Blockchain as a Learning Management System for Laboratories 4.0

https://doi.org/10.3991/ijoe.v18i12.33515

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Abstract—Remote laboratories have been developed at many universities worldwide to provide students with access to apparatus and experiments via the Internet around the clock, thus giving partner institutions the opportunity to share resources, expensive equipment and specialized laboratories, whether within a single country or at regional and international levels. Universities usually implement learning management systems (LMS) such as Moodle and Blackboard to enable students to interact, carry out learning activities and access remote labs. However, remote labs generate enormous amounts of data, which is stored, processed, analyzed, and accessed using centralized systems that lack transparency, traceability, security features, trustworthiness, and reliability. In addition, they are vulnerable to the single point of failure problem due to centralization. The application of blockchain technology in remote labs is proposed as a promising solution for future online learning as it combines a new pedagogical approach with various state-of-the-art technologies in an era that embraces Education 4.0 as the education norm. Furthermore, a novel blockchain-based framework for remote labs allows data streaming and transfer in a decentralized, transparent, traceable, reliable, secure, and trustful manner, where only authorized peers can join or access the network, thereby providing privacy of students' data files and reports. An initial pilot of an Ethereum-based remote lab show promising result for effective management of online experiments, originally hosted in a Moodle LMS.

Keywords—blockchain, remote labs, Engineering Education 4.0, Moodle, big data management, Ethereum, cyber-physical systems

1 Introduction

The world has witnessed a fusion of several emerging technologies at the turn of the century that has ignited a fourth industrial revolution, which seems to sweep the planet with excitement, uncertainty and careful expectations. The new revolution has actually blended the physical, digital and biological worlds in a way that has never been experienced before. Artificial intelligence (AI), robotics, Internet of Things (IoT), 3D printing, drones, cloud computing, augmented reality, big data, blockchain, nanotechnology, new materials, genetic engineering, quantum computing, and other technologies, have become effectively amalgamated with the internet and mobile devices to form new physical-cyber systems, which are expected to shape the future and have profound implications on individuals, industries, institutions, countries and even international relations [1]. One of the most crucial issues of the fourth industrial revolution is its creative disruption; replacing old jobs with new ones, and its possible impact on the labour market and the nature of skills and competencies needed for employment, as well as matters related to job and career choices, development, and counseling [2–3]. Accordingly, governments and authorities worldwide are acting promptly to adapt to the new revolution and adopt the emerging technologies to sustain development, improve services, and ensure good quality of life to citizens [4–5].

Educational institutes, universities in particular, bear the responsibility and have the potential to produce graduates ready to navigate the complexities of the new era by embracing Education 4.0; which fosters innovation and creativity, and retains the agility to respond to the ramification of Industry 4.0, where machines are interconnected and able to independently communicate and cooperate throughout the manufacturing and production processes. [6–8]. At the heart of Education 4.0 lies the blueprint for the future of learning where students expect learning experiences that reflect and enhance the way they live in the world, and where artificial and human intelligences interact through the symbiotic web to explore and create new possibilities [9].

Engineering Education 4.0 is particularly essential in realizing the vision of Industry 4.0 as it aims to enable engineers to effectively deal with digital technologies in a globally connected and technically driven world [10–11]. Modern virtual and remote labs have played a decisive role in articulating and presenting a new cyber-physical paradigm in education where physical experiments of several types and topics are monitored and controlled through software algorithms and simulation, thereby allowing dynamic interaction between the real and virtual worlds, thus forming a fundamental pillar of Education 4.0 [12–13].

In this paper, the application of blockchain technology in remote labs and cyber-physical systems is suggested as a decentralized management system that allows data streaming and transfer in a transparent, traceable, reliable, secure, and trustful way. In addition, an Interplanetary File System (IPFS) was employed to store and share the remote lab big data.

2 Evolution from Lab 1.0 to Lab 4.0

The first industrial revolution had a substantial impact on manufacturing, production and transport to a degree that has completely changed society and the human way of living. Education in particular was influenced by the new industrial innovations to the extent that contemporary schools and universities were designed based on the factory model. Specifically, engineering education at universities was established because of the first industrial revolution as demand for skilled labour and engineers grew rapidly. The trainer-trainee model for disseminating technological mastery in workshops was replaced by a systematic knowledge-based approach taught at universities, polytechnics, E´coles and applied science institutions. Consequently, acquiring practical skills shifted from the model of conducting primitive single-experiment set up performed by individual scholars to test a specific phenomenon to new laboratory paradigm, which became a fundamental pillar and a core component of engineering education [14]. The first recorded experiment goes back as far as 430 BC when the Greek philosopher Empedocles used clepsydra, a device for conveying liquids from one vessel to another, to prove that air is a material substance. On the other hand, the Danish astronomer Tycho Brahe (1546–1601) established the first laboratory in the late 16th century at Uraniborg research centre [15]. However, the first university to establish a laboratory for teaching and research purposes was University of Giessen, Germany at the hands of Justus Liebig (1803–1873), who conducted empirical research in chemistry and the natural sciences in the 1820s. Other universities followed the model that may be termed lab 1.0 in the era of education 1.0. German-speaking institutions dominated Lab 1.0 and its spread to universities within Europe was not a uniform and one-dimensional endeavor but rather a multi-faceted process of transportation, transfer, adaptations as well as translation, which occurred on various levels of language, instruments and experimentation procedures [16].

The second industrial revolution, which started in the mid-nineteenth century until the end of WWII, witnessed the invention of electricity, steel, mass production and a host of other major advancement that brought with it numerous instrument, devices tools, equipment, apparatus, appliances and standardization. A comprehensive industry was established to manufacture and provide solutions to quality testing laboratory equipment and accessories in pure and applied sciences and engineering that meet a set of international standards. Consequently, teaching and research laboratories experienced major improvements and progress, which enhanced the learning processes significantly, giving rise to lab 2.0 in the era of education 2.0. In fact, lab 2.0 flourished in a period when university curricula was well-developed with officially sanctioned undergraduate and graduate degrees and disciplines, and demand for specialized jobs and technical professions, inside and outside of academia were in high demand. In addition, the professional norms of academic science and engineering had become firmly established and the group rather than the individual was the operative entity in lab 2.0, both for research practice as well as for education and training [17].

Lab 3.0 emerged with the advent of the third industrial revolution which began with the invention of the transistor and reached its climax with the wide spread use of the Internet at the end of the 20th century. Meanwhile, new engineering and science programs and topics emerged in the era of education 3.0, which contributed to the increasing internationalization of universities and motivated by the rise of accreditation agencies. In fact, education witnessed a major transition towards a new paradigm where the teaching and learning processes were supported by communication and information technologies that dominated the global landscape, spearheaded by online learning, and remote labs in particular [18]. Consequently, remote laboratories have become increasingly popular all over the world because they allow students to conduct experiments via the Internet with 24/7 access, and open up opportunities to share expensive equipment and apparatus with other institutions instead of each institution duplicating, developing and running the same laboratory [19]. The first remote lab successfully implemented via the Internet was developed at the University of South California around a system that allowed tele-operation an industrial robot manipulator via the WWW [20]. A great many remote labs have been developed in the last two decades that cover almost all scientific and engineering disciplines all over the world. Different types of architectures, programming languages, technologies, modalities and learning management systems were employed in running and administrating these remote labs [21–22].

The fourth industrial revolution brings with it the notions of industry 4.0, education 4.0 and lab 4.0 where humans, technology, man, and machine may be aligned through the integration of real and virtual worlds to enable entirely new possibilities [23]. Lab 4.0 is mainly focused on providing a closer experience to real environments by utilizing emerging technologies such as artificial intelligence, virtual and augmented realities, data analytics, IoT, 3D animation to provide the best environment for practical training, educational skills, assembly industry and real time tutorials as well as remote collaboration. In fact, lab 4.0 may help in moving engineering education in the direction of a just and equitable access for all if technologies are sensibly interwoven with contents and applied throughout the teaching-learning processes at universities as well as lifelong learning [23].

3 Traditional remote lab data management systems

The general architecture of a traditional remote lab is based on client-server structure deployed using different methods of integration into a common framework that offers login access, file sharing, indexing facilities as well as running the experiments. The main choices of such integration include a control dashboard, virtual learning environment (VLE) [24] and grid technologies [25]. Moodle is one of the most popular open-source platform that has been extensively implemented as a learning management system (LMS) of remote labs to allow students to access the experimental hardware [26]. In fact, Moodle actually contains powerful features, mainly ease of use for a large community of users and the availability of tools for administrative, assessment, tracking, and accommodating remote practical laboratory sessions. The platform itself operates under an open source Apache web server based on PHP language and MySQL database. Certain plugins support the platform along with other software tools to manage e-content, virtual classrooms, assignments, task submissions and grading, quizzes, exams, tasks queue, lab booking, and scheduling online experiments [27].

Remote students manipulate the physical devices through the Internet, usually located at the university premises. Two servers are commonly employed in the remote lab system; one controls the lab equipment and the other links the set up to the Inter-net for student's access as shown in Figure 1. Another server may be implemented for the purposes of hosting multimedia tools, as an example [27]. The linking server acts as a middleware for the remote lab to handle all client requests by sending back values of experimental parameters and sensor readings or other information to the web clients. In addition, the linking server assumes responsibility of acquisition and control loop tasks. The laboratory deployment also includes IP webcam pointing to the physical devices, usually used to provide students with real-time video images and a visual feedback of what happens in the laboratory.

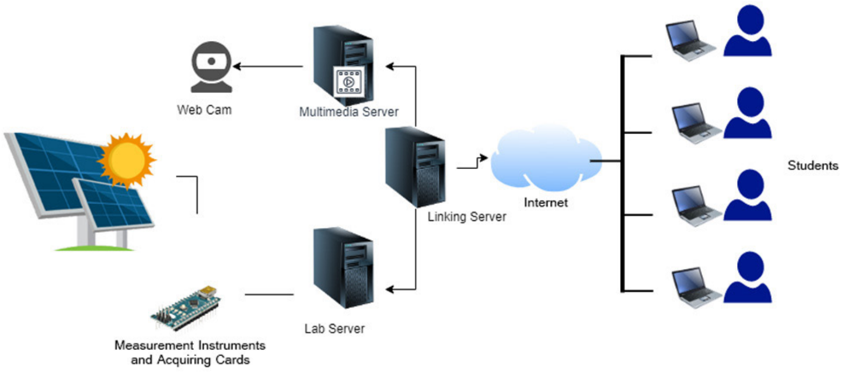


Fig. 1. Traditional architecture of a remote lab integrated into lms with a scheduling system

The server that hosts the Moodle VLE serves the remote lab clients applications such as scheduling procedure needed for managing and arranging the connections of students to the experiment. The data is read using web service, selected for its characteristics as a universal technology, cross-platform, non-intrusive, and low bandwidth usage [28]. The graphical user interface (GUI) was designed using Java, HTML, CSS and web service technology to create interactive simulations for teaching and learning purposes. Three simple RESTful web services were employed in the design, one dedicated to the laboratory instuments and hardware, the other to transmit data from its sensors, and the last to monitor the laboratory status. The RESTful web services facilitate request management using AJAX technology from any website or programming language. In addition, data is formatted using JSON instead of XML to reduce the required bandwidth during the transmission of information. Moodle consequently allowed for easy and smooth administration, documentation, tracking, and reporting of remote experiments. Furthermore, the lecturers may offer a complete e-learning solution including conducting experiments with relativly simple management and interactivity [29].

The administrator of the VLE initially installs scheduling plugins, defines the laboratory and its corresponding experiments, enrolls eligible students and register their records in the Moodle database, thereby granting them access to conduct the remote lab experiments. In addition, the administrator creates experimental activity modules, configures the experiments parameters and monitors the performance of the students during the activity. Furthermore, the administrator prepares the environment for the student to book a free session to conduct the experiment by clicking on a table containing all available experiments. A new window appears showing all corresponding free time slots for that particular experiment by clicking a “book” button. The sequence of steps of the selection procedure is shown in the flowchart of Figure 2. This scheduling scheme offers students the opportunity to avoid long waits for a free time slot as the system computes all possible sessions according to the experiment restrictions and the selected date.

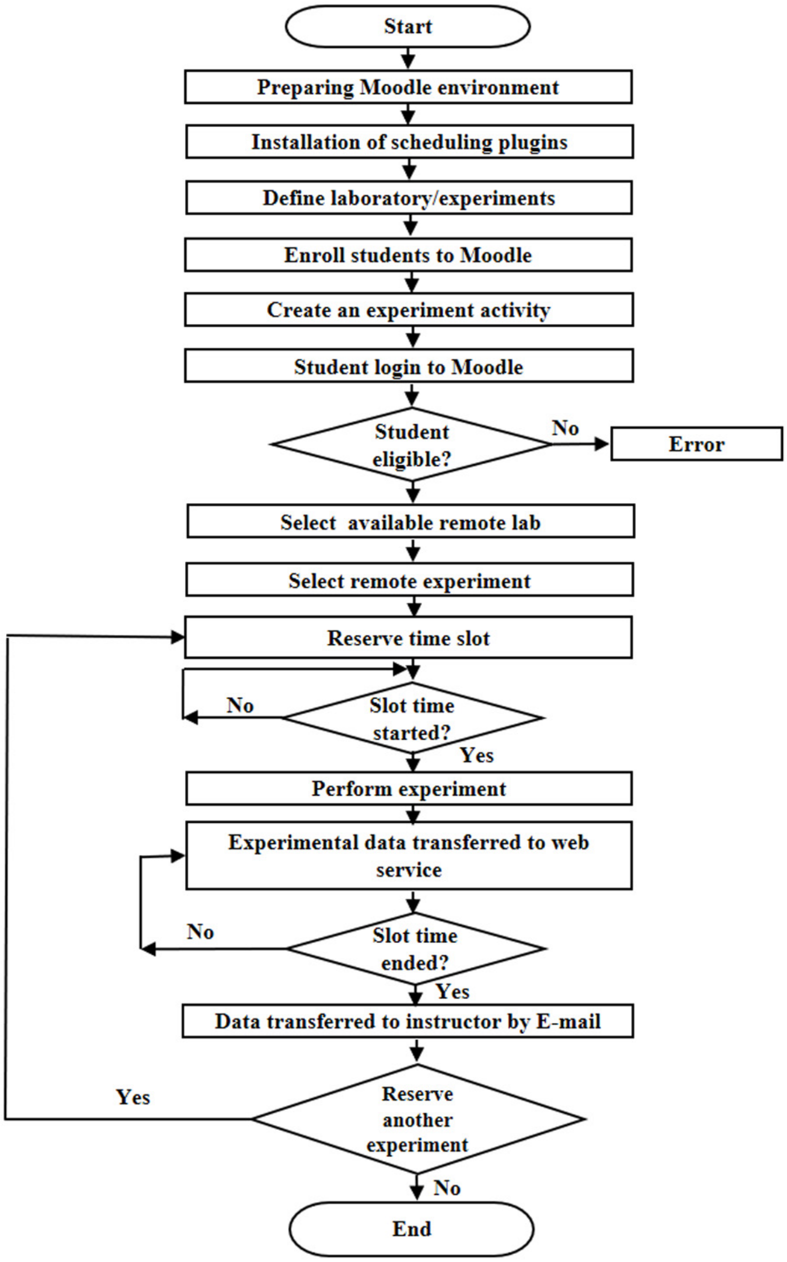


Fig. 2. Flowchart of design of the Moodle platform

The scheduling plugin shows two tables, one contains the data correlated to the laboratory, and the second lists the registered experiments as shown in Figure 3. On top of the administration page, three functions are added, the first includes the addition of a new laboratory by opening a form in order to register into Moodle. This is the first step when adding a new experiment to the platform. The second function is the facility to insert the new experiment itself by opening another form in order to fill in the appropriate information pertaining to the experiment. The last function enables the administrator to view and observe a table comprising all sessions to help monitor all plugin activities. The session page has several status tasks such as pending, running, finished sessions, as well as time out or unused, in addition to the possibility of deleting sessions, which is a useful added-value if an activity is no longer required in the course. Therefore, the administrator can recover the data of the sessions for instructors. On the other hand, concurrency is controlled by the plugins as the system allows only one active session at a time per experiment.

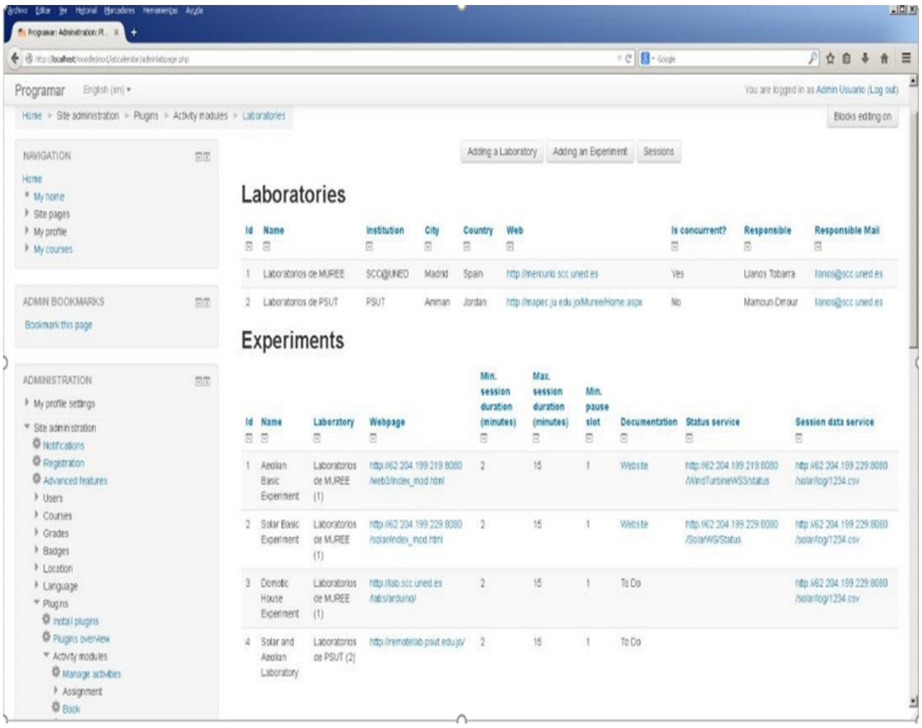


Fig. 3. Remote lab scheduling plugin administration view

The student accesses the experiment webpage directly to conduct the experiment. When the session starts, a special window appears showing documents and services such as experiment description, instruction sheet or manual, slide presentation, as well as equipment live stream through the webcam. Every experiment points to a URL of the webpage where the hardware setup is controlled. In turn, the experiment provides back another link that shows its status which may include any possible errors in the hardware or if there is an already running session. Other parameters include a web service link for the experiment to retrieve a file with the results, and details of minimum and maximum duration of a session. These limits determine how long an instructor can configure the experiment sessions in the courses. The administrator may also create a pause gap between experiments with a minimum time for each lab specified but instructors may change. A timer is designed to indicate to the student the minutes left of the session is also designed. Furthermore, a button to download student experimental data is included. In addition, a copy of the experiment data will be saved in the private file area of Moodle. The GUI of the experiments and a live webcam streaming are then displayed as shown in Figure 4.

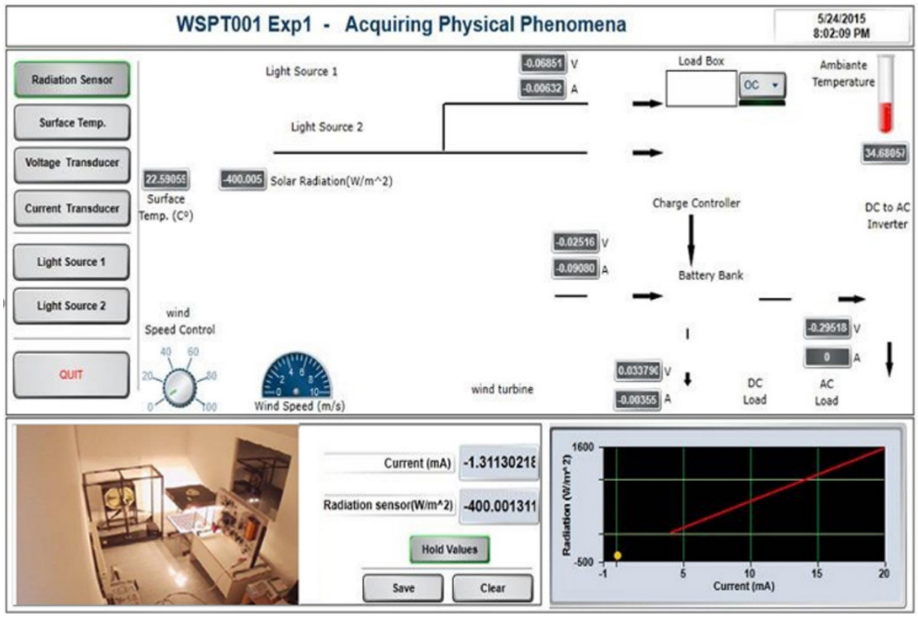


Fig. 4. A pilot renewable energy remote lab homepage

Students may make sure that the hardware platform responses to the user interface controls and changes of the values through checking the webcam live streaming. At the end of the experiment and before finishing the session, students also check that everything is performed correctly and allow for a proper time to download the results by clicking the save button which generates an excel file that may be downloaded. Students then analyze the results and finally submit to the instructor onto Moodle or by email.

4 Proposed blockchain-remote lab system

Blockchain is decentralized, distributed and public digital ledger that forms a network infrastructure able to organize information securely as it creates trust by acting as a shared database, distributed across wide peer-to-peer networks that have no single point of failure and no single source of truth. No individual entity can own a blockchain network or modify the data stored unilaterally without the consensus of all peers. New data may be added to a blockchain only through agreement between the various nodes of the network, a mechanism known as distributed consensus. Each node of the network keeps its own copy of data, which cannot be changed without agreement by other nodes [30]. The blockchain actually stores the data in a chain of blocks connected via encryption techniques to preserve the integrity of information and to verify transactions through a mining process. Every time a new block is appended to the chain, a miner who solves a certain mathematical riddle is rewarded with a pre-defined amount of crypto coins. This mining process, termed Proof of Work (PoW) requires other miners in the network to check the validity of the results before the consensus is reached [31].

The traditional framework of Ethereum private blockchain, shown in Figure 5, provides a platform to run smart contracts used to facilitate storing important data in a distributed ledger. In addition, smart contracts allow data storage via variables such as mapping or arrays with structs [32]. The integration framework shows the relation between the web applications and the Ethereum private blockchain network, which is applied to support remote lab data management and each university can have its own web and databases server, and consequently connects to the same blockchain via the web3.js, API and Geth client. In fact, Geth client is utilized in setting up the node, access the chain, and participate in transactions [33].

When the private blockchain is ready, the next step is to program the web application to communicate and interact with an Ethereum node using HTTP. Web3 application programming interfaces (API) support different programming languages such as JavaScript, Python and PHP. The library web3.js, which was the first API developed, defines the rules and formats of how blockchain data should be exchanged between web3.js and Geth. The web3.js HTTP request triggers a procedure to execute the smart contract remote Ethereum node [34]. The JavaScript application does not interact with the blockchain directly, rather it communicated with one Ethereum node, which in turn interacts with the blockchain.

The key concept of integrating management information systems with blockchain has recently been introduced in order to enable business enterprises to store records and data securely and serves as a single source of truth for the enterprises and across the supply chain [35]. A framework of integrating traditional Web 2.0 applications with Web 3.0 blockchains was also proposed, which highlights the main software technologies required for the implementation in applications and business processes such as the libraries that are required to connect the web application to the platform node [35].

A new framework is proposed to replace Moodle with blockchain to run and organize the remote lab. The framework is divided into three layers as shown in Figure 5, the front-end, the back-end, the Ethereum platform and its associated IPFS. The front-end consists of the data management system dashboard, which is developed and designed using python, JQuery and JavaScript. The dashboard has the responsibility of multiple operations such as user login, lab experiments scheduling, and experiments data upload to the blockchain and IPFS. In addition, the dashboard facilitates the connection to the blockchain environment using MetaMask browser extension. The back-end, on the other hand, consist of Web3.js library, which acts as a middleware for data flow from the front-end to the blockchain environment, data encryption/decryption, and MySQL database, which contain users information. The third layer forms the blockchain environment, which consist of the private Ethereum network and IPFS servers.

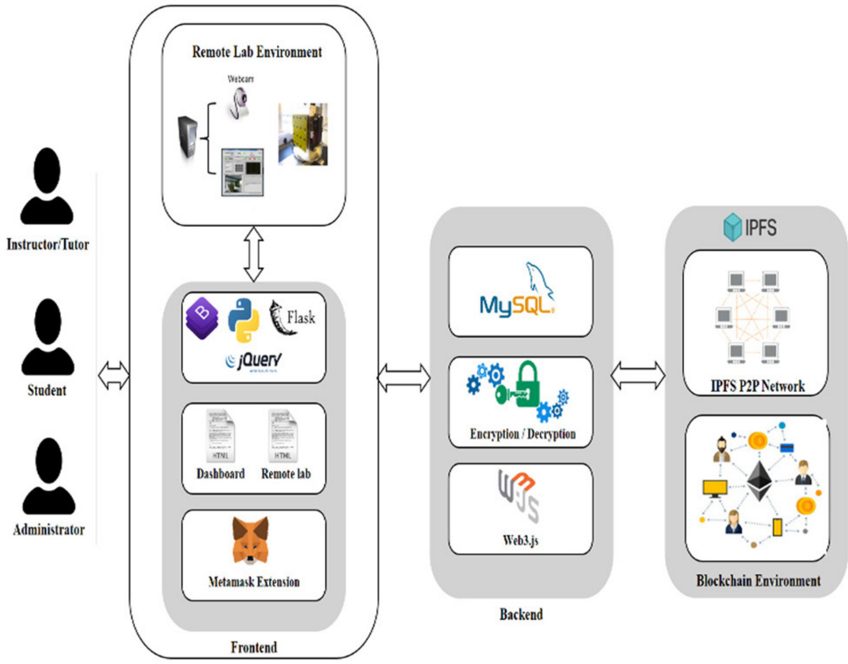


Fig. 5. Proposed blockchain-based remote lab management system

The flowchart of Figure 6 illustrates the process of the remote lab management system, which commences in preparing the Ethereum blockchain environment to run on local servers and other dedicated to IPFS. The first step in the process was setting up the Ethereum node, web-server applications and MySQL database server. In the second step, the dashboard was developed using several programming languages including HTML, CSS, JS, and Python to communicate and interact with the Ethereum nodes using HTTP. In addition Remix Integrated Development Environment (IDE) was utilized in the development and deployment of the learning management system due to its built-in solidity compiler to generate machine-level bytecode that can be executed by the Ethereum node, in addition to its capability to supports testing, debugging, and deploying of smart contracts [36]. As such, the smart contracts execute transactions in trustable, secure, and automated fashion. After the private blockchain was prepared for integration, multiple Ethereum nodes running Geth were deployed, and the decentralization of the chain was enabled. Hence, the data generated from experiments is distributed across every device connected to the blockchain.

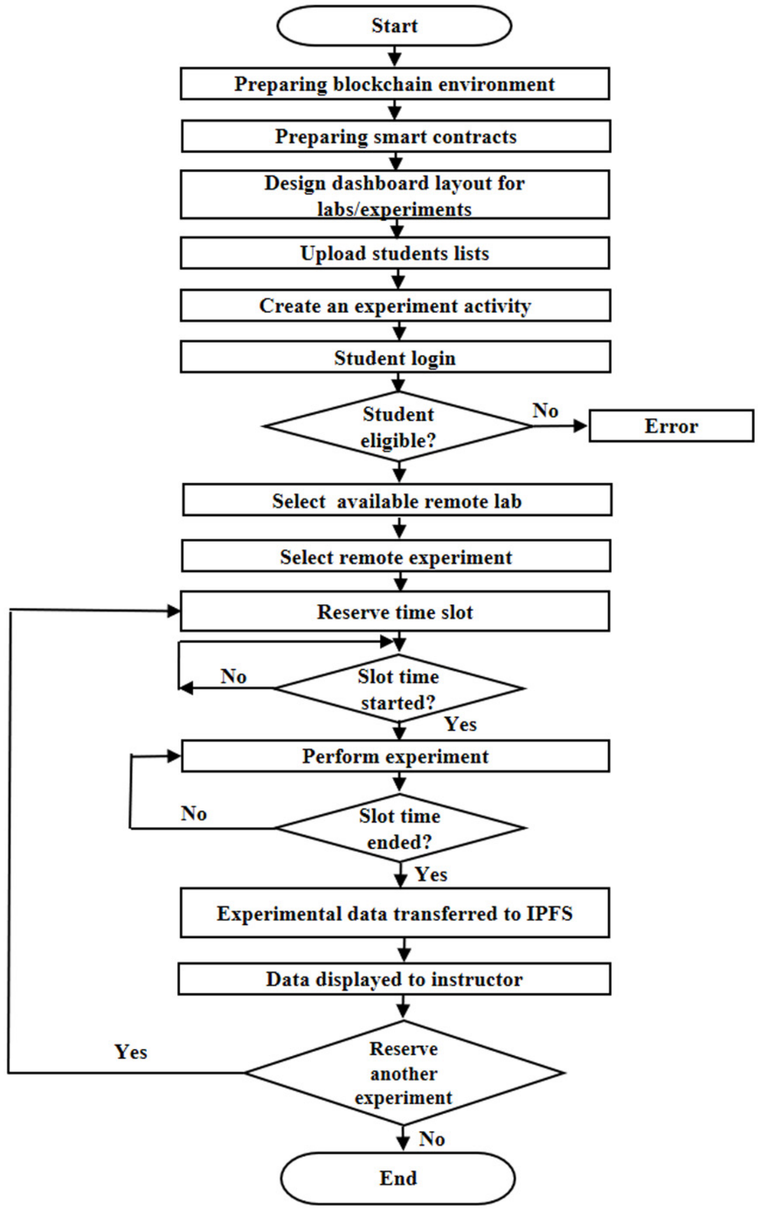


Fig. 6. Flowchart of design of the blockchain learning management system

The third step was to read the information of students from the server of the university registration unit by either uploading an excel sheet containing all necessary details of each students, or directly from an online web service. In fact, the registration unit should prepare complete lists of registered students with information that includes details such as name, number, specialization and others. The list is uploaded to a secure MySQL database server created by the administrator. Geth, meanwhile, creates accounts in the trail version, in the form of a public hash key containing 42 hex characters, and a private hash key of 66 hex characters. The public key is assigned to the student as an anonymous identity equivalent to the student credentials, while the private key is used to access the system the same way as a password does. The student then receives an amount of ethers, the Ethereum currency. The account then enables the student to connect to the Ethereum platform via MetaMask extension within the browser in the remote lab data management system, with the private key as the identifier. The student is considered eligible if found in the registration students list, otherwise an error message is displayed. Meanwhile, the administrator arranges the remote lab list and the corresponding experiments in a dashboard with attributes comprising details such as experiment name, duration, URL, and data web service link.

Once the student accesses the dashboard home page in the user client side using the private key, the smart contract will check the available remote experiment in the appropriate lab, to reserve sessions within a given time slot. Once the time slot is reserved, and the student begins conducting the experiment using the instructional manual, which is uploaded to the experiment page, the smart contract approves the transactions and stream the experimental data. This process continues until the experiment time is over, the solidity mapping array accommodates for the streamed data which may then be transferred as an excel file to IPFS location for proper recording and archiving. When the instructor/tutor requests to grade a lab report of specific student, the details of the student is retrieved from the MySQL server and the corresponding experimental data is retrieved from the blockchain mapping array and IPFS simultaneously.

5 Results and discussion

The proposed data management system for remote lab was piloted on a renewable energy lab consisting of solar cells and wind energy turbine. The lab was programmed in LabVIEW graphical language installed in the web server, and enabled by a programmable automation controller to run the experiments. Wind and solar photovoltaics power is a sample of the labs, where students learn the characteristics of solar photovoltaic panels and wind power generators, and enable them to monitor data such as the output current, voltage and power from solar photovoltaic panels and wind turbines. In addition, they will be able to measure temperature, wind speed, battery voltage and load current. The experiments covered topics such as load box and parameters configuration, measuring IV characteristics curve of the solar photovoltaic module as well as measuring the current by incidence angle and distance [37].

The smart contract, shown in Figure 7, is an example that shows how to create students' records on the blockchain. A structure named StudentInfo is defined, which contains the main data to be recorded such as student name, ID, lab number, experiment name, hash of the uploaded student streamed data file provided by IPFS, timestamp of the block which records the estimated time when the student streamed data file was uploaded. The smart contract contains two main functions, the first is setHash, which takes parameters such as hash string of the student streamed data file which represents a public function that can be called from outside the contract, and the second is experimentInfo, which is invoked when a new record is created. As the function only submits the transactions to the blockchain, therefore, the results are not shown until transactions is mined and included in the blockchain. For each new transaction, it is necessary to pay a fee in ether required by 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.

```
Untitled-1

pragma solidity ^0.8.0;

contract RemoteLab{

  struct StudentInfo{
        address user;
        uint stuid;
        string stuname;
        uint labno;
        string experimentname;
        string filehash;
        uint timestamp;

    }

  File[]  files;

  function setHash(string memory _fileHash,string memory _desc) public{
        files.push(File(msg.sender,totalFiles,_fileHash,block.timestamp,_desc));
        totalFiles++;
  }

  function getAllFiles() public view returns(File[] memory) {
        return files;
  }
   mapping(uint256 => File) public files;

    struct File {
        uint256 fileId;
        string filePath;
        uint256 fileSize;
        string fileType;
        string fileName;
        address payable uploader;
    }
```

Fig. 7. Source code of the implemented smart contract

Another smart contract was written to arrange for session booking as illustrated in the snapshot of Figure 8 where the available time slot is booked by students as shown on the right side of the calendar by clicking the "book" button. The booked sessions may be updated and deleted by student and the system administrator.

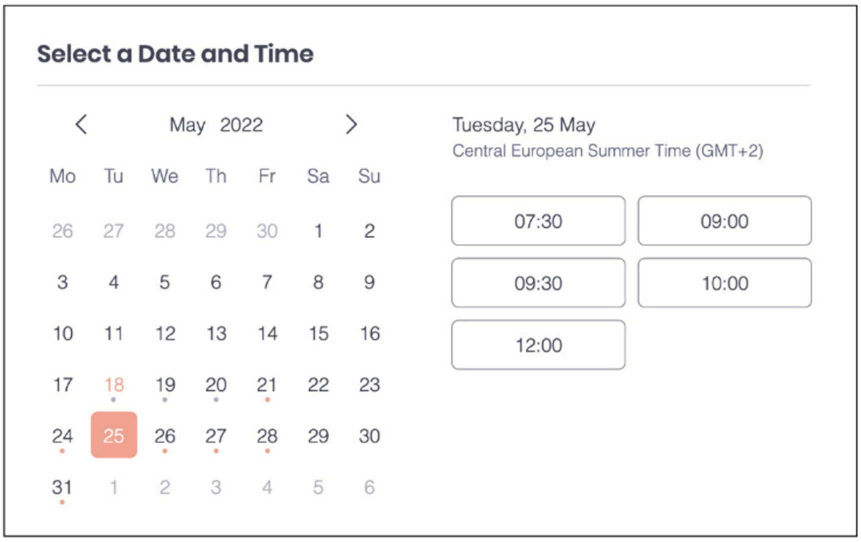
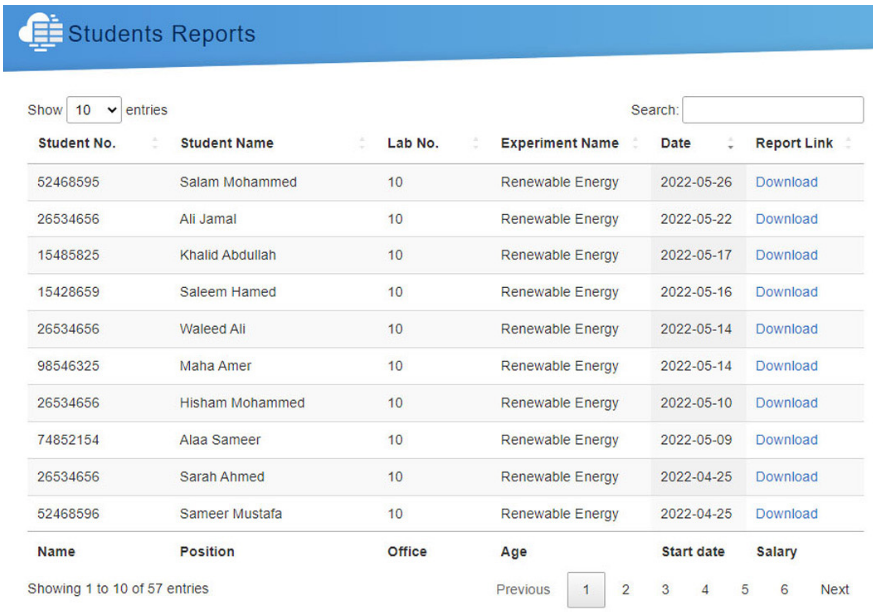


Fig. 8. Students' scheduling scheme

Once students perform the experiment, their reports are retrieved from the blockchain and IPFS and then listed in a special page as depicted in the snapshot of Figure 9. The list includes the university number and name of student, lab number and experiment name, date and the report itself. The instructor may consequently access and view all submitted reports and hence download students information and experiment data files for grading.



Students Reports

Show 10 entries Search:

Student No.	Student Name	Lab No.	Experiment Name	Date	Report Link
52468595	Salam Mohammed	10	Renewable Energy	2022-05-26	Download
26534656	Ali Jamal	10	Renewable Energy	2022-05-22	Download
15485825	Khalid Abdullah	10	Renewable Energy	2022-05-17	Download
15428659	Saleem Hamed	10	Renewable Energy	2022-05-16	Download
26534656	Waleed Ali	10	Renewable Energy	2022-05-14	Download
98546325	Maha Amer	10	Renewable Energy	2022-05-14	Download
26534656	Hisham Mohammed	10	Renewable Energy	2022-05-10	Download
74852154	Alaa Sameer	10	Renewable Energy	2022-05-09	Download
26534656	Sarah Ahmed	10	Renewable Energy	2022-04-25	Download
52468596	Sameer Mustafa	10	Renewable Energy	2022-04-25	Download
Name	Position	Office	Age	Start date	Salary

Showing 1 to 10 of 57 entries

Previous 1 2 3 4 5 6 Next

Fig. 9. Blockchain page for retreived students' experimental reports

Blockchain was chosen as a learning management system for wide range of users due to its distributed nature that makes it robust against hacks and prevents single point of failure. If a failure does occur, each network node possesses a complete copy of data, which is never lost, unlike Moodle that is built on a centralized server. In addition, private and public keys encrypt the blockchain-distributed database, which makes it more secure than any other open source application like Moodle. In fact, Moodle is not fully developed to cope with bigdata that allows users to obtain information quickly and with high privacy and transparency. On the other hand, building private Ethereum blockchain network to execute transactions and build smart contracts without the need for real ether, thus reducing transaction cost.

An application for a virtual lab based on blockchain technology for instrumentation and measurements has recently been developed using LabVIEW [38]. The proposed lab performed both simulation and the data in a local blockchain private wallet. In addition, attempts to create a security system for remote FPGA lab are currently ongoing through a collaboration project between the University in Montreal, Canada and the Federal University of Santa Catarina, Brazil, with the aim to deliver a functional platform with standardized security processes based on blockchain techniques [39]. The primary focus of the project is to develop a secure and accessible control system based on Ethereum by adding a third verification process to an initial authentication and authorization processes in order to enhance the security of remote experimentation. [39]. Furthermore, a solution to developed and integrate Moodle with Ethereum was introduced recently in order to bridge the gap between bigdata and blockchain platforms. A performance evaluation of the proposed solution was carried out considering different usage scenarios [40]. Furthermore, the application of blockchain in e-learning framework with an integrated LMS to safeguard the university-distributed repository was also proposed [41]. The system consisted of material, question and assessment banks that allow for safe storage and verification of certifications everywhere, thereby showing how to develop a large-scale distributed system based on a private blockchain model programmed in PHP and Google Firebase [41]. The proposed blockchain-LMS for Lab 4.0 complements all above efforts to integrate blockchain in technology-enhanced learning.

6 Conclusions

Blockchain technology has become an important tool in the management process of data generated by various ecosystem in a secure manner. A novel Ethereum-based learning management system for remote labs that easily allows data streaming and transfer in a decentralized fashion was developed to showcase the potential of blockchain in the management of bigdata generated by remote labs in transparent and secure ways while ensuring privacy of students' files and reports. The pilot Ethereum-remote lab show promising result for effective management of online experiments, thus extending the horizon of engineering education to accommodate a new generation of labs or Lab 4.0. Combined with MOOCs and other emerging technologies such as augmented reality, bigdata, 3D printing and machine learning, a new pedagogical paradigm will eventually lead to Education 4.0 as the education norm where lecturing and lab experiments over the internet offer opportunities for decentralized, transparent, traceable, reliable, secure, and trustful life-long learning.

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Article submitted 2022-06-21. Resubmitted 2022-08-02. Final acceptance 2022-08-02. Final version published as submitted by the authors.