recorded information related to various educational aspects, such as courses, activities, and the interactions that occur between students and teachers through forums. The BlockMoodle solution accesses the Moodle database, where the required data is collected through SQL queries. This data is chosen by the user (2), and examples of this data include personal information of the students, the courses in which they are enrolled, and their respective grades. The user responsible for issuing documents in BlockMoodle is an employee of the educational institution, and this employee can generate documents according to the institution and students' requests.

All this information is organized in reports in PDF format (3), which is a widely disseminated standard for document exchange, and then registered on the Blockchain. The generated documents are made available to the requester and will remain stored in the BlockMoodle service. After creating a report, the application calculates the document hash (4). For this purpose, it is used the sha256 hash function, which receives as input the report file and returns a 64-bit string, which corresponds to the hash value of the document. This string is a numerical representation of the corresponding file. After this, the hash of the file is sent to the Smart Contract registered on the Ethereum Blockchain (5).

To communicate BlockMoodle with Blockchain, the Web3 API is adopted, and this API uses the JSON format to exchange the necessary information with the Ethereum platform. A Web3 instance is created, which is responsible for communicating with the Metamask cryptocurrency wallet. This instance verifies if there is sufficient balance for the document registration. This same instance also communicates with the Infura API, which is responsible for interacting directly with the Ethereum network.

Through BlockMoodle it is also possible to perform the validation of the reports. To execute this validation, the file is uploaded, and its hash is calculated (6) using the sha256 0.2.0 library After this step, the Smart Contract is consulted to verify if this hash is registered on the Blockchain. The Blockchain data registration is done through a Smart Contract, written in the language Solidity 0.4.17. Figure 2 presents the source code of the implemented Contract.

Figure 2 - BlockMoodle Smart Contract source code.

```
1  pragma solidity ^0.4.17;
2
3  contract Moodle{
4
5      struct Report {
6          string description;
7          uint timestamp;
8          address sender;
9          string doc;
10         uint tipo;
11     }
12     address public manager;
13     Report[] public docs;
14     function Moodle() public {
15         manager = msg.sender;
16     }
17     function createReport(string memory description,
18         string memory valor, uint tipo) public {
19         Report memory newReport = Report({
20             description: description,
21             timestamp: now,
22             sender: msg.sender,
23             doc: valor,
24             tipo: tipo
25         });
26         docs.push(newReport);
27     }
28     function getLength() public view returns (uint) {
29         return docs.length;
30     }
31 }
```

Source: Authors.

In this contract, a structure named "Report" (line 4) is defined, which contains the main data to be recorded: the report description, the Timestamp of the report creation, the hash of the report, and its type. The Smart Contract contains two main functions: "createReport" (line 17), which is invoked when a new record is created, and the "getLength" function (line 28), which is used to validate a report, as it can be used to find the hash of the document that must be validated.

For each new transaction, it is necessary to pay a fee in the Cryptocurrency Ether. This fee is required by the Blockchain Ethereum due to the mining costs required to validate each block and to add them to the chain. Metamask was used to perform this task, which is a cryptocurrency wallet and can be used as an extension of Chrome and Firefox browsers.

Another important feature is report validation. For this validation process, it is necessary to upload the file to be validated in the solution. The file is sent via POST, and then its hash is calculated and its value compared to the one recorded on the Blockchain. If it is a valid value and it is registered in the Blockchain, a confirmation message is displayed. This message contains data related to the document, such as its creation date, its hash, its type, among other relevant information.

If the inserted file was not generated by BlockMoodle, an error message is displayed informing the user that the document is not valid. For this validation process, there is no fee charged by the Ethereum network. Based on that, students or any interested parties can perform document validations whenever necessary.

6. Evaluation

This section aims to evaluate the main contribution of this article, BlockMoodle.

6.1 Financial cost assessment

On the Ethereum Blockchain, there is a computational cost associated with the mining process. Therefore, to include new data in a block, it is required to pay a fee. This value, measured in Gwei, varies frequently depending on the level of network usage at that instant. Transactions that offer higher rates are more likely to be chosen first by Blockchain's mining algorithms to enter the block that will be mined. The total value is given by:

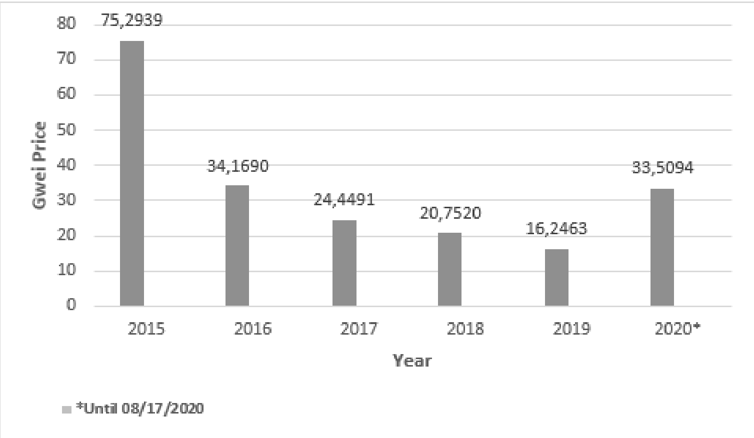
Total Value = Gas Limit * Gas Price (1)

In this equation, the Gas Limit corresponds to the total amount of Gas that the transaction may consume. This value depends on the operation that will be performed in the Smart Contract. Each code statement, processed by the Solidity language compiler, is associated with a cost required for execution on the Blockchain. The costs adopted in the Ethereum network operation were defined by the Ethereum Project Yellow Paper (Wood et al., 2014).

The BlockMoodle code has a Gas limit execution cost equal to 174000, and this value was obtained through empirical observations of Metamask executions. After each new record on the Blockchain, it was observed that this number was repeated. The value of the Gas price varies depending on the number of transactions being included in the Blockchain at any given time. The daily averages of the Gas price are made available by the Etherscan.io platform Team (2017), where the values are displayed from the beginning of the network operation (August 2015) to the present.

To measure the cost of including a report generated by BlockMoodle was produced a spreadsheet with all daily values of the Gas Team (2017) and the annual average of the Gas Price, and a high-level summary of this data is presented in Figure 3. For example, the average price value of Gas in 2019 was 16.24 Gwei.

Figure 3 - Gwei Annual Historical Average Price.



Source: Authors.

With this information, it is possible to perform a cost estimate and perform a comparison of how much it would cost to generate each report. Using equation (1), for the year 2019, for example, considering the Gas Limit of 174000 and the average price of Gwei in that year of 0.0000000162463 (converted to Ether), the cost would be:

Total= 174000 * 0,0000000162463 = 0,0028268 Ether (2)

Thus, the cost required for including a report on Blockchain in 2019 would be 0.0028268 Ether. To support a better analysis, the Ether price can be converted to the dollar. As the Ether price undergoes constant changes, a process similar to the previous one was carried out, with the average calculation of the Ether price in dollars annually. For example, in 2019 the average price of Ether was US$182.01. Multiplying this value by the number obtained in equation (2), the cost in that year would be US$ 0.51.

Table 1 compares costs over the years, from August 2015, the start date of the Ethereum network, until August 2020. It is possible to notice that the total amount required for the insertion of a report suffered several oscillations over time, starting from $ 0.01 in 2015 and reaching its highest value in 2018: $ 1.74.

Table 1 - Costs overview.

Year	Gas Limit	Gas Price (Ether)	Total (Ether)	Total (US$)
2015	174000	0,00000007529	0,0131	$ 0,01
2016	174000	0,00000003416	0,0059	$ 0,06
2017	174000	0,00000002444	0,0042	$ 1,00
2018	174000	0,00000002075	0,0036	$ 1,74
2019	174000	0,00000001624	0,0028	$ 0,51
2020	174000	0,00000003350	0,0058	$ 1,27

Source: Authors.

Considering the generated data, each educational institution can assess the financial feasibility of the BlockMoodle solution. If the institution considers that this fee is high, it is possible to use a private Blockchain, implemented by the institution itself. In this case, the institution will not pay fees but will have to invest financial efforts to implement and maintain the Blockchain infrastructure. By opting for a public Blockchain, such as Ethereum, the institution should be aware that its costs will undergo constant changes due to the price variations of the cryptocurrency Ether and the dollar.

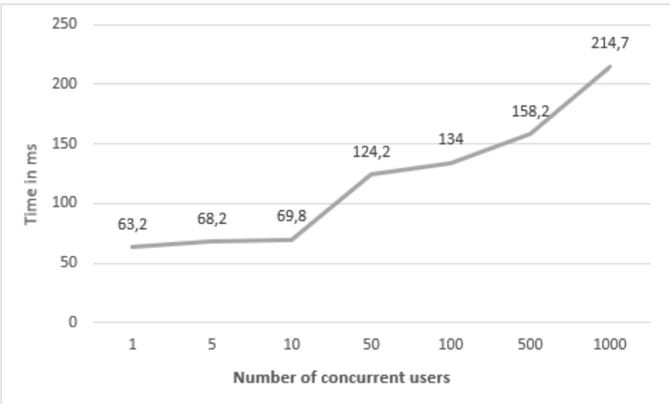
6.2 Performance Evaluation

To execute a performance evaluation, it is possible to use different techniques (Jain, 2008; Yadav, Sousa & Callou 2018). One of them is a measurement, which performs the analysis directly on the real system. This technique applies different workloads to measure the system performance through the collected metrics. Measurement was chosen as the adopted technique to perform the BlockMoodle performance evaluation.

The metrics chosen for the BlockMoodle analysis were the flow rate, which corresponds to the rate at which the requests are met by the system, and the response time, which is the time elapsed between the start and completion of the service (Menasce, Almeida, Dowdy & Dowdy, 2004). Different workloads were applied, which simulate different amounts of users performing simultaneous access to the application. The applied loads were 1, 5, 10, 50, 100, 500, and 1000 simultaneous accesses. To generate the workload, the JMeter tool was used. This tool supports the creation of the simultaneous access amount that must be analyzed. In this evaluation, each one of the requests performs a GET HTTP request, simulating a user accessing the application.

Figure 4 presents the flow rate for the applied simultaneous requests. It is possible to observe that as the number of simultaneous access increases, the flow time required to meet all requests also increases. It is also possible to observe that this increase becomes more significant when reaching more than 100 simultaneous requests.

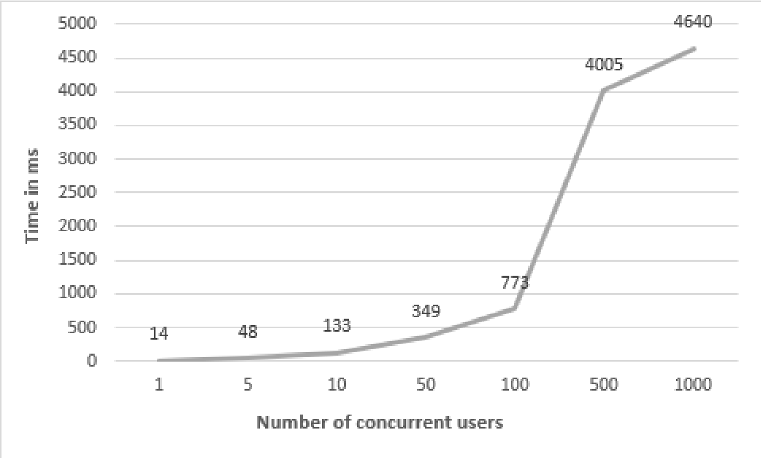
Figure 4 - Flow rate evaluation.



Source: Authors.

The other chosen metric was response time. Figure 5 presents the results considering this metric. As the number of concurrent users increases, so does the solution response time.

Figure 5 - Response time evaluation.



Source: Authors.

By observing Figure 5, it is possible to notice that there is a considerable growth of response time from 100 simultaneous users. Thus, in cases where the number of simultaneous accesses is less than this number, no significant variations will be noted by the user.

Finally, it is possible to conclude that the flow rate and response time values are acceptable. For 1000 simultaneous accesses, for example, the flow time in milliseconds was 214.7. For up to 100 simultaneous accesses, the response time was 773 milliseconds. According to Miller (1968), response times between 0.1 and 1 second are considered tolerable and do not cause attention deviation by the user. The usage of the BlockMoodle solution does not impact Moodle's performance, as it only queries the Moodle database. No data is inserted or modified into Moodle tables.

7. Conclusions and Future Work

This work aimed to present a proposal for the integration of the Virtual Learning Environment Moodle to the Ethereum Blockchain, through the creation of the BlockMoodle solution.

The proposal described in this work brought advances to the state of the art, as it presents a solution that allows integration between a virtual learning environment and a Blockchain platform. This solution will allow the secure recording of distance education data and will enable reliable verification of this data due to its immutable registration on the Blockchain platform.

To evaluate the proposed solution, a cost assessment was carried out, which shows the amount to be paid for the registration of each report on the Blockchain. The educational institutions can evaluate if the adoption of the solution is in line with their budgets or if a private Blockchain is more suitable. In addition, a performance evaluation was also carried out, and the obtained results indicate acceptable performance results.

As future work, additional performance evaluations of the proposed solution will be carried out, evaluating other metrics such as memory and CPU consumption and network usage. With this, it will be possible to verify possible bottlenecks in the system. It is also intended to carry out intrusion tests to verify the level of security offered by the solution. Finally, support for other possibilities of VLEs and Blockchain platforms is also planned.

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