Decentralized E-Learning Marketplace: Managing Authorship and Tracking Access to Learning Materials Using Blockchain

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Abstract. The difficulty in protecting and enforcing Intellectual Property (IP) rights has been a major obstacle to sharing intellectual works in digital forms. In this work, we present a prototype design for a decentralized e-learning market-place where teachers, authorized publishers and authors can publish their learning materials, establish conditions for allowing access, and grant or revoke access based on adherence or infringement of their rights. Using the Blockchain of Learning Logs (BOLL) and a digital book reader (BookRoll), we demonstrate how authors can be empowered to deploy smart contracts that protect and enforce these rights on their intellectual works in a distributed manner. We particularly use the blockchain in order to enable trust, trace-ability, rights protection, transparency and collaboration between authors and users of their work with no third party interference. Finally, we examine the implications of our proposed design, its limitations and directions for future work.

Keywords: Intellectual Property · Copyright elearning · Education privacy · Security · Blockchain · Smart contract · BOLL · Bookroll

1 Introduction

As the amount of data in the digital space continue to grow leading to more meaningful use cases, it is important to ensure appropriate use, reward ingenuity and foster collaboration among diverse parties. Intellectual Property Rights (IPR's) are rights that allow creators or owners of industrial properties (patents for inventions, trademarks, etc.) or copyrighted works (books, poems, artistic works, etc.) to benefit from their own work or investment in a creation by defining terms of usage which potential users of their work should comply with [1]. With many works on the use of technology to solve is-sues relating to IPR's protection and enforcement such as [2–7], we focus on specific issues on how educators including students and teachers can share learning materials in a secure, privacy-enabled, intellectual rights-aware and collaborative environment. new resources that other students or the teacher might find helpful. With more knowledge resulting from simple interactions like this, we consider it necessary to have a system that supports exchange of these resources, reward ingenuity, increase distribution,

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foster collaboration, and protect the intellectual rights of the authors. Thus, this paper is inspired by the need to solve these problems:

1. How do we ensure trust and transparency between an author of a work that is made available to students and a sponsoring organization that pays for the author's work based on the usage quota of each student without using any third-party?
2. How can students generate and share learning materials with their peers across different schools with IPR's protection?
3. For companies, other learning organizations, and publishers, how can we establish a trusted and transparent network where these actors can co-exist and provide a wide pool of educational resources to students?.

We provide solutions to the above problems by extending the framework for a blockchain-based learning analytics platform proposed in [8] and implemented in [9] as a Blockchain of Learning Logs (BOLL). BOLL is a decentralized platform that enables logical movement of students and their academic records from one institution to another. Different from certificates or transcripts issuing systems, BOLL provides a mechanism to share learning logs of students on the various learning tools they interacted with while studying at different institutions. Our main contributions are:

1. We engender trust between sponsors, authors, and users of their work by providing transparent auditing of access to learning materials on a decentralized network.
2. We propose algorithms for programming smart contracts that enforce privacy and IPR's.
3. We design and discuss a framework for realizing a decentralized e-learning marketplace for a healthy co-existence among parties with varied interests.

The rest of this paper is organized as follows. The next section reviews related works and how our idea differ from existing solutions. This is followed by the section on our proposed framework and its components. Our discussions and ideas to solving identified problems and potential challenges are provided in the discussions section. Finally, we conclude this paper and provide potential directions for future work.

2 Related Work

There are many previous works on the need to protect IPR's in a digital world including [2, 10–13]. Anderson et al. [2] proposed an eXtensible Access Control Markup Language (XACML) geared towards achieving more usability of digital assets over a broad spectrum of applications and to also ensure security policies defined by asset owners are adhered to. Lorch, Proctor, Lepro, Kafura and Shah [3], demonstrated how XACML can be used by distributed systems to achieve a more robust access control. However, XACML and the implementation in [3] does not provide a mechanism for engendering trust between two or more potentially distrustful parties without the need for a central authority to act as a mediator.

To solve the problem of lack of trust and eliminate the need for a third-party, Zhu et al. [5] proposed a Transaction-based Access Control (TBAC) assets management sys-tem on blockchain which is fundamentally built on an Attribute-based Access Control (ABAC) model [14]. Using the Bitcoin blockchain, Zhu et al. showed how a digital asset can be escrowed on the blockchain and protected with policies defined in state functions. While the ideas proposed by Zhu et al. are similar to ours, we find their work limited in handling multi-party scenarios such as a sponsoring organization providing access to learning resources to a learner and only pays for what the learner actually uses (parties involved: sponsor-author-learner). Another difference is a scenario in academic where one or more authors may write a learning resource together but each of the authors would like to manage access or changes to their contributions differently. Thus, an education-specific implementation of IPR's management becomes even more necessary as educational assets are frequently accessed, updated, and constitute different kinds of data that engender further analytics by not just the asset owner but also the accessor (learner or her institution).

Also, we consider implementations of e-learning systems and/or marketplaces such as these [15–17] to be limited in facilitating interactions between potentially distrustful parties and the lack of transferability of learning footprints across different institutions. Hoffman et al. [7] and Janowicz et al. [6] also identified the possibility of using a decentralized network to offer IPR's protection in education but focused on using the blockchain to manage journal management workflows.

The Blockchain of Learning Logs (BOLL) proposed in [9] enables the realization of lifelong learning logs for students as they move from one learning environment to another. The BOLL framework forms a fundamental background for our work. Our pro-posed framework allows broad auditing by concerned parties on the network and also permits digital content owners to decide how their contents from the DDS are served to other users in order to facilitate better policy violation tracking. Also, to improve learning outcomes, we introduce a mechanism for users to rate and recommend useful contents to one another.

3 Proposed Framework

Figure 1 shows our proposed framework for enabling a decentralized e-learning market-place for managing authorship and tracking access to digital contents on BOLL. BOLL Marketplace (BOLL-M) comprises of two groups of stakeholders; authors and users. Authors refer to actors on BOLL-M who own intellectual rights to learning materials made available in the marketplace. While users refer to members of the BOLL network who wish to access learning materials made available in the market and/or organizations that provide sponsorship for students to access learning materials (e.g. a government education ministry or other funding organizations). A student or teacher on BOLL-M can also be an author of a learning material in the marketplace. In this scenario, the student or teacher can rely on the learning material publishing tool made available to them by their institution. For publishers who do not belong to an

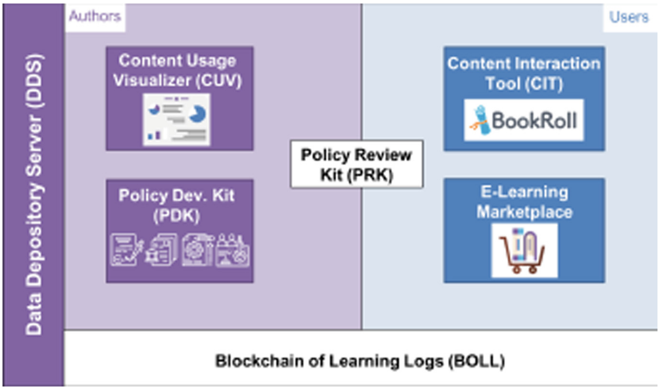

Fig. 1. Decentralized e-learning marketplace.

academic institution, it is required for them to be authorized by the BOLL Consortium proposed in [9]. After such an authorization is acquired, the publisher can setup a node on the BOLL network as show in Fig. 2. We will now describe each of the components shown in Fig. 1.

3.1 Policy Development Kit (PDK)

To enable appropriate use of learning materials on BOLL-M, it is necessary to define policies that accessors should comply with. We represent these policies as state transition functions in the smart contracts. Due to the technical skills required to write smart contracts, we provide multiple templates as a PDK which authors can choose from, adapt to their use case and install on BOLL to protect access to their learning materials. We represent these smart contracts in four broad categories.

One-time Signatory Policy (OSP). This refers to smart contracts that can be installed once and contain clauses on how a learning material can be accessed and used with the permission of the author. When an OSP is issued on BOLL-M, it is irrevocable and the issuer either grants a limited or lifetime access to a learning material depending on the duration specified. An example of a useful application is where students are given a one-time limited access to a professional or degree examination provided by another organization. In Algorithm 1, we show a pseudo-code for issuing an OSP by an author identified by public key, Pkauthor to a learner with public key, Pklearner. The implementations of the get Signer(message) and notify(message) are not shown in this work as one could easily use the public key resolution and event emitting features of the blockchain as well.

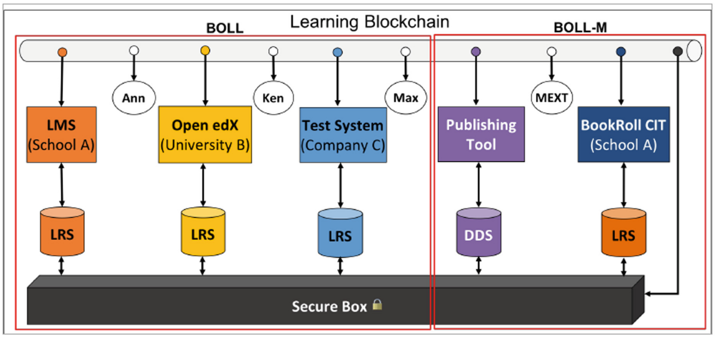

Fig. 2. Decentralized e-learning marketplace on BOLL

Dual Party Signatory Policy (DPSP). This is a revocable version of OSP where two parties can agree or disagree on the terms of access to a learning material. In a DPSP, terms of access can be modified by the issuer and such modified version becomes valid only when the accessor of the learning material agrees to the new terms. DPSP is useful in scenarios where an author maintains a continuously improved version of a learning material (e.g. lecture slides being updated regularly) and does not wish to create an entirely new version with the new changes. Although, smart contracts once installed are immutable, we achieve versioning of terms of access by allowing the execution of sets of instructions within the contract until all parties, S Pk append their signatures, SPk. The learner will be notified when this happens and only after that can the learner access such learning material. Algorithm 2 gives an illustration of a typical DPSP.

Multi Party Signatory Policy (MPSP). The MPSP is a collaboration enabled smart contract that allows multiple parties to determine the conditions for accessing a learning material. To enable multi party arbitration, MPSP starts off with the proposed clauses of the originating party. Another party can review these proposals and either refuse or accept them by invoking the state transitions functions contained in the initial MPSP. The originating party is tasked with initializing the MPSP with some settings including the participating parties (Pkvoter1 …Pkvotern ∈ VPk), the wining strategy (wining ratio) and the tie breaker (Pkarbiter) as shown in Algorithm 3. For example if a simple majority wining strategy is specified (wining ratio > 50%), the smart contract becomes valid if a simple majority agrees with the stated terms. In a case where a tie occurs, the parties can propose one party (Pkarbiter) whom they think should be the final arbiter. This party is then given the ability to override all votes and either accept or deny the approved installation of the MPSP terms. For instance, we find the MPSP useful in a three-party scenario where one party owns and provides the learning material (e.g. publisher), the second party pays for the learning material (e.g. government) and the third party is the consumer of the learning material at no cost (e.g. students). This solves the particular problem where an organization sponsors access to a learning material on behalf of the students. The tie breaker is useful in a case where the sponsoring organization is unable to ascertain the usefulness of a learning material to the student. In this case, both the sponsoring organization and the author can delegate the student to adjudge whether they find such learning material useful or not. Algorithm 4 provides a typical demonstration of the voting procedure on an MPSP.

Algorithm 1: Procedure for issuing a One-time Signatory Policy (OSP)

Pk_{author} : author's public key, $Pk_{learner}$: learner's public key Pk_{owner} : public key of the policy recipient
$getSigner(message)$: returns public key of the signer $notify(message)$: emits an event or sends a broadcast

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procedure issueOSP (Pk_{author}, $Pk_{learner}$, $message$)
if $getSigner(message) = Pk_{author}$ **then**
  if $Pk_{owner} = Pk_{author}$ **then**
    $Pk_{owner} \longleftarrow Pk_{learner}$
    notify($Pk_{learner}$)
end procedure;

Algorithm 2: Procedure for issuing a Dual Party Signatory Policy (DPSP)

S_{Pk} : public keys of stakeholders S'_{Pk}: public keys of stakeholders who've approved DPSP
$access_{grant}$: indicates if DPSP is approved

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procedure issueDPSP (Pk_{author}, $Pk_{learner}$, $message$)
if $access_{grant} = false$ **then**
  if $Pk_{author} \in S_{Pk}$ *and* $getSigner(message) = Pk_{author}$ **then**
    if $Pk_{author} \notin S'_{Pk}$ **then**
      $S'_{Pk}[Pk_{author}] \longleftarrow 1$
    if $length(S_{Pk}) = length(S'_{Pk})$ **then**
      $Pk_{owner} \longleftarrow Pk_{learner}$
      $access_{grant} \longleftarrow true$
      notify($Pk_{learner}$)
end procedure;

Discovery Policy (DP). In order for an author or a publisher's learning material to show in the e-learning marketplace on BOLL-M, the author is required to install a DP smart contract. This contract contains a basic information about the learning material such as title, date published, version, description, applicable smart contracts (at least one of OSP, DPSP, MPSP). Because the DP smart contract does not contain the actual learning material or pointers to it, it is publicly available to anyone on the network to access but not modify.

Algorithm 3: Procedure for initializing a Multi Party Signatory Policy (MPSP) V_{Pk} : public keys of stakeholders who can vote $Pk_{arbiter}$: public key of arbiter (tie-breaker)
$arbitrate_{start}$: indicates if arbitration should/has started $Poll_{open}$: indicates if voting is still open $Votes_{Pk}$: votes cast $wining\_ratio$: the minimum fraction of total votes required for victory

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procedure initializeMPSP (V_{Pk}, $Pk_{arbiter}$, $wining\_ratio$)
$V_{Pk} \longleftarrow V_{Pk}$
$arbiter \longleftarrow Pk_{arbiter}$
$arbitrate_{start} \longleftarrow false$
$Poll_{open} \longleftarrow true$
$Votes_{Pk} \longleftarrow \{\}$
$wining\_ratio \longleftarrow wining\_ratio$
end procedure;

Algorithm 4: Procedure for issuing a MPSP

Pk_{voter} : voter's public key *message* : a message signed by the voter *vote* : 1 (for) or -1 (against)
$sgn(value)$: signum function

procedure issueMPSP $(Pk_{voter}, message, vote)$
if $Poll_{open}$ **then**
  if $Pk_{voter} \in V_{Pk}$ and $getSigner(message) = Pk_{voter}$ **then**
    $Votes_{Pk}[Pk_{voter}] \longleftarrow vote$
    $\text{totalVotes} \longleftarrow \sum_{i=0}^{length(V_{Pk})} \begin{cases} \text{Votes}_{Pk}[V_{Pki}] & \text{if } V_{Pki} \in Votes_{Pk}. \\ 0 & \text{otherwise.} \end{cases}$
    if $\frac{length(Votes_{Pk})}{length(V_{Pk})} \geq wining\_ratio$ **then**
      $\text{no\_tie} = |\frac{totalVotes}{length(Votes_{Pk})}| \geq \text{wining\_ratio}$
      if no_tie **then**
        $approve \longleftarrow sgn(totalVotes)$
      else
        $arbitrate_{start} \longleftarrow true$
        $notify(arbiter)$
      end
      $Poll_{open} = false$
      $\text{notify}(V_{Pk})$
else if $arbitrate_{start}$ **then**
  if $getSigner(message) = arbiter$ **then**
    $approve \longleftarrow vote$
    $arbitrate_{start} \longleftarrow false$
    $\text{notify}(V_{Pk})$
end procedure;

3.2 Policy Review Kit (PDK)

The PDK contains a set of useful tools for reviewing proposed as well as installed policies or smart contracts. This include policy modifying tools like acceptance, refusal or arbitration, and learning material rating tools. The policy modifying tools are pro-vided to ensure that other parties understand the defined terms before accepting them. Learning material rating tools are useful for helping students find contents that might be appropriate for different scenarios based on the perception of their peers or teachers.

3.3 Content Usage Visualizer (CUV)

We propose an interface for authors and sponsors to visualize the interactions users have made with their learning materials. Since all transactions on the blockchain are written to a public ledger whose contents are immutable, we realize the CUV by querying this public ledger. However, because some functions in the installed smart contracts do not modify state and thus do not lead to transactions, we consider it a necessity that all request to view a learning material should invoke at least, a payable transaction so that access histories can also be written to the ledger. This can be achieved by mandating that all functions used to check access authorizations before responding with the learning material should write on the ledger a message signed by the accessor.

3.4 Data Depository Server (DDS)

We recommend that authors or publishers should store their learning materials on a DDS. For students and teachers who might not be able to setup the publishing tool shown in Fig. 2 (Consisting of CUV, PDK, and a part of PRK), we envisage that their schools would setup a shared publishing tool and a DDS. The DDS is connected to the SecureBox proposed in [8] and all requests sent to the DDS are verified with BOLL through the SecureBox.

3.5 E-Learning Marketplace

The e-learning marketplace is an interface that lists all learning materials published on BOLL-M. For an author's learning material to be displayed in the marketplace, it is required that the author should install a DP smart contract. This contract can be retrieved from the PDK and adapted to the author's use case. An author may also specify that their learning material can be discovered in the marketplace by only selected users.

3.6 Content Interaction Tool (CIT)

To ensure that intellectual rights of authors are not violated, we recommend that the tool for viewing escrowed learning materials, here referred to as Content Interaction Tool (CIT), should be connected to BOLL. In Fig. 2, we use BookRoll, a digital book reader as our CIT. BookRoll traditionally logs user interactions with digital books including bookmarking, highlights, page turns, etc. We consider these interactions enough to know when a user accesses an escrowed learning material. For recording a simple interaction on BOLL-M, one can simply log an access event when the content is being served for the first time. In a case where monitoring more interactions is desired, we can listen to specific events of the CIT. As BookRoll stores user logs on a Learning Record Store (LRS), it is possible to listen to page turn events and subsequently notify BOLL-M of these interactions. We note that monitoring of the user's interactions can be an invasion of privacy. Hence, we recommend that this should only be done according to the terms of the smart contracts.

4 Discussion

What Should Authors Track? By default, authors should only be aware of direct access such as a request to serve a given learning material. But in a case where detailed interactions such as page views are required to calculate cost, users should be informed during the policy review phase by selecting an appropriate smart contract. In turn, the CIT can then query BOLL-M before feeding forward any interaction events to the concerned smart contracts if required.

Collaborative Content Authoring. In a situation where two or more authors want to in-dependently improve a particular learning material, BOLL-M should provide a medium for such collaboration. This can be achieved through a version control mechanism with each author ascribing a particular smart contract to their own section. A simple approach might be to consider these versioned sections as either preceding or succeeding learning material depending on the changes time-line.

Rewarding Intellectual Contribution. Students who interact with certain learning materials, contribute useful learning materials and/or solve quiz problems could be rewarded with points. These points can then be traded for other learning materials or digital assets on BOLL-M or on other platforms.

5 Limitations

When a learning material is illegally reproduced outside the CIT, the reproduced version is no longer within the control of BOLL-M to manage its authorship rights. While this is a challenge, we recommend the development of interactive features within the CIT that renders any illegal reproduction unattractive and deficient in serving the original purpose. Also, in our proposed framework, we assume that authors and/or publishers will provide high quality learning materials. To detect content quality and/or plagiarism on BOLL-M, it is required to analyze contents of submitted learning materials. While we consider this to be outside the scope of our current framework, we suggest that users should take advantage of the PRK and report suspected plagiarized works through it.

6 Conclusion and Future Work

In this work, we proposed a framework for enabling decentralized e-learning marketplace on BOLL. This framework facilitates managing of intellectual rights, tracking access and fostering collaboration between different users, authors and publishers. We described how authors can define terms of use on their learning materials and how students can access these learning materials on the blockchain where their privacy is not violated. Alongside other smart contracts, MPSP smart contract plays an important role in facilitating collaborative policy formulation, learning material sponsorship and verifiable proof of learning material consumption. Future work will be focused on providing a concrete implementation of this framework on BOLL towards enabling BOLL as a wide-reaching system.

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