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TMchain: A Blockchain-based Collaboration System for Teaching Materials

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Abstract: Using existing resources to create teaching materials can save effort and achieve the desired quality easily. Yet while some resources can be used freely for educational purposes, others such as textbooks or online course materials cannot. This is a particular problem during a pandemic when much teaching has gone online and the risk of teachers violating copyright is even higher. Therefore, a solution that facilitates the usage of copyright-restricted resources for generating teaching materials with royalty sharing is needed. Our work exploits the advantage of blockchain technology and proposes a system to bond participants with a smart contract; it securely registers records of multiple authorships and contribution distribution of a teaching material that reuses in part, existing resources. Such records can be used as authorship evidence to claim economic benefits when a material is used. We implement TMchain on Ethereum-Remix IDE with a core smart contract. To lower the cost of using blockchain, the material files are stored off-chain and tied to the word processing system for the final authorship and contribution share determination when a material is completed. Furthermore, we test TMchain with teaching material creation scenarios to demonstrate its effective and practical potential.

Keywords: blockchain, collaborative content creation, educational resources, open collaboration

1. Introduction

Collaboration is common in the education sector. Apart from working collaboratively to write a book or doing research, collaboration in the educational context consists of sharing original creations for others to use, build on and so on [1]. Research also suggests that using and building on existing materials can save effort and yield quality materials more easily [2]. Many resources can be used freely based on the standard copyright exemption for educational purposes or as open resources under the collaborative commons license [3], such as Open Educational Resources (OER) [4]. However, others, such as textbooks or online courses cannot. Authors who do not donate their works and want royalty sharing cannot collaborate with each other without some prearrangement. It can be risky for teachers to violate the copyright law when using other people's work in creating teaching materials. This is a particular issue during a pandemic as most of teaching as well as the teaching material goes online. Accidentally redistributing copyrighted content online can have severe consequences.

Thus, an alternative system is needed that can allow the usage of copyright-restricted resources for collaboration in teaching material generation. Sharing copyrights or royalty among the contributors of the resources constituting a teaching material can be a solution. Based on a framework proposed in our previous paper [5] we introduce TMchain, it provides a full record of multiple authorships and contributions when education resources are used in creating a teaching material and such records support royalty sharing.

TMchain exploits the advantages of the blockchain technology, as blockchain provides a smart contract among participants. The transaction output yielded by the smart contract is stored in a secure, immutable, and reliably distributed ledger without centralized management. This is suitable for community collaboration [6]. It can store authorship and contribution distribution information securely for the individual works involved. This characteristic can facilitate the sharing of other teachers' work and thus support collaboration in creating teaching material.

There are blockchain studies dedicated to the protection of intellectual property by providing reliable records of the collaboration process in creating academic papers and scientific research [7], [8], [9], [10]. Unfortunately, these studies provide solutions for the creation of single outputs, such as a research paper. They fail to address collaboration in the sharing and reuse of existing materials. In addition, as these studies proposed to store the collaboration history on the blockchain, the memory usage and calculation cost of storing the history is high.

Many blockchain applications also have been developed for the education ecosystem, such as storing certificates issued by different institutions, identifying online education solutions, protecting the intellectual property of educational contents, supporting collaboration between students and teachers in higher education, cryptocurrency payments for education and administration of the educational process etc. [11], [12], [13].

Other papers use blockchain or others system to tackle the

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distribution of teaching material [14], [15], [16], [17], [18] and record when the material is distributed to students. Again, collaboration in the reuse of existing materials to create new materials was not considered.

Our proposal, TMchain, uses blockchain technology to tackle the authorship problem of using other-teacher-created material by storing the authorship of a completed teaching material. The blockchain system first provides a smart contract among teachers who agree with the use of their materials and creates secure records of the use of teaching materials. The transactions on the blockchain provide proofs of a material's authorship as well as recording multiple authorships and contribution distribution of the product when multiple materials are involved. The system uses word processing software to record editing activities involved in reusing existing material and only the authorship information and contribution distribution information of a completed teaching material is stored in the blockchain. In addition, the material files are stored in the network rather than in the blockchain. In this way, we can minimize blockchain cost and enhance support scalability.

We introduce real-world scenario implementations that show our solution has the abi78lity to record the authorship of a teaching material, calculate contribution distribution of multiple authors, and handle the authorship records when the material is updated. We also report the feasibility and effectiveness of system with ether and runtime costs. There are three main contributions of this paper:

- We propose a complete system to support the collaboration needed when creating teaching materials that involve existing copyrighted resources.
- We design a novel blockchain-based system with the functions required to track authorship and contribution distribution records to allow educational resources to support royalty sharing.
- We implement the smart contract of the proposed system with material creation scenarios on Ethereum Remix-IDE to demonstrate its practical usage potential.

2. TMchain System Overview

We consider the collaboration needed in creating teaching material through the sharing of work. In this section, we describe the collaboration process in which multiple authors participate in developing one teaching material. We then design a system that records authorship and contribution sharing. After that we illustrate the smart contract code provided by the blockchain and transaction flow for registering authorship and sharing financial returns by function calls in the smart contract.

2.1 System Requirement

To elucidate system requirements, we first consider how teaching material is created. Research suggests a simple teaching material creation process [2]. The teacher collects resources, then convert them into the teaching material via word processor or content conversion software. Teacher also add in his/her own content. Last, the teacher exports the final material. The upper part in **Fig. 1** illustrates this process. To incorporate this process into a

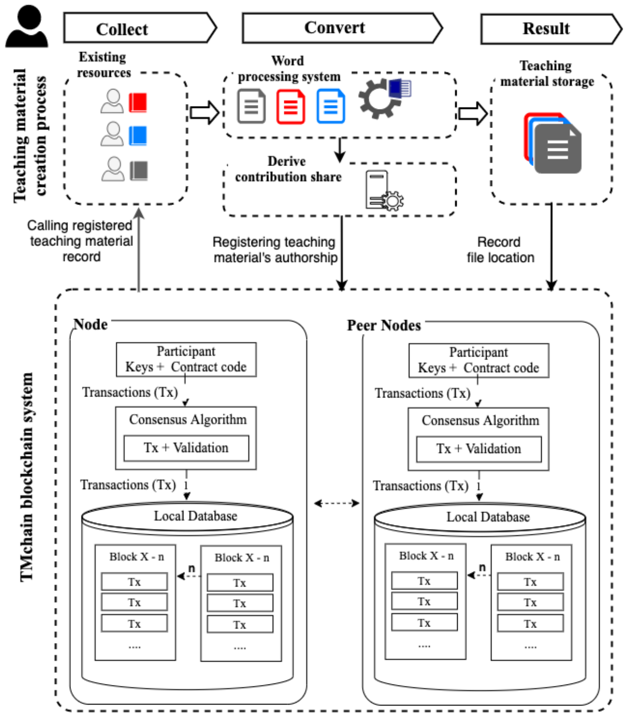


Fig. 1 Teaching material creation process and TMchain system framework.

collaboration system, there are two core requirements. First, the system allows reuse of a resources and records attributing authorship when a material is used.

In addition, there is also a consideration of using blockchain [19]. Due to the transaction recorded on the blockchain is immutable, the chain can grow so long that scalability is eventually degraded. This means the transaction data recorded on the blockchain should be kept to a minimum [22]. Thus, we propose to store only the authorship distribution information of the finished teaching material in the blockchain, not each revision event. The authorship distribution information of the finished material on the blockchain is enough to confirm authorship and acts as evidence. In addition, the revision history recorded in the material itself by the word processing software, such as MS word or GoogleDoc and TMchain registers the authorship and contribution distribution of a completed teaching material. The material file is stored outside the blockchain, using technology such as IPFS [20] to identify the correct version of material related to the authorship records in the blockchain.

2.2 System Framework

To extract the required information from the material creation process and denote authorship record in blockchain, our framework has two main parts:

- Extract authorship distribution from editing activities: Existing word processing systems such as MSword and GoogleDoc provide the function of recording editing history and file mergers. So, this requirement can be fulfilled with an addon function to calculate the contribution distribution of a finished teaching material as shown in the middle part of Fig. 1. This part is outside the blockchain. While there are various methods to calculate the contribution share [6], we discuss this in detail in a later section.

- Register authorship and contribution distribution information into blockchain (lower part of Fig. 1): This is realized by the smart contract function of blockchain. The two pieces of information must be recorded. First is the authorship of each material created. Second is the contribution distribution information of each material with its authorship in the blockchain system.

The proposed framework works with the teaching material creation process. During the creation process, the teacher starts by collecting existing resources to be used. Once they are selected, their content is extracted and edited to form the teaching material. The editing history recorded by the word processing software is used to create authorship records and contribution distribution of a finished teaching material. Then the information is stored in the blockchain.

2.3 Smart Contract Functions

To allow teachers make use of each other's teaching materials, the participants are bound with smart contracts. Entering into a smart contract is taken to mean that the teachers allow their works to be used in the collaboration system as well as truthfully committing to record authorship distribution information of the material they created.

We use Solidity language to create the smart contract named TeachingMaterialManager.sol to govern this agreement where record is the transaction executed by teachers. Each teacher needs to have an account in the system. The contract is specified with two methods (functions) namely *createMaterial* and *deriveMaterial*. *createMaterial* is used to register the authorship of a work and *deriveMaterial* is used to record the authorship information of collaboratively created teaching materials. This function creates transactions to record the material that incorporates the teaching materials of others in blockchain. We show the code snippets written in Solidity in **Fig. 2**. The input of calldata name and calldata hash is the author's account name and account hash registered in the blockchain system.

The data structure of a material contents material id, author information (msg.sender), name of the teaching material, a string hash to identify the material, references for the material id array of used teaching materials. The proportion array in bytes form is for contribution distribution which indicate the proportions of the materials involved in the teaching material.

The contribution distribution calculation is performed by *getProportion* function which is outside of *deriveMaterial*. It is also possible to embed the calculation within *deriveMaterial*. The *getProportion* function reads only data from the transaction and calculates the contribution percentage of reused material as input. Then it calculates the remaining portion as the contribution from the teacher creating the collaboratively created teaching material. This proportion share is recorded in blockchain for contribution distribution. In the case of material created using another teaching material that already contains other collaboratively created materials, the authorship distribution of the materials used can be called to perform nested calculations.

The blockchain part of our system is a simple application of the Ethereum system. One main difference from other Ethereum

```
## A material registration function to record the material information
on the blockchain. Input: author account ID, name of the material, hash
of the material, return: teaching material ID.

    function createMaterial(string calldata name, string calldata hash)
    public returns (uint){
        uint id = materials.length;
        uint[] memory references;
        bytes8[] memory proportions;
        materials.push(Material(
            id, msg.sender, name, hash, references, proportions));
        materialToAuthor[id] = msg.sender;
        materialToRegisteredTime[id] = block.timestamp;
        ownerMaterialCount[msg.sender]++;
        emit NewMaterial(id, name);
        return id;
    }
```

(a) *createMaterial* function

```
## Register the record of a teaching material that incorporates other
teachers' materials. Input: author account ID, name of the material,
hash of the material, incorporated material ids and proportions,
return: teaching material ID.

    function deriveMaterial(string calldata name, string calldata hash,
        uint[] calldata references, bytes8[] calldata proportions)
    public returns (uint){
        uint id = materials.length;
        materials.push(Material(
            id, msg.sender, name, hash, references, proportions));
        materialToAuthor[id] = msg.sender;
        ownerMaterialCount[msg.sender]++;
        emit NewMaterial(id, name);
        return id;
    }
```

(b) d*eriveMaterial* function

Fig. 2 Smart contract codes of TMchain.

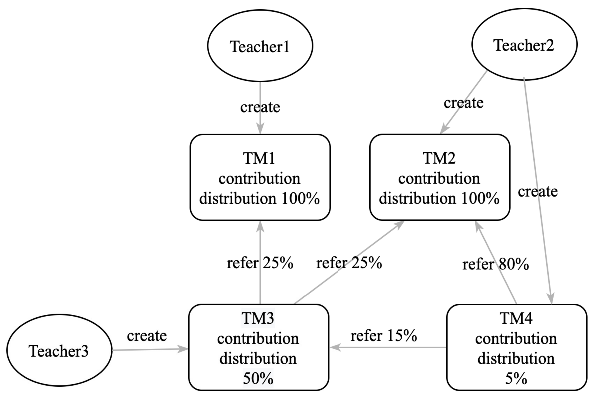


Fig. 3 Logical graph data structures of TM information.

systems is the storage of authors and material/graphs as smart contract states. Though graphs usually represent nodes, edges as properties, our system stores the material reference graph as a simple sequential array that contains material information and links to other information. This approach decreases memory usage and calculation costs.

An example of logical data structure representation of teacher and teaching material is shown in **Fig. 3**. Tearcher1, Teacher2 and Teacher3 created teaching materials (TM) TM1, TM2 and TM4, respectively. The graph structure shows that TM1 is 100% created by Teacher1 and TM2 is 100% created by Teacher2. TM3 is created by Teacher3 but also used TM1 (accounts for 25% contribution share) and TM2 (accounts for 25% contribution distribution). Thus, the contribution distribution of TM3 created by Teacher3 is 50%. TM4 is an updated version of TM2 (accounts for 80% contribution distribution) and TM3 (accounts for 15% of contribution distribution.) So, the originality of TM4 is 5%. The physical data structure stored in blockchain is shown in **Fig. 4**.

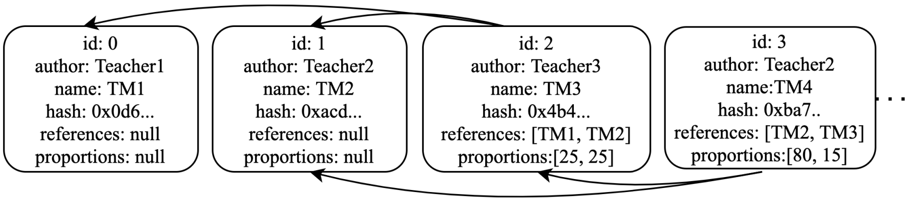
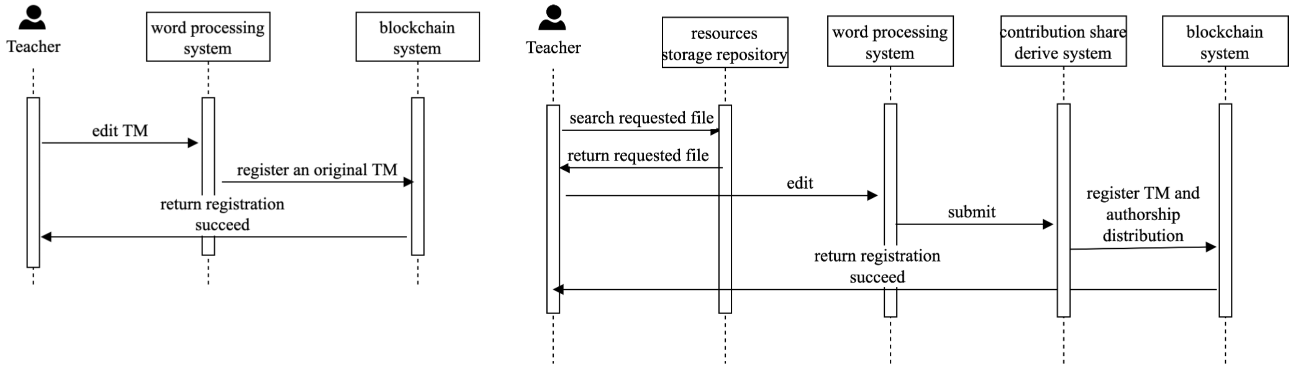


Fig. 4 Physical data structures of TM information in Blockchain.



a. register an original Teaching Material (TM) **b.** register collaboratively created Teaching Material (TM)

Fig. 5 Transaction flows of TMchain.

2.4 Transaction Flows

As we saw in the previous section, the authorship distribution recorded in blockchain mainly involves two functions: *createMaterial* and *deriveMaterial*. To make this clearer, we illustrate the general transaction flows of registering an original teaching material and registering a teaching material which has other materials through the use of the two functions. **Figure 5**a shows a typical transaction flow of registering an original material; it calls *createMaterial* in the smart contract. The procedure starts with a teacher using a word processing system to write the material and upon completion the material is registered with blockchain by calling *createMaterial*. Once the authorship of the material is registered on the blockchain system, the system returns log information notifying the author that registration has succeeded.

Figure 5b illustrates how the authorship and contribution distribution information are created in the blockchain if the teaching material uses other teaching materials. The teacher first searches for resources that he/she wants to use. The resource storage repository returns the requested resources to the teacher. After that, the teacher uses a word processing system to edit the teaching material and submit the changes. When the final version of the teaching material is confirmed, the editing history held by the word processing system can be used to generate the authorship distribution information based on contribution share calculation. *deriveMaterial* is then called to register multiple authorships and contribution distribution information in blockchain. Once such information is recorded successfully, the blockchain system returns a log message indicating transaction success to the teacher.

The smart contract generates transactions of authorship of an original teaching material as well as the multiple authorships and contribution distribution of a teaching material that uses other materials. The transaction data is held in blockchain. The document file of the teaching material is stored outside blockchain. When a collaboratively created material is used by other teachers, multiple authorship and contribution distribution information can be extracted from previous records and the latest teacher simply adds on his/ her editing activities to create and register the new material.

3. Scenario Implementation

In this section, we demonstrate TMchain smart contract implementation with teaching material creation scenarios and test its functionality with Ethereum Remix IDE [23]. We use lecture presentation slides from the "Field based Learning/Problem Based Learning" (FBL/PBL) course of the Design School of Kyoto University. The course has been taught for several years and the teaching material is constantly updated by different teachers.

3.1 Register Original Teaching Material in TMchain

In **Fig. 6**. we show a scenario of the system registering an original teaching material. The teaching material was first created for "FBL/PBL" course by Teacher1. It was named TM1 by Teacher1 for TMchain registration. Teacher1 was given an account with id account{0} with account hash of "0x1fb3e76fA2b83d7F8A53ba74867296c0fcDC6c37" by the TMchain system. In this scenario, it called with *createMaterial* function under TeachingMaterialManager.sol contract. When the registration of TM1 succeeds, the transaction is stored in block 342 with txIndex[0] from account{0} (shown as account hash as "from" item in the block). The transaction data is stored as a binary record under "data". The blockchain transaction log and storage on blockchain is shown in Fig. 6.

3.2 Registering Teaching Material That Uses Other Materials in TMchain

In this section, we demonstrate how a teaching material that

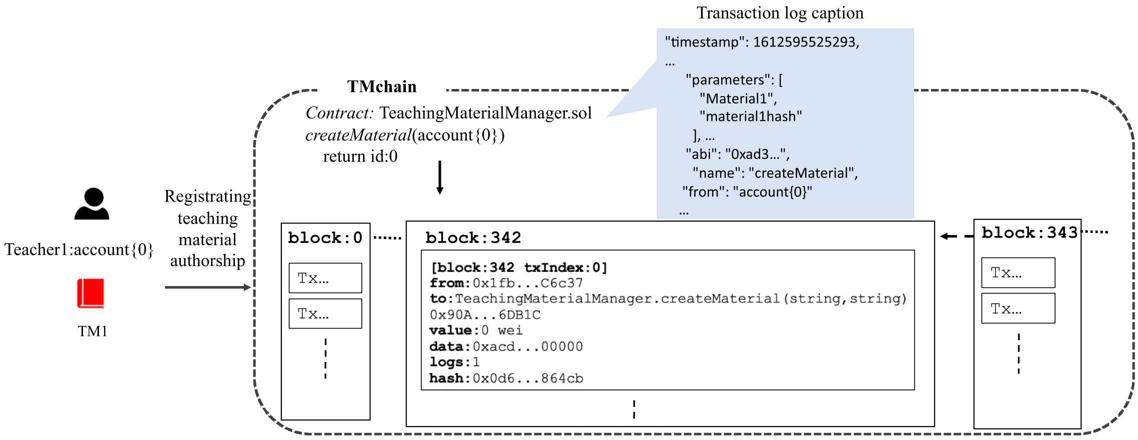


Fig. 6 *createMaterial* scenario: Teacher1 registering TM1 to TMchain.

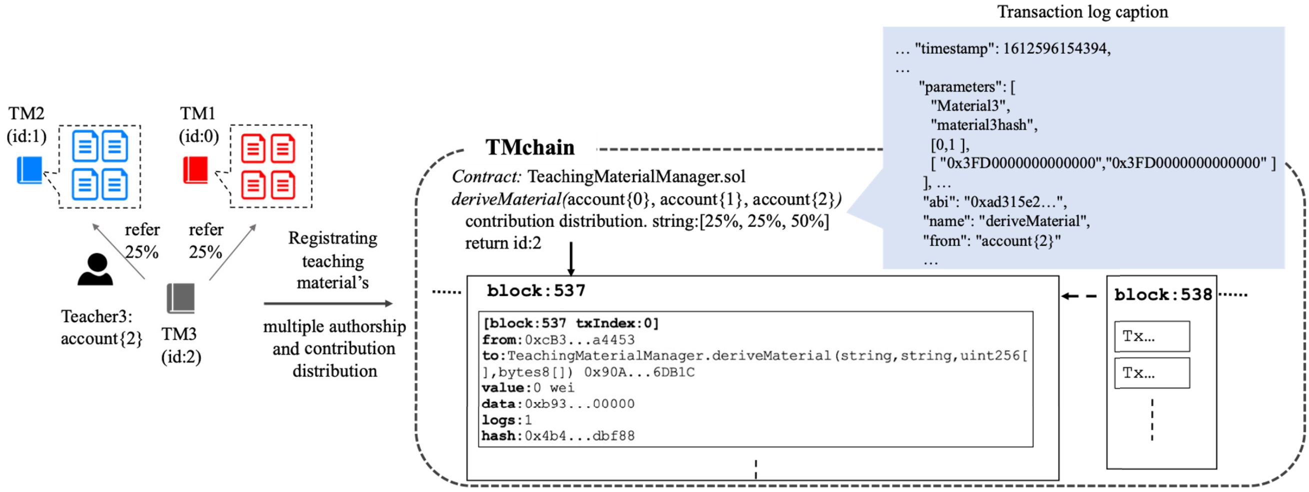


Fig. 7 *deriveMaterial* scenario: Teacher3 registering TM3 to TMchain.

uses other materials is registered in TMchain. We count the presentation slides to determine contribution distribution.

In a later semester, Teacher3 is assigned to teach "FBL/PBL" course. She decides to extract four presentation slides from the previous "FBL/PBL" teaching material (TM1) and extract some content from the teaching material (TM2) created by Teacher2 for another course: "Information and Society". To use TM2, Teacher2 needs to register this material in TMchain. The registration of TM2 follows the process shown in Fig. 6. So, we omit the log and block information here. Teacher3 uses TM1 to create four slides and TM2 to create four slides. Last, she creates 8 slides by herself as shown in **Fig. 7**. For TM3, authorship is splitting among Teacher1, Teacher2 and Techer3 with contribution shares of 25%, 25% and 50%, respectively, as shown in Fig. 7.

To register this teaching material, which has multiple authorship and contribution distribution, *deriveMaterial* is called. The input data are material ids and their proportions. TM1 (material id: 0) accounts for 25% and TM2 (material id:1) accounts for 25%. The transaction log holds materials used with their work id in a list array as [0,1] and contribution distribution is represented in binary 64 format in a list array of ["0x3FD0000000000000", "0x3FD0000000000000"]. The rest of the 50% contribution share belongs to Teacher3 (account{2}) who creates TM3. This transaction was executed by Teacher3 with account hash of "0xcB3420DD4D4573b779517f605646849595Fa4453" as "from" item in the block transaction item and the information is recorded in binary form in "data" item.

This scenario calls *deriveMaterial*. When the registration of TM3 succeeds, the transaction is stored in block 537 from account{2} as in Fig. 7. In block:537, txIndex:0 shows Teacher3's account hash by "from" item and used TeachingMaterialManager.sol contract with *deriveMaterial*. The data of the transaction is stored in binary form under the "data" item. This transaction runtime is reported to be within 5145 milliseconds. In the case that Teacher2 updates TM2 to yield new teaching material TM4 (in Fig. 3 and Fig. 4) through the addition of more presentation slides. This also calls *deriveMaterial* function to register a new material. The transaction process and result are similar to the registration of TM3 shown in Fig. 7.

4. Evaluation and Discussion

In this section we provide evaluation details of feasibility and effectiveness based on TMchain's implementation. In addition, we discuss the practical usage and future research direction of our proposed system.

4.1 Function Evaluation

We consider the need for a solution to support teaching material sharing with royalty sharing property. The system is used to support the collaboration in using existing material. The system requirement is to record the authorship of a teaching material as well as multiple authorship and contribution distribution information when there are multiple teaching materials involved. We report its functionality evaluation in this section.

TMchain satisfies the required feature with *createMaterial* and *deriveMaterial* functions. In Section 4, we show that the authorship information as well as the contribution distribution information can be stored successfully. Each original teaching material is first registered by calling *createMaterial* to receive a unique ID with timestamped transaction record in blockchain to provide security. Such information is immutable and cannot be altered due to the property of the blockchain technology.

The record of a teaching material that uses multiple materials is created by *deriveMaterial*. *deriveMaterial* is called to establish multiple authorships, calculate contribution distribution, record the result in blockchain. With these two functions, the system records the authorship of teaching materials. The authorship information can be used as evidence to support royalty sharing when collaboration involves the use of copyrighted material.

4.2 Performance Evaluation

The performance evaluation focuses on function call runtime. We use MacBook Air with 8 G memory and 1.6 GHz Intel Core i5 process to realize the environment. We also implement a virtual machine with Docker software on the MacBook Air and use Web3provider which offers a private Ethereum node to measure the performance. The default "gasLimit: 0x47b760" and the "difficulty: 0x100" was set. Gas is the measure of execution complexity for Ethereum.

The following reports the runtime of calling functions of *createMaterial* and *deriveMaterial* from create new transaction block to save material information on blockchain but does not include off-chain function runtime. Our smart contract just read the data of contribution distribution generated by the off-chain word processor.

We called *createMaterial* 50 times and determined the average runtime to be 4,127 milliseconds. For *deriveMaterial,* we use scenario of create a material that uses the material of previous version. For example, a material version 1 is used in creating material version 2. Then material 2 is used in creating material 3 and so on. We perform *deriveMaterial* function call up to 10 version levels. The average runtime for 50 calls was around 6,000 milliseconds when the teaching materials involved did not exceed the 8 version levels as shown in **Fig. 8**. The runtime grew exponentially as teaching material versions increased as teaching materials of previous versions had to be called upon and nested calculations performed. Note that the runtime for calculating contribution distribution has less impact on runtime required. It only took 20 milliseconds when there was only one other teacher's material involved. It took on average less than 100 milliseconds when there were less than eight materials involved and 0.5 seconds with 10 materials involved.

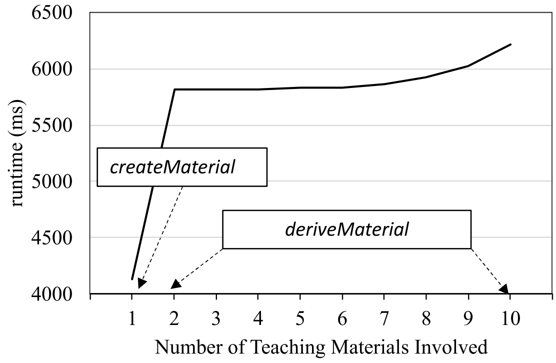


Fig. 8 Function runtime in milliseconds when call *createMaterial* with 1 material and call *deriveMaterial* with 2 to 10 version levels involved in collaboratively created teaching materials.

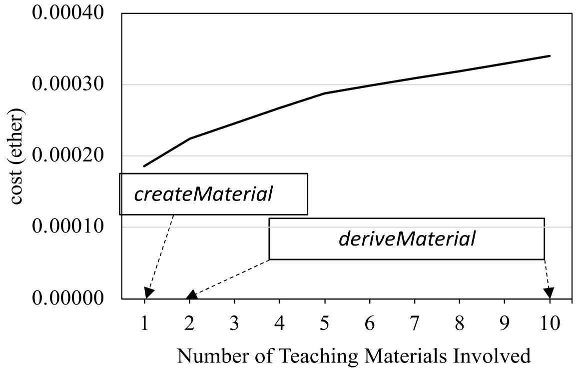


Fig. 9 Cost of ether with 1 material by calling *createMaterial* and a teaching material with 2 to 10 materials involved by calling *deriveMaterial* function for collaboratively created teaching materials respectively.

Considering it can take days and even weeks to create a teaching material, the time to register the material and/or calculate the authorship distribution on TMchain is insignificant at only several seconds. This runtime makes real world usage possible.

4.3 Discussion

TMchain currently supports only teachers who have accounts and materials for reuse also need to be registered with the system. We adopted the Ethereum Remix-IDE platform environment and code the smart contract with Solidity language. This implementation might be altered if a different platform is used.

The system relies on teachers faithfully using the system. We use existing network consensus of existing blockchain technology to prevent alteration of the transaction records. In its present version it cannot guarantee if a participant is registering material not created by him/herself. Of course, such actions would leave evidence of the illegal acts.

There is cryptocurrency payment cost involved when using the blockchain system. In the experiment, we assigned the cost to the teacher who registered their teaching material. It costs 0.000185488 ether per transaction on TMchain for calling *createMaterial.* This is the cost for registering a teaching material with one author in the system. For *deriveMaterial* transactions, the ether cost increases linearly with the number of materials involved. It costs 0.00002096 ether for each additional teaching materials as shown in **Fig. 9**. How to share this cost among stake holders is a future research direction.

Ethereum uses gas to indicate the amount of computational effort required to execute specific operations on the Ethereum network and gas fee is determined by supply and demand between the network's miners and users. In order to represent the practicality of TMchain in the real-world scenario, we calculate the gas cost of ether. In our system, 1,000,000 gas cost is fixed to 9.21147E-12 ether. Yet in real world, ether cost is not fixed. This issue, considering gas price with real Ethereum network when using TMchain, can be part of future research.

In addition, the execution time of our smart contract is influenced by both test environment and contract overhead. In this paper, we used a MacBook Air PC with 8 GB and 1.6 GHz CPU. It is expected that runtime can be improved by using a more powerful computer [29]. Yet [29] also found that the runtime reduction saturates at high computing powers. They implemented a simple smart contract using an 8 GB and 3 GHz CPU and the result was a runtime over 4 seconds. This was reduced to slightly over 3 seconds for both 16 GB and 32 GB. This means when the computer's memory and CPU power reach a certain level, the smart contract overhead is more influential as regards the runtime.

In the TMchain smart contract, functions are also simple. They only add one array element and few map elements. Yet of the functions *createMaterial* and *deriveMaterial*, *deriveMaterial* is more complex than *createMaterial*. An example can be found in Fig. 4; id:0 is created by *createMaterial* and id:2 is created by *deriveMaterial*. The average runtime of *createMaterial* with only 1 teaching material involved is 4,127 milliseconds as shown in Fig. 8. Figure 8 also shows that the runtime of *deriveMaterial* with 2 teaching materials is 5,816 milliseconds. This means the time required is also influenced by the complexity of the functions in the smart contract. Yet this runtime result shows it only takes a few seconds to register a collaboratively created material with the system. This is still insignificant compared with the whole teaching material creation process.

In this paper, we mainly consider ether cost and runtime in evaluating the practical usage of TMchain. Yet there are additional parameters that must be considered by a full-scale scalability report. They include block size, transaction rate and others [29]. Future work includes large scale scalability analysis of the system.

Contribution allocation is also a research area of interest. Various contribution calculation methods have been suggested [6]. In this paper, the scenario considered the number of slides used in a material, but this is merely for demonstration purposes. The proposed system can adopt any contribution calculation algorithm.

The legal implication of using blockchain records is also a concern. While our proposed system has special provisions aimed at facilitating teacher's trust in blockchain records, their good faith usage of copyrighted teaching materials is assumed. How to legalize the transactions and the status of smart contracts and their consequences is also a future research area. This involves how to support intellectual property right enforcement and so assumes blockchain records will be a legitimate evidence in different legal regimes.

Blockchain technology provides an immutable ledger that complicates the alteration of a registered teaching material. In the case of removing some content, it is better to reregister the material by recompiling the multiple authorship and contribution distribution based on the editing history captured by the word processing tool used. TMchain treats a finished teaching material as a unit and stores its authorship. Our system does not record the editing history of the material, only the authorship distribution of a completed material. Therefore, we rely on the word processing system used to support the tamper resistance of the editing history. If the submitted record of authorship of a completed work is the final version, our system stores the record. Our system uses blockchain technology to assure the alteration resistance of the authorship information of completed teaching materials.

Teaching material files can be stored off-chain in TMchain with a hash to indicate file location. While the hash can be an URL, the author needs to keep the content of the URL unchanged to support the usage of TMchain. It is better to use IPFS to store material files in our system to resist content modification.

Finally, the TMchain system is impacted by inheritance of existing blockchain technology as well as the implementation platform and system environment limitation. While it took about 10 seconds on average to complete the registration of a collaboratively created teaching material in our experiment, we can envisage a faster blockchain system and configuration to improve system performance.

5. Related Work

With the goal of collaboration for creating teaching materials with royalty sharing, there are online collaboration writing tools that can provide authorship record and editing activity history. This is suitable given the prearranged agreement on collaboration for generating teaching material. However, the central concept of open collaboration is to accept the reuse of one's work in other teacher's teaching material. This is similar to work collaboratively performed in creating single outputs and the intellectual property right of the material contains multiple authors' contribution. A system to automatically generate the record of authorship (who made which work) and contribution distribution (authorship share in the material) that supports reuse of a material is required.

Blockchain technology has been proposed that can record collaboration history [14] because it sets participants to commit to a smart contact and stores the transactions in a ledger shared by the participants. Blockchain also has the advantages of providing a higher security, transparency, immutability of a record with decentralized management. The "smart contract" of blockchain is triggered by an event or participant's enquiry via prespecified computer protocol [14] with predefined parties who can join the network to read and transfer data. It also has a network consensus to support decentralized management of the ledger. The consensus ensures all blockchains in the network are legitimate and supports the existence of multiple copies in the network so no single party can manipulate the record [22]. Many blockchain-based applications that act as public ledgers have been proposed, namely for medical records, logistics and Internet of Things as well as for academic publications [22]. Yet no consideration was made of collaboration that combines existing educational resources into one teaching material like our work.

There are research efforts on using blockchain systems in the context of education collaboration. For supporting academic publication collaboration, research has focused on collaboration for creating individual academic publications. These systems preserve participant activities to acknowledge the contribution of each party [7], [8], [9], [10], [20], [24]. Eureka [7] is a blockchain-based public network for cooperation publication. It has incentive sharing scheme that enables authors, referenced/linked author, editors, data providers and reviewers to receive the economic reward with digital token "EKA". Orvium [9] is an open source blockchain platform to manage and support collaboration in science publications. The system allows researchers to share their work as well as to create open access journals. The system provides a public transparent trace of all the activities pertaining to a research paper from first submission, revisions, accepted or rejected peer reviews, copyright and user license changes. Mohd Pozi et al. considered collaborative writing of scientific publications and preserving editing history in a block which can then be used for contribution calculation [10].

Guo et al. [17] proposed a blockchain-based digital rights management system for recording digital rights of educational resources. Yet each editing history is limited to 1024 characters which cannot support a creation of large documents with figures. ScienceRoot [24] focused on a blockchain-enabled scientific ecosystem which tokenized the research process; it views itself as a science research marketplace that supports grant funding, publishing, and scientific collaboration. Marjit et al. [25] introduced a solution with IPFS to support the OER to resolve the high cost of centralized storage of these resources in blockchain. In addition, other smart contracts have used in this research field for controlling access to teaching material [24], [28]. Yet none of these works provide multiple authorship recording functions when combining existing educational resources into one teaching material and our proposed system provides an alternative solution.

6. Conclusion

We consider the collaborative effort possible in creating a teaching material which reuses existing educational resources. Open Educational Resources Organization organize a library where teachers can donate their materials to be reused under creative commons, some resources may have copyright provisions. We propose to use blockchain technology to support royalty sharing in collaboration when using another teacher's teaching material. It features to store authorship of an originally created material as well as multiple authorships when various material files are involved in a teaching material.

We propose TMchain to support collaboration in the use of existing TMs as well as to record attributing authorship. It is a simple Ethereum application that stores the authorship and contribution distribution information when existing resources are used and /or referenced in creating teaching material. The security of storing such records is supported by blockchain. We also consider how to minimize the blockchain cost by storing material files off-chain and utilizing the functionality of existing word processing systems to capture edit history before finalizing the authorship and contribution distribution for blockchain storage. In addition, we also propose to utilize a distributed file system on the network to store material files. We implemented TMchain on Ethereum Remix-IDE and used real life scenarios to demonstrate the practicality and effectiveness of TMchain.

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References

[1] Hilton, J. III and Wiley, D.A.: The creation and use of open educational resources in Christian higher education, Vol.9, No.1, pp.49–59, Christian Higher Education (2009).
[2] Putnik, Z., Budimac, Z. and Ivanović, M.: A practical model for conversion of existing teaching resources into learning objects: MASAUM, *Journal of Computing*, Vol.12, pp.205–214 (2009).
[3] Creative commons Homepage, available from ⟨https://creativecommons.org⟩.
[4] Hylén, J: Open educational resources: Opportunities and challenges, *Proc. Open Education*, pp.49–63 (2006).
[5] Chou, H., Lin, D., Nakaguchi, T. and Ishida, T.: A blockchain-based collaboration framework for teaching material creation, *International Conference on Human-Computer Interaction*, pp.29–43, Springer (2021).
[6] Torres, J., Jimenez, A., García, S., Peláez, E. and Ochoa, X.: Measuring contribution in collaborative writing: An adaptive NMF topic modelling approach, *International Conference on eDemocracy & eGovernment* (*ICEDEG*), pp.63–70, IEEE (2017).
[7] Niya, S.R., Pelloni, L., Wullschleger, S., Schaufelbühl, A., Bocek, T., Rajendran, L. and Stiller, B.: A blockchain-based scientific publishing platform, *International Conference on Blockchain and Cryptocurrency*, pp.329–336 (2019).
[8] Novotny, P., Zhang, Q., Hull, R., Baset, S., Laredo, J., Vaculin, R., Ford, D.L. and Dillenberger, D.N.: Permissioned blockchain technologies for academic publishing, *Information Services & Use*, Vol.38, No.3, pp.159–171, IOS Press (2018).
[9] Orvium homepage, available from ⟨http://orvium.io⟩ (accessed 2021-08-01).
[10] Mohd Pozi, M.S., Muruti, G., Bakar, A., Jatowt, A., and Kawa, Y.: Preserving author editing history using blockchain technology, *Proc. 18th ACM/IEEE on Joint Conference on Digital Libraries*, pp.165–168, JCDL (2018).
[11] Chen, G., Xu, B., Lu, M. and Chen, N.: Exploring blockchain technology and its potential applications for education, *Smart Learning Environments*, Vol.5, No.1, pp.1–10 (2018).
[12] Fedorova, E.P. and Skobleva, E.I.: Application of Blockchain Technology in Higher Education, *European Journal of Contemporary Education*, Vol.9, No.3, pp.552–571 (2020).
[13] Ocheja, P., Flanagan, B. and Ogata, H.: Decentralized e-learning marketplace: Managing authorship and tracking access to learning materials using blockchain, *International Cognitive Cities Conference*, pp.526–535, Springer (2019).
[14] Crosby, M., Pattanayak, P., Verma, S. and Kalyanaraman, V.: Blockchain technology: Beyond bitcoin, *Applied Innovation Review*, Vol.2, pp.6–10, University of California, Berkeley (2016).
[15] Ellervee, A., Matulevicius, R. and Mayer, N.: A comprehensive reference model for blockchain-based distributed ledger technology, *ER Forum/Demos*, pp.306–319 (2017).
[16] Hou, Y., Wang, N., Mei, G., Xu, W., Shao, W. and Liu, Y.: Educational Resource Sharing Platform Based on Blockchain Network, *IEEE Chinese Automation Congress* (*CAC*), pp.5491–5494 (2019).
[17] Guo, J., Li, C., Zhang, G., Sun, Y. and Bie, R.: Blockchain-enabled digital rights management for multimedia resources of online education, *Multimedia Tools and Applications*, pp.1–21 (2019).
[18] Chunwijitra, S., Junlouchai, C., Laokok, S., Tummarattananont, P., Krairaksa, K. and Wutiwiwatchai, C.: An interoperability framework of open educational resources and massive open online courses for sustainable e-learning platform, *IEICE Trans. Information and Systems*, Vol.99, No.8, pp.2140–2150 (2016).
[19] Nakamoto, S.: Bitcoin: A peer-to-peer electronic cash system (2008).
[20] Nizamuddin, N., Hasan, H.R. and Salah, K.: IPFS-blockchain-based authenticity of online publications, *International Conference on Blockchain*, pp.199–212, Springer (2018).

[21] Steichen, M., Fiz, B., Norvill, R., Shbair, W. and State, R.: Blockchain-based, decentralized access control for IPFS, *IEEE International Conference on Internet of Things* (*iThings*) *and IEEE Green Computing and Communications* (*GreenCom*) *and IEEE Cyber, Physical and Social Computing* (*CPSCom*) *and IEEE Smart Data* (*SmartData*), pp.1499–1506 (2018).
[22] Belotti, M., Božić, N., Pujolle, G. and Secci, S.: A vademecum on blockchain technologies: When, which, and how, *IEEE Communications Surveys & Tutorials*, Vol.21, No.4, pp.3796–3838 (2019).
[23] Wood, G.: Ethereum: A secure decentralised generalised transaction ledger, Ethereum project yellow paper, 151 (2014).
[24] Günther, V. and Chirita, A.: Scienceroot, Whitepaper (2018).
[25] Marjit, U. and Kumar, P.: Towards a decentralized and distributed framework for Open Educational Resources based on IPFS and Blockchain, International Conference on Computer Science, *Engineering and Applications* (*ICCSEA*), pp.1–6, IEEE (2020).
[26] Zheng, Q., Yi, L., Chen, P. and Dong, X.: An innovative IPFS-based storage model for blockchain, *IEEE/WIC/ACM International Conference on Web Intelligence* (*WI*), pp.704–708 (2018).
[27] Remix-IDE, Ethereum Foundation, available from ⟨https://github.com/ethereum/remix-ide⟩ (accessed 2021-08-01).
[28] Irshad, S., Brohi, M.N. and Soomro, T.R.: Block-ED: The Proposed Blockchain Solution for Effectively Utilising Educational Resources, *Applied Computer Systems*, Vol.25, No.1, pp.1–10 (2020).
[29] Schäffer, M., di Angelo, M. and Salzer, G.: Performance and scalability of private Ethereum blockchains, Business Process Management: Blockchain and Central and Eastern Europe Forum, *Lecture Notes in Business Information Processing*, Di Ciccio, C. et al. (Ed.), Vol.361, pp.103–118, Springer (2019).

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