EtherLearn: Decentralizing learning via blockchain

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***Abstract*— In institutes of higher learning, most of the time course material development and delivery follow a centralized model which is fully lecturer-controlled. In this model, engaging students as partners in learning is a challenging problem as: 1) students are usually hesitant to contribute due to the fear of getting it wrong, 2) not much incentive for them to put in the extra effort, and 3) current online learning systems lack adequate facilities to support seamless and anonymous interactions between students. In this work, we propose EtherLearn, a blockchain based peer-learning system to distribute the control of how course material and formative assessments could be developed and delivered over the set of stakeholders in the particular course. EtherLearn leverages features of the rising blockchain technology, e.g., decentralization, anonymity, transparency and security to address the aforementioned concerns in university learning environments. To this end, we have successfully implemented a proof of concept for EtherLearn based on the Ethereum blockchain network. We have also conducted preliminary evaluations to demonstrate that it can be useful in decentralizing learning resource creation and student sharing in an encouraging teaching and learning environment.**

***Keywords—blockchain, Ethereum, learning resource development, formative assessment, decentralization*.**

I. INTRODUCTION

Traditional course development and delivery in institutes of higher learning (IHL) follows a centralized model, which is carried out and controlled by the lecturers of the course. In particular, the lecturers design the learning material, deliver the lectures/tutorials, conduct assessments, and assist with queries from students. In this model, engaging students as partners in learning is challenging, since students can be hesitant to contribute as they are usually afraid of getting it wrong, and there are not much incentive for them to put in the extra effort. Last but not least, current online learning management systems (LMS) used at many IHLs [1-3] lack adequate facilities to support seamless, incentivized and peer-to-peer interactions between students. For instance, based on our observation, online discussion forums in university-controlled LMS [4] usually do not attract much student participation due to the lack of incentives. Popular questions & answers (Q&A) sites such as StackOverflow have been useful; but they are not designed for any specific classes taught in the IHLs; thus are not able to offer tailored help for students.

In this work, we propose and develop a peer-to-peer learning system, named EtherLearn, in which students could be truly active contributors and owners of the teaching and learning process. The first iteration of this project focuses on computer science courses, but extensions to other courses are possible. The proposed system leverages the rising blockchain technology, e.g., Ethereum [5], to decentralize and incentivize learning resource development and formative assessments. In particular, EtherLearn provides a peer-learning system which serves the following purposes:

Student-contributed learning resource. To enable students to continuously contribute knowledge, curriculum feedback, learning resource, etc. with anonymity and on a consensus-based manner. For instance, students can submit their code, slide animations, etc. to explain a particular concept in the course. A blockchain-based consensus protocol, e.g., one that favours the most voted contributions, enables such content to be recorded into a public, distributed database, and the contributors rewarded.

Student-centered formative assessments. To enable formative assessments in a decentralized and peer-to-peer manner, i.e., such assessments can be conducted by any students in the system. The anonymity nature of a blockchain-based system encourages participation and to-the-point qualitative feedback which enables further learning. Furthermore, student-designed assessment tasks could carry perspectives which might not be obvious to lecturers. Similarly, we can design appropriate incentives or disincentives to prevent poorly designed assessments which may come from any of the participants.

Incentivized student contributions. To create lasting incentives and recognitions that students can carry further into their employment life and beyond. One of the problems when engaging students as partners in learning is the lack of motivation and incentives [6]. In EtherLearn, a quality contribution in any forms would be rewarded with digital tokens or cryptocurrencies which are valid in the system. Even when the students are no longer with the institution, such rewards/tokens could still be easily accessible, and moreover verifiable by HR/recruiters, thanks to the blockchain-based design which provides replication and irreversibility of recorded transactions. In the longer term, this incentive system could even be used to maintain the verifiable records of students' graduation qualifications and certificates [7].

This paper makes the following contributions:

- We conceptualize and design the EtherLearn web application based on the popular Ethereum blockchain to enable seamless student participation, and to incentivize learning resource development for specific courses in the curriculum of an IHL.
- We implement a fully functional prototype of EtherLearn with Solidity smart contracts for the back-end, and Javascript for the web front-end. The application has been successfully deployed on Amazon Web Services (AWS) and the Rinkeby Ethereum test network for performance study and user evaluation.
- We conduct preliminary evaluations in performance testing, and user experience study with a focus group

of computing students at our university to evaluate the usability of EtherLearn, and to gather student feedback for further improvements.

The rest of the paper is organized as follows. Related work is discussed in Section II. Section III describes the EtherLearn's pedagogy-informed approach, and its system design. Implementation details are reported in Section IV. Section V presents evaluation results; and Section VI concludes the paper with plans for future work.

II. Related Work

In this section, we review relevant research in the context of online learning systems usually employed in IHLs, as well as publicly available online resources to support student learning. Finally, recent work in blockchain based educational systems are discussed.

IHL learning systems. LMS solutions developed by Blackboard, Moodle and Canvas have been widely deployed in IHLs [1-4]. These systems provide students with learning resources in the form of lecture sides, video recording, discussion forums, online quizzes, etc. to support their learning. However, it does not mean that learning can occur effectively just by having a LMS in place [4]. We have identified a few gaps in these systems. First, they are centralized systems maintained by educational institutions. Such systems require much effort and financial resource in maintenance and up-keeping. It might not be straightforward to ensure properties such as anonymity, distributed persistency and tamper-proof of learner-contributed content in existing LMS. Second, current centralized learning systems in IHLs, while can be effective in a lecturer-controlled setting, lack facilities for student to contribute actively and easily to courseware development, or course delivery. Last but not least, we note that such centralized systems lack mechanisms to motivate students to participate in the process of co-creation of knowledge, as there are basically not much incentive for them to spend the extra effort.

Public learning systems. Many students in computer science make use of online resources such as Quora or StackOverflow to clarify doubts and to find solutions to their programming problems and project work [8]. StackOverflow is basically a web app designed for anyone to contribute their knowledge on computer science and IT topics by posing and answering questions. It has a reputation system which rewards users with quality contributions (each question or contribution could be voted by users). The content of such systems is not tailored to the need of students in a specific IHL course. In addition, we note that such a centralized system may not be suitable for IHLs for several reasons: 1) it is not straightforward for outsiders, e.g., HR department or recruiters, to verify the actual contributions of users - most of the time, users have nicknames which could not be mapped reliably to real-world identities; and 2) significant expenditure is required to maintain the system over the long term.

To complement traditional LMS, many lecturers including the authors of this paper use publicly available interactive questioning tools like Kahoot [9] and Wooclap [10] as a way to conduct continuous, formative assessments [11] throughout the duration of a course. However, we as lecturers lack the student's perspectives. Therefore, active contributions from students in the course are of critical importance. This enables the lecturer to design or tweak increasingly difficult versions of the same assessment task, which could be originally proposed by students, so that learning can happen at a more gradual and effective manner. In fact, recent research has demonstrated that working on a modified version of the same task over time leads to better learning outcomes compared to doing the same thing repeatedly [12].

Blockchain in education. Blockchain is a type of distributed, public ledger that was introduced in the seminal work of S. Nakamoto [13] when he created the first blockchain network for the cryptocurrency bitcoin. A blockchain based system would exhibit the following properties which make the technology attractive to a wide range of applications: 1) the distributed ledger is publicly visible, persistent, and tamper-proof, so it is easy to verify records or claims of contributions; 2) the data is distributed over all participants, thus it does not require the provision of a centralized authority or centralized server infrastructure; and 3) monetary incentives could be facilitated in the forms of cryptocurrency or tokens which are implemented and transacted on the blockchain system.

Blockchain applications are most seen in finance, supply chain management, healthcare, distributed optimization, etc. A recent comprehensive survey of such applications can be found in [14]. Over the past few years, there have been several attempts to make use of blockchain for educational applications [15-17]. Most of the existing work concern the use of blockchain to store educational credentials; and to verify transcripts and certificates. To the best of our knowledge, there has been no blockchain based systems implemented specifically for the purpose of course material development and peer learning. Blockchain makes it possible to implement various incentive mechanisms to reward learning [6]. In this work, we go one step further by using blockchain based credentials to encourage students' active participations in the teaching and learning process.

Summary. We note that most IHLs adopt a centralized, lecturer-controlled model when it comes to curriculum design, learning resource development, and assessment. In such a model, it is hard to introduce incentives for student participations as learning partners. Public Q&A websites such as StackOverflow and Quora do not cater to specific course content delivered in IHL curriculums; and they require centralized maintenance and control. The education sector has just started to apply blockchain mainly to store and verify educational credentials. Our work is different in the sense that we leverage blockchain to create a peer-learning environment which aims to encourage and incentivize curriculum-tailored learning material development; as well as student-centered formative assessments in an IHL degree program.

III. EtherLearn: Approach and Design

Approach. In computer science, it is not unusual to measure the life of knowledge on the order of months or even weeks. In such a dynamic context, it is frequently not possible for the lecturers to comprehensively cover latest developments in some particular courses. A peer-learning environment will enable the co-creation of content and other learning resources leveraging contributions of all learners in the community. EtherLearn aims to distribute the control of creating, sharing and validating learning resources over the set of all stakeholders in the particular course. In this way, students can truly be in charge of their own learning process. The approach of EtherLearn is two-fold:

Decentralizing learning material development. In a specific course, students are to continuously contribute knowledge, curriculum feedback, learning resource, etc. which will help others in the same course. For instance, in a computer programming course, students can answer questions from their peers by uploading their code, slide animations, algorithm analysis, and software configuration guides. EtherLearn provides blockchain-based tokens, e.g., ERC-20 token, to reward highly valuable contributions via a voting (rating) mechanism (shown in Fig. 1). On the other hand, a disincentive method can be implemented: students who submit irrelevant or spam content could lose their token deposit, or incur expensive blockchain transaction cost. Such blockchain-based recognitions are persistent, tamper-proof, and easily verifiable by external HR/recruiters, so students can carry them on their CVs even after graduation.

Enabling student-centred formative assessment. Due to the inherent anonymity and security of blockchain technology, EtherLearn can serve as an ideal platform to conduct formative assessments, i.e., continuous assessments designed to encourage learning. Formative assessment is usually compared and contrasted against summative assessment ; the latter aims to measure learning outcomes. In formative assessments, the lecturers or student peers would provide qualitative feedback, so that learners could reflect, apply and progress. EtherLearn can enable a wide range, i.e., varied in terms of standards, of assessment types (which could be posed by any students anonymously), solutions and feedbacks, which could be ranked, voted or highlighted by anyone using the same incentive mechanism shown in Fig. 1. In this way, EtherLearn complements and enhances the standard course delivery model by incorporating student-perspective assessment tasks to: 1) repeat and reinforce difficult concepts for weaker students; and 2) challenge better students for further learning and self-discovering of knowledge.

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1. Blockchain tokens distributed to students at
the start of the course.
2. Student A deposits N tokens when asking a
question.
3. Other students can vote for the question by
contributing additional tokens to the deposit.
4. Student B can upload learning material to
answer questions.
5. Answers to be voted by A and other students.
6. The highly voted answers get a share of
deposited tokens.
7. Questions can expire after a deadline, and
tokens returned to A if there are no good
enough answers.
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Fig. 1. Incentive mechanism in EtherLearn

Pedagogy. The EtherLearn approach has been informed by pedagogical strategies leveraging main ideas from the well-known constructivism [18] and the recently introduced connectivism [19] learning theories. There is a significant body of work regarding the constructivism theory, i.e., learning by doing. The theory suggests that we as learners build knowledge mainly via reflecting on our own experience. From the constructivist's point of view, learners must have interactions with their environment and accumulate experience in order to adapt and to learn. In this sense, EtherLearn provides such an environment in which students could be motivated to get more academic interactions with their peers and instructors in the subject, and to share their knowledge without fear of potential embarrassments when they make mistakes. The anonymity and consensus based protocol provided by blockchain technology enable a peer-to-peer, constructive learning space in which students would feel more comfortable to ask questions, explore, contribute, and reflect, i.e., to become active creators of their own knowledge.

The connectivism learning theory has been introduced recently [19]. In connectivism, it is argued that much learning can take place across connected peer networks. A lecturer would guide students to appropriate information sources and explain key ideas of the subject. Students could then go on to support learning and sharing on their own. In connectivist learning, building a network of knowledge for a particular subject is important, i.e., in addition to know-how, know-what, learners also need to acquire know-where, which is the ability to find the right sources to meet the knowledge requirement. This is particularly useful in the domain of computer science, due to the challenge of rapidly diminishing life of knowledge [19], e.g., such life could be measured in terms of months. EtherLearn implements connectivism by creating a community network in which participants could learn and share knowledge with each other in a non-threatening setting due to the blockchain's anonymity.

The connected community would help generate more learning resource, content and experiential environments along the way. This in turn encourages constructivist learning, as learners are increasingly provided with new opportunities to acquire experience. In this way, EtherLearn leverages the inherent synergies as well as complementary features of the connectivism and constructivism approaches. Recently, massive open online courses (MOOC) have become popular, effectively promoting the connectivist learning theory [20]. EtherLearn differentiates itself by employing blockchain to support a truly decentralized learning environment. This is in contrast with traditional web based MOOC platforms which are centralized, i.e., the degree of participation of learners in these systems is usually limited to Q&A forum posting and messaging.

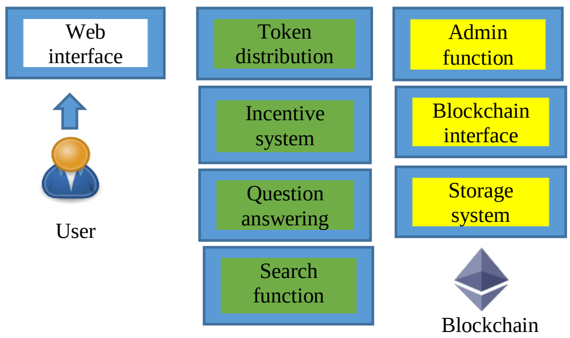

Fig. 2. System design and components of EtherLearn

Design. Fig. 2 illustrates the system design of EtherLearn, which has the following components: 1) Web-based interface for easy access by students and lecturers. 2) A token implementation and distribution mechanism to provide the basis of incentives in EtherLearn. The token, named ETL, is pre-minted with a fixed amount. Each system user will be given a certain amount of tokens free of charge before the start of the semester. 3) A question answering component is needed for users to post assessment questions, queries, contributed content, etc. This component will be interacting with the incentive system for facilitating the deposit and distribution of

ETL tokens as specified in Fig. 1. 4) A search function is necessary for users to find the content they are interested in. 5) The incentive system is a set of smart contracts implemented on the blockchain, e.g., Ethereum, to ensure the safe deposit and distribution of ETL tokens to users contributing learning materials to EtherLearn.

On the back-end side of EtherLearn, we have the following components: 1) The admin function is for lecturers or system administrators to make changes to the web interface, e.g., to add or remove courses. 2) The blockchain interface consists of mechanisms for connecting to the actual blockchain network, e.g., Infura nodes. 3) The storage system provides methods for storing large learning artifacts, e.g., documents, video, images, etc. efficiently with a peer-to-peer file system such as IPFS.

IV. Implementation

We implement a fully functional prototype of EtherLearn on the Ethereum blockchain. In this section, we describe the specific implementation details, including the ETL token, the smart contracts, and the learning incentive mechanism.

ETL token. EtherLearn introduces a native token named ETL, which follows the OpenZeppelin ERC-20 implementation for custom tokens on the Ethereum network. OpenZeppelin provides libraries and tools for secure smart contract development. ETL can be configured with an initial supply, and to be distributed to students at fixed intervals, for example at the start of each semester. Depending on the specific situation and funding availability from the IHL, we can actually assign a monetary value to ETL, i.e., it can be exchanged for a popular and valuable cryptocurrency such as ETH and vice versa. Currently, EtherLearn is deployed on an Ethereum test network (Rinkeby) and dummy ETH are used for testing.

Smart contracts. The incentive mechanism and question answering logic in EtherLearn are built with several smart contracts, written in Solidity, to handle question creation, token deposit, voting, reward sharing, user profile, etc. The smart contracts, once deployed, will be stored on the Ethereum blockchain with immutability. The web front-end will call functions implemented in these contracts for user to interact with the EtherLearn app. We briefly describe the most important contracts as follows.

QuestionFactory contract is instantiated only once upon app deployment. It provides key mechanisms for interacting with the front-end web app. It has a wrapper function named *createQuestion* which is called when a user posts a question, e.g., a formative assessment task, or just simply asking for help with a particular topic in the course. User can enter various fields for a question, e.g., category, title, description, number of ETL deposit, validity duration etc. The wrapper function then creates an instance of the *Question* contract (which is described below). *QuestionFactory* also provides some other functionalities for management tasks, e.g., to list all questions posted, etc.

Question contract: an instance of this contract is created with each question posted on EtherLearn. Each contract instance stores data specific to the corresponding question, notably the answers to the question, which are kept in a list, as well as any file attachments. Apart from storing data, the contract also exposes getter functions to retrieve the question details (title, description, deposit, etc.) and ratings of the question as well as the answers. Lastly, it also provides functions to check whether the question's duration has expired, whether there are any highly rated, e.g., 4 or 5-star answers, and it allows users to share token or have their deposits returned once the question expires without acceptable answers.

Profile contract: to use EtherLearn, each user will need an Ethereum wallet, e.g., MetaMask, which is a software cryptocurrency wallet for accessing the Ethereum blockchain via a web browser extension or a mobile app. An instance of the profile contract is created when a user posts something for the first time. The profile contract stores details pertaining to the specific user, notably the wallet address, the number of ETL tokens owned, number of questions and answers posted, as well as the average question and answer ratings to be displayed on users' profile pages.

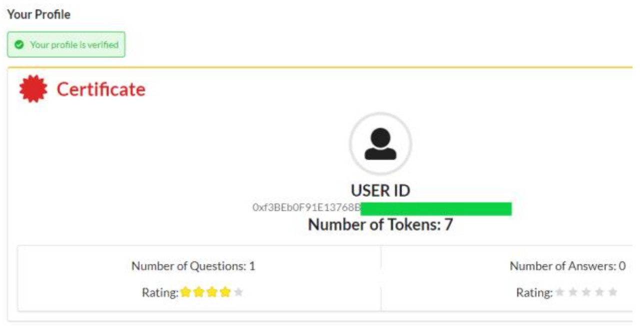

Fig 3. User profile in EtherLearn

With a MetaMask account, users now can participate in EtherLearn anonymously. They can post questions asking for help; or to set timed assessment tasks. The answers to these questions can be in the form of text replies, PowerPoint slides, code, guides, etc. Attachments will be stored in IPFS, a popular peer-to-peer file system commonly used in blockchain applications. Good answers would receive the deposited tokens as reward. This is how EtherLearn incentivizes all students in a course to actively contribute learning resource.

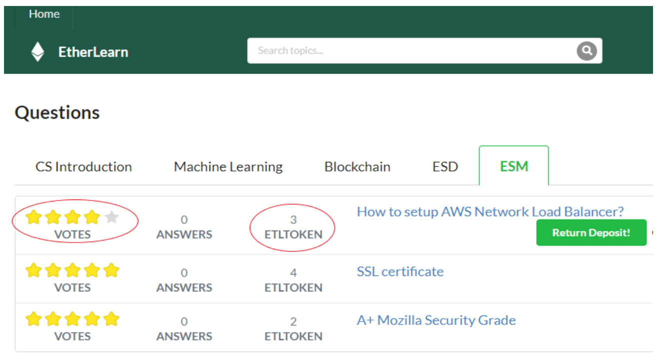

Fig. 4. Two-fold incentive mechanism in EtherLearn: votes and ETL token

Incentive system. We implement a simple incentive based on ETL tokens in this first version of EtherLearn as shown in Fig. 4. The incentive is two-fold: 1) the amount of ETL deposited for a question; and 2) the rating of the question itself. It is natural that questions with higher rating and deposit amount would attract more participants. Each question requires some ETL tokens as deposit – this serves as the reward for anyone contributing quality answers. If students see a question similar to what they want to find out, they might want to rate/vote the question with 4-5 stars, and at the same time add an ETL token to the total deposit of the question. Once the duration of the question expires, and there are any 4 or 5-star rated answers (the rating can be from 1 to 5), the deposit amount will be shared equally amongst those who contributed the 4-5 star answers. Otherwise, the deposited tokens will be returned. We plan to further evaluate this incentive mechanism in the near future, and fine-tune it to better match the needs of our students.

Similarly, a disincentive mechanism can be realized via the transaction cost (gas fee) in the Ethereum network, as shown in Fig. 5. To post content, users will incur gas fees, which are monetary payments for the computing resource needed to process transactions on blockchain. This fee can prevent spam and low quality content sent to EtherLearn. A downside of this method is that the high, sometimes prohibitive, transaction costs on the Ethereum main network can actually hinder actual utilization of our application. At the moment, we deploy and evaluate EtherLearn on the Rinkeby test network, thus dummy ETH which is free of charge can be used. In the future, we plan to switch to another blockchain network with minimal transaction costs; or to roll out own own network if Ethereum gas fee remains high.

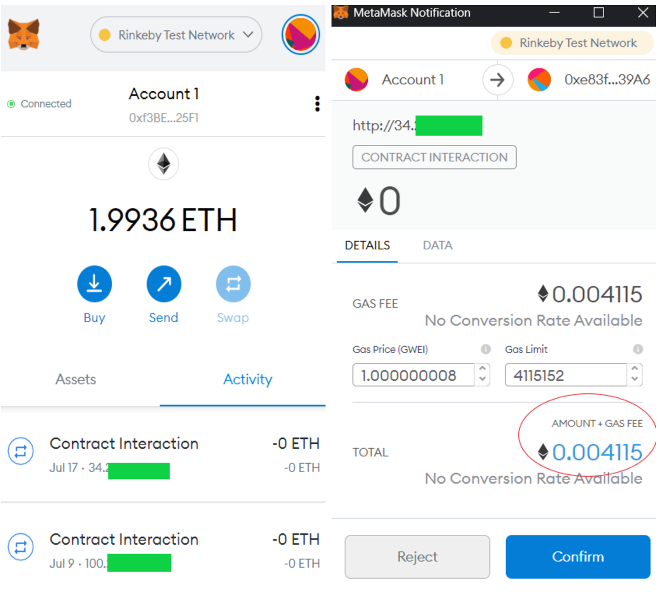

Fig. 5. Gas fee incurred (in red circle) when posting on EtherLearn

Web interface. The web interface shown in Fig. 4 is built with ReactJS. It also uses web3.js, the Ethereum JavaScript API, to interact with smart contracts. It organizes the content into courses (or categories); each of them can be a specific course in the IHL's curriculum. Under each course, students can interact with their peers anonymously by posting questions, answers, learning materials, and rating the contributed content. EtherLearn also implements a simple search feature to allow users easily filter the content within each course. For example, a user passes the search phrase 'ssl' under the course 'ESM', if either the question title or its description includes the relevant phrases, it will be returned in the search result.

Blockchain interface. The deployment and interactions with various smart contracts on the blockchain network are achieved using the Infura Ethereum API. The Infura API suite provides convenient access over secure network connections to the Ethereum network, handling all requests and function calls made on the app.

V. Evaluation

In this section, we describe our preliminary evaluation of the first EtherLearn prototype. The evaluation covers two key aspects; namely system performance and user experience.

A. *System performance*

We conduct performance testing, in particular the responsiveness of the EtherLearn web app, using Selenium, which is an automated web testing framework. In the evaluation, we are interested in the average time taken for users to make use of key functions in EtherLearn, particularly to post questions, to contribute learning material as replies to questions, to rate a question, and to rate a contribution.

For performance testing, we deploy the EtherLearn web app on an AWS t3.large instance. The smart contracts are deployed onto the Rinkeby Ethereum test network, as we do not wish to spend actual ETH due to budget constraints. We note that the performance reported here might not be representative of an actual deployment on the Ethereum main network. However, we believe it is useful to identify potential bottlenecks in the system, as well as to solicit user feedback first before spending money on the mainnet. We then make use of the Selenium IDE to simulate realistic usage scenarios in EtherLearn, and export the test scripts into Python programs for further customization.

TABLE I. Response Times (sec) in EtherLearn

Function	Avg. time	Min. time	Max. time
Post question	0.61	0.15	1.1
Post answer	0.42	0.3	0.52
Rate question	0.42	0.16	0.69
Rate answer	0.45	0.37	0.6

Table I shows the average, minimum and maximum response times obtained via running the Selenium tests. For each test, we implement Python code to automatically measure the time from clicking of buttons, e.g., to submit an answer, until a response from the server is received successfully. We run the tests 10 times each, and measure the response times. It is observed that the responsiveness of core functionalities in EtherLearn are acceptable for realistic usage scenarios, despite having to communicate with smart contracts deployed in a decentralized blockchain network.

B. *User experience*

A small-group user evaluation (sample size of 10 computing students) is carried out to assess the usability and to solicit ideas for improvement of the EtherLearn app. The participants are given a detailed user guide with instructions on how to set up their MetaMask wallets, and to perform certain actions such as posting a question, rating answers etc. Their feedback are captured in a post-testing survey form using a mix of quantitative and qualitative questions. In particular, for the quantitative questions, we ask users to rate if EtherLearn is easy to use, could it be useful in their school modules, and the overall rating of the app. Quantitative responses should be given in a scale from 1 (lowest) to 5 (highest). For the qualitative questions, we ask users for potential areas of improvement; and what they find good about EtherLearn.

The feedback obtained are generally positive. For the quantitative feedback, in terms of user-friendliness, EtherLearn was pretty well received amongst the students as about 90% of participants gave a score of 4 or higher. In terms of usefulness, about 56% participants gave a score of 4 or higher. Many of them commented that they weren't too sure what the ETL tokens are for. This is an area for improvement, as there could have been a clearer elaboration given to the participants regarding the incentive mechanism in EtherLearn. In future, we plan to give ETL a certain monetary value to see how it would affect the contribution level of students. Implementing this would depend on the funding support from our institution. At the end of the survey, on top of other questions, students are asked to give an overall rating for the app. In this rating, 67% of participants gave a score of 4 or higher for EtherLearn.

Regarding the qualitative feedback given, there were many participants who commented that something good about EtherLearn is its potential to incentivize information sharing, and to promote learning as well as a supportive culture amongst students. Other participants also felt that the user interface and design are good; it was easy for them to navigate and intuitive to use.

In terms of any areas of improvement to be made, some participants brought up the relatively slow loading speed of the web pages at first. This is because our app was on an AWS t2.micro instance, which is quite constrained in terms of computing power, when the user testing started. On the other hand, several others mentioned that the setting up of the MetaMask wallets are time-consuming and complex. These feedback have been taken into consideration and the necessary follow-ups made; in particular, we upgraded the AWS instance type for hosting EtherLearn from t2.micro to t3.large, which is more expensive and powerful. The response times are now more acceptable; as shown in Table I.

VI. CONCLUSION

In this work, we have successfully conceptualized, designed and implemented a working prototype of a peer-learning application named EtherLearn. The application leverages blockchain technology, i.e., Ethereum, to decentralize the learning process in which each student could truly be the owner of his/her learning experience. Central to EtherLearn is the token-based incentive mechanism that encourages students to develop their own learning materials and to share them with their peers; and be rewarded with ERC-20 tokens in our system. The design of EtherLearn also promotes student-centered formative assessments due to its inherent anonymity and appropriate incentives.

We have deployed a working version of EtherLearn on the AWS cloud and the Rinkeby Ethereum test network for performance evaluation and user experience study. We found that the response times of the application are generally acceptable despite the frequent communication with Ethereum smart contracts. The user experience was also quite positive; most users believe that EtherLearn could be useful in encouraging peer learning and sharing in IHL environments.

In the future work, we plan to introduce EtherLearn to a larger cohort of students for further evaluation and feedback. One limitation for a wider deployment is the transaction cost and speed of the Ethereum main network. For this, we can consider other blockchain networks with much lower cost and higher throughput; or to roll out our own blockchain setup with potential funding support from the university.

ACKNOWLEDGMENT

This research has been supported in part by the SMU UResearch in Computing programme.

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