Smart Contracts for e-Learning

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I would like to dedicate this paper to Mum, Dad, Vivien, Viviana and Jorden.

Abstract

The properties of a blockchain could bring new features to e-Learning. Properties such as immutability and peer executed smart contracts could bring a new level of trust, transparency and personalisation to the education market.

This project focused on features that would improve the experiences of students and teachers in assessments, and curriculum personalisation. They were identified as two of the key concerns in the current UK higher education industry that can be improved by a blockchain powered e-Learning platform.

The logic of the smart contracts and data models for such a platform were proposed. A working prototype was also developed based on the IBM Hyperledger Composer project.

Acknowledgements

The formatting of this report is done with Krishna Kumar's Cambridge University Engineering Department PhD thesis LaTeX template, and with referrence to a Microsoft Word template provided by Dr. Simon Kent.

The following open source software libraries and free resources were used to complete the demonstrator:

- Material Icons, from https://material.io/icons/
- Vue.js framework, from https://vuejs.org/
- Vue Material package, from https://vuematerial.io/
- vue-youtube-embed component, from https://github.com/kaorun343/vue-youtube-embed

Declaration

I hereby declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other university. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements.

Tsz Yiu Lam

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Academic Year 2017 - 2018

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Chapter 1

Introduction

The global e-Learning industry already generates US$60 billion per year, and by 2019, over half of all courses will be taken online (Pantò and Comas-Quinn, 2013, p.17). This rising trend presents an opportunity to improve higher education.

Some current problems in higher education are related to transparency (more in Chapter 2.2.1). Tension exists between the educational provider and the learners over assessments. "There is abundant evidence that assessors are not particularly good at making exams valid, reliable, or transparent to students." (Brown Jr, 1999, p.62).

There is also a lack of curriculum personalisation for higher education learners in the UK [TODO: cite interviews, other refs] Condie and Munro (2007) pointed out that the personalisation of the education curriculum for learners helps "overcome barriers, raising self-esteem and achievement".

Being able to deliver education curricula and conduct assessments in a transparent, conflict-free way would be central to a future e-Learning marketplace that is open, trusted and autonomous. This is where immediate value could be provided by blockchain systems and smart contracts.

A blockchain is a type of database that is spread across multiple sites, such as different institutions, companies or participants. A "block" of records is "chained" to the next with a cryptographic signature, creating permanent records through a consensus corroborated by all the operators. (Walport, 2016, p.17) The verifiability of all actions on a blockchain gives systems an inherently high degree of integrity and transparency. Some types of blockchain can also have permissions that enables granular transparency and privacy (Walport, 2016, p.22), which fits well in the education paradigm where personal data can be highly sensitive.

Smart contracts are "contracts" that are "defined by the code and executed (or enforced) by the code" (Swan, 2015, p.16). They are logic embedded in a blockchain that defines the rules and penalties around an agreement and could automatically enforce those obligations (Gulhane, 2017), and can be used to exchange or transfer digital assets when certain conditions are met.

The potential of blockchain enabled systems in education has been noted by the community, with Swan (2015, p.62) proposing that “learning smart contracts could automatically confirm the completion of learning modules through standardized online tests”. Appropriate configurations in permissions and visibility can also provide improved security and privacy to e-Learning.

1.1 Aims and Objectives

The aim of the project is to design an e-Learning platform that fulfill educational assessments and rewards with smart contracts on a blockchain, providing improvements in assessments and curriculum personalisation for learners and teachers.

To satisfy this aim, the following objectives were planned:

1. Identify issues in education and e-Learning that can be improved by a blockchain-based system.

2. Propose data models and the smart contract logic in the proposed blockchain for e-Learning.

3. Propose permission models for the e-Learning blockchain that balances appropriate access and privacy protection.

4. Build a demonstrator system that includes client side applications for learners and teachers.

1.2 Project Approach

1. Review literature on current issues in e-Learning and education, and existing work in blockchain in education.
2. Further gather requirements for a blockchain solution for e-Learning using interviews with stakeholders.
3. Design data models, smart contracts and permission rules for assets and participants in the proposed blockchain solution.
4. Analyse popular blockchain development platforms that can be used to produce the desired solution.
5. Build the distributed ledger network and client side applications for learners and teachers.
6. Evaluate the design of the deliverables using interviews with stakeholders and relevant subject matter experts.

1.3 Dissertation Outline

Chapter 2 discusses the background for my project, and identifies some key techniques that can be adopted during the development of the proposed solution.

Chapter 3 explains how the project will be undertaken . . . etc, etc.

Chapter 4 requirements incl. primary data from interviews

Chapter 5 design

Chapter 6 implementation

Chapter 7 evaluation

Chapter 8 conclusion, future work

Chapter 2

Background

2.1 Properties of Blockchain Technologies

The advent of cryptocurrencies made blockchains an overnight darling, set to make significant disruptions in several industries such as financial services, currency exchanges, supply chain management, retail advertising and identity management (Bessonov, 2017).

The blockchain data structure is a timestamped list of blocks, which stores data about transactions that occur within the blockchain network. It only allows the insertion of transactions, not the update or deletion of existing transactions. Its ability to prevent tampering is known as "immutability". (Xu et al., 2016, p.182)

Blockchains can be classified into two types: one being a permissionless (public) blockchain which anyone can use and no central authority exist to allow or ban peers; the other a permissioned blockchain (usually private) where a central entity assigns read/ write rights to individual peers (Wüst and Gervais, 2017, p.1). These two types of blockchain each provide varying degrees of the properties summarised in table 2.1.

Using blockchains as a data storage gives the system a very high degree of integrity. The public verifiability, redundancy (see table 2.1) and immutability of the blockchain makes it very difficult to corrupt or lose the data stored.

Table 2.1 Comparison of permissioned and permissionless blockchains, modified from Wüst and Gervais (2017, p.3)

Properties	Permissioned blockchains	Permissionless blockchains
Speed	Low throughput and slow latency	high throughput and medium latency
Peers	High number of both readers and writers	High number of readers, small group of writers
Consensus	Proof of work or proof of stake by miners	BFT protocols such as PBFT
Central Authority	No	Yes
Privacy	Can be achieved using cryptographic techniques but typically comes at the cost of lower efficiency	Reading rights can be restricted by central authority, readers and writers can also run separated parallel blockchains that are interconnected.
Verifiability	Observers can verify the state of the blockchain	
Redundancy	High, provided through replication across the peers	

2.1.1 Decision Framework for Blockchain Solutions

Wüst and Gervais (2017, p.3) proposed a decision flowchart (figure 2.1) to determine whether a blockchain is the appropriate solution for a problem, and which type of blockchain is the most appropriate. We could analyse our problem at hand using these steps:

1. **Do you need a store state?** Yes. Records in an e-learning system require secure storage.

2. **Are there multiple writers?** Yes. There are many different authorities, institutions, educators and learners involved in an e-learning blockchain that demands write assess into records.

3. **Can you use an always online Trusted Third Party (TTP)?** Wüst and Gervais (2017, p.2) described two options of using a TTP: delegate write operations completely to the TTP if it is always online so that it verifies all state transitions, or use the TTP as a

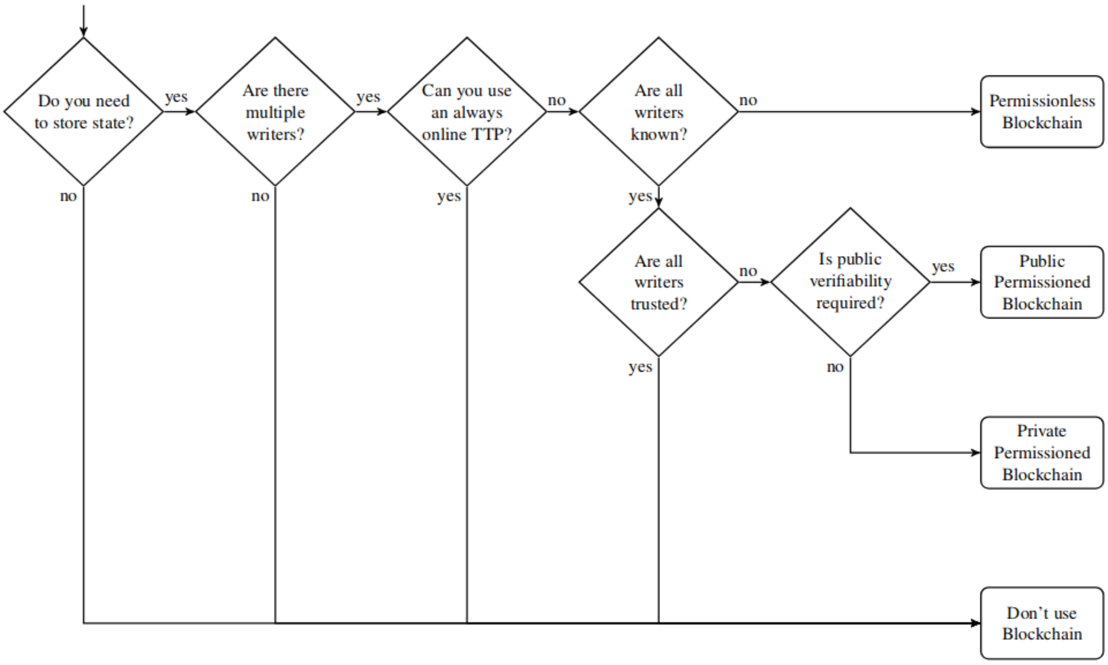

Fig. 2.1 "Do you need a blockchain?" flowchart (Wüst and Gervais, 2017, p.3)

certificate authority in the setting of a permissioned blockchain if the TTP is usually offline.

In the e-learning context, a TTP could be the e-learning platform provider. However, the delegation of write operations to the platform goes against modern principles of autonomy and independence for higher education institutions. Governmental education ministries in most modern states audits and regulates higher education without writing student records or conferring degrees. An always online TTP should not be used in order to replicate the real world context. This project will answer no for this step.

4. **Are all writers known?** Yes. Users of the system should be registered and not be anonymous to the system administrators. [TODO: Why? Are there arguments to anonymous education?]

5. **Are all writers trusted?** No. Malpractices from education institutions can occur, especially in the private, for-profit sector. In a future open e-learning market, it could

also be possible for anyone to start offering education services. We cannot assume that all writers are trusted.

6. **Is public verifiability required?** Yes. One of the objectives of this project is to boost trust in e-learning credentials by increasing public verifiability of education journeys, increasing public accountability especially for stakeholders such as employers and postgraduate studies providers.

This process led to the recommendation of a **public permissioned blockchain** for this project.

2.1.2 Properties of Smart Contracts

Again, smart contracts are logic embedded in a blockchain that defines the rules and penalties around an agreement and could automatically enforce those obligations (Gulhane, 2017). The term "chaincode" is also used interchangeably as a synonym for smart contracts (Valenta and Sandner, 2017, p.6).

There are three main properties of smart contracts:

- **Autonomous**: after launching and running, no further communication is required between a smart contract and its initiating agent;
- **Self-sufficient**: a smart contract should have the ability to keep itself alive when it needs to be, such as raising funds by providing services, and spending them on computing power or storage;
- **Decentralised**: a smart contract does not exist on a single server, they are distributed and self-executing across all of the blockchain peers.
  Swan (2015, p.16)

2.2 Review of Relevant Education Research

Identifying issues in traditional higher education today that a future system can better tackle is one of the objectives of this project. This informs the scope of the project and the design of the deliverables.

There is an abundant amount of pedagogy and learning method research, which focuses on the instruments and mode of delivery. These include methods such as "scaffolding", "constructivism", "problem-based learning", and "active learning" (Ali, 2005). However, this research area is considered out of the scope of discussion for this project, which does not aim to provide new insight into ICT-enhanced pedagogies, nor will it be designed around any preferred pedagogies. This project is interested in representing components of e-learning, such as delivery, assessment, and record keeping in a more generic, general purposed manner.

2.2.1 Assessments and Transparency

Assessment is arguably the most important process in the business of education as it "drives what is learnt and taught" and "convert learning into credentials". (Campbell, 2010, p.160)

Brown Jr (1999) summarised examples of popular sentiments learners held about both continuous assessments and traditional exams, such as:

1. Assessment tasks do not increase students' want to learn, only their need to learn, promoting unhappiness;
2. Invalid and unreliable marking due to speed or fatigue of assessors, plagiarism and unwanted collaborations, etc.;
3. Sub-optimal levels of feedback after many types of assessments;
4. Students feel forced into surface learning
   (Brown Jr, 1999, p.62-65)

The importance of assessments, coupled with popular unhappiness and mistrust amongst learners towards them, grows the tension between the teacher (or educational provider) and the learners.

Suhre et al. (2013) looked into motivation on study progress in a higher education setting by collecting data from 168 first-year university students for six months. The study found three main factors that motivates academic progress: intrinsic abilities, personal motivations such as a need to achieve or fear of failure, and transparency in exams and assessments.

Transparency here refers to both the clarity of assessment goals and the procedures for assessing these goals. It should be clear to learners what knowledge is required for a sufficient level of mastery. (Suhre et al., 2013) The difference this makes was significant:

- Students' perceptions of degree programme organization and transparency of exams are significantly correlated with academic performance;
- Academic pressure is substantially influenced by the perceived transparency of assessments.

An improvement in the transparency of goals, procedures, knowledge required of assessments and an increase in feedback can directly tackle some of the negative sentiments listed above from Brown Jr (1999), such as 1, 2 and 3.

2.2.2 Personalisation in Education

[TODO: Cover personalisation broadly and in terms of curriculum (which modules to take, customised passing thresholds) which can be negotiated on the blockchain. To be added if there is time for the project to cover this area.]

2.3 Literature Review in e-Learning

E-learning has been growing as an industry and research area, and various standards have been devised. A review of these frameworks could provide valuable insights.

2.3.1 e-Learning Systems

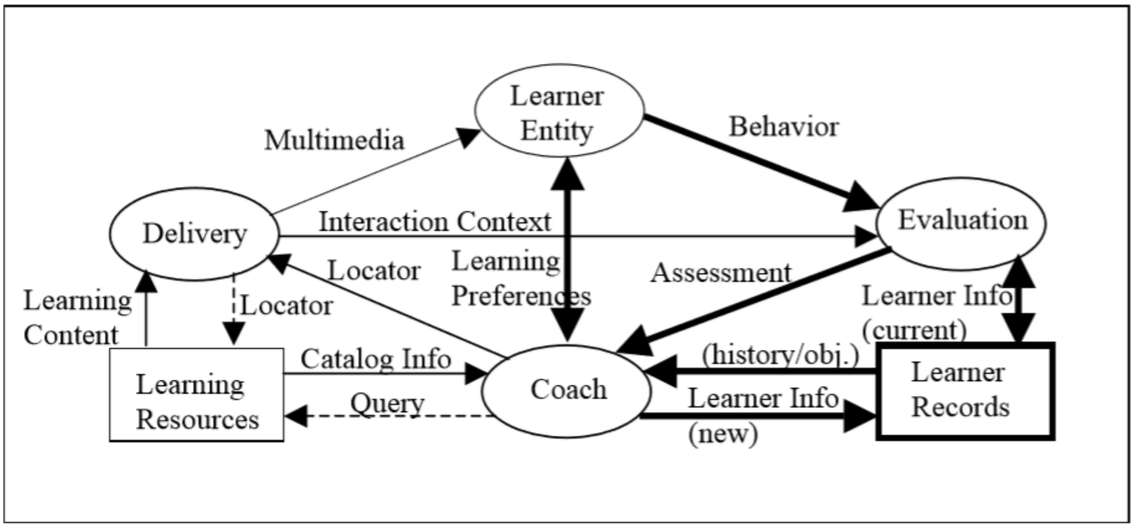

Fig. 2.2 Learning Technology Systems Architecture, IEEE P1484.1/D9 (Farance and Tonkel, 1999)

IEEE P1484.1/D9: the Learning Technology Systems Architecture (LTSA) provides a valuable way of organising the scope and discussion in this project. It identified four main components: learner entity, coach, delivery and evaluation; and two main resources: learning resources and learner records (See figure 2.2).

Identifying the properties of a blockchain-based system that could improve these components is critical to this project. For example, the distributed, immutable storage of learner records could provide extra security.

2.3.2 e-Learning Research Framework

Garrison (2011) provided a framework for research and practice called the "Community of Inquiry (CoI)" framework, which included three main categories:

1. Enhancing the social presence, such as collaborative learning
2. Enhancing the cognitive presence, such as practical inquiry and critical thinking

3. Enhancing the teaching presence, especially with asynchronous e-Learning (eg. pre-recorded lectures)

A blockchain back-end could potentially provide experiential improvements in the above three categories as well. For example, smart contracts could enhance the social and teaching presence by facilitating teacher-learner, or learner-learner negotiations.

2.3.3 Security and Privacy

The security of e-learning systems have also been a concern. For example, El-Khatib et al. (2003) noted that “while many advances have been made in the mechanics of providing online instruction, the needs for privacy and security have to-date been largely ignored. At best they have been accommodated in an ad-hoc, patchwork fashion.”

The consequences of cybersecurity breaches have also become more and more expensive. For example, when the General Data Protection Regulation (GDPR) comes into effect across Europe in May 2018, the maximum fine for poor practices and data breaches will be £17 million or 4% of global turnover (Denham, 2017).

The scale and severity of historic breaches of of internet services has been worrying. Most notably in the e-learning industry, the education platform Edmodo was hacked and 77M account details were lost and on sale on the dark web, endangering students, teachers and parents who are account holders (Opsecmonkey, 2017).

The sizable threat and consequences makes a "security by design" and "privacy by design" approach for future e-Learning systems very important.

2.4 Existing Efforts in Blockchain for Education

2.4.1 Blockcerts

Blockcerts is an open standard for blockchain certificates led by MIT’s Media Lab. Education providers can use it to store the records of certifications they have awarded (See figure 2.3).

One bitcoin transaction is performed for every batch of certificates, with the certificates stored in the OP_RETURN transaction field on the bitcoin blockchain. This is paid for by the certificate issuer. (blockcerts.org, 2018)

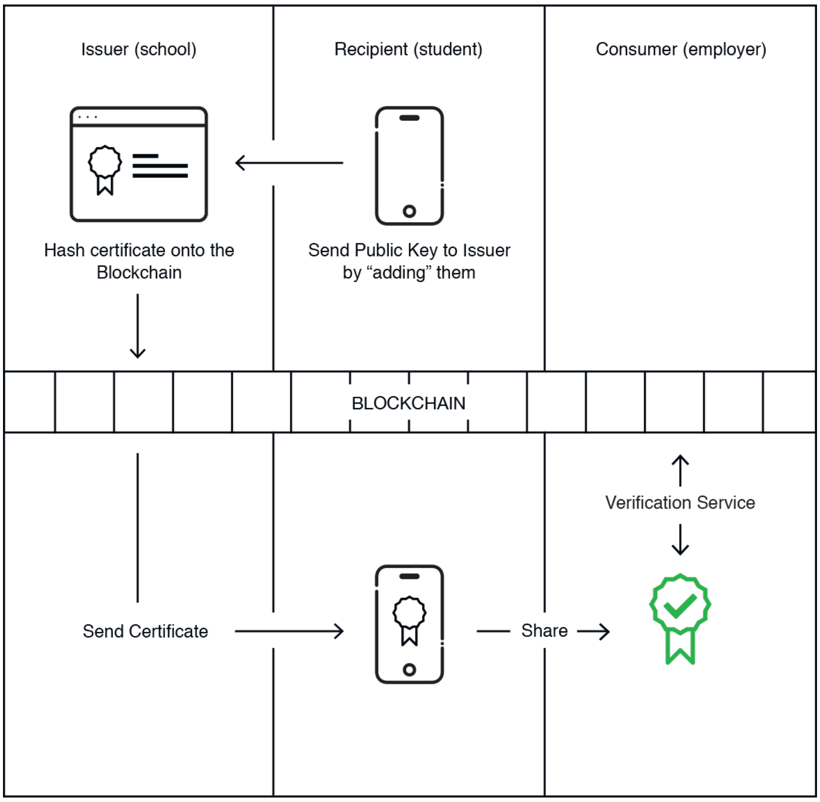

Fig. 2.3 How Blockcerts work (blockcerts.org, 2018)

2.4.2 Sony Global Education Blockchain

The Sony Global Education Blockchain is based on the Hyperledger project, an open source distributed ledger for businesses. It provides an application program interface (API) for developers at education institutes, allowing integration with third party applications. It aims to provide tamper-proof, secure storage of learning history data for institutions. (Sony Global Education, 2017)

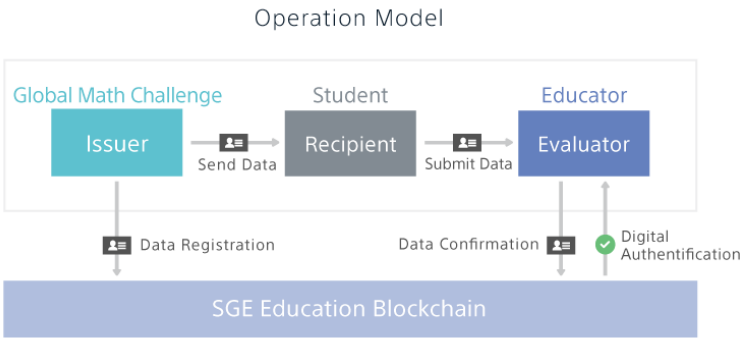

Fig. 2.4 Operation Example of the Sony Global Education Blockchain (Sony Global Education, 2017)

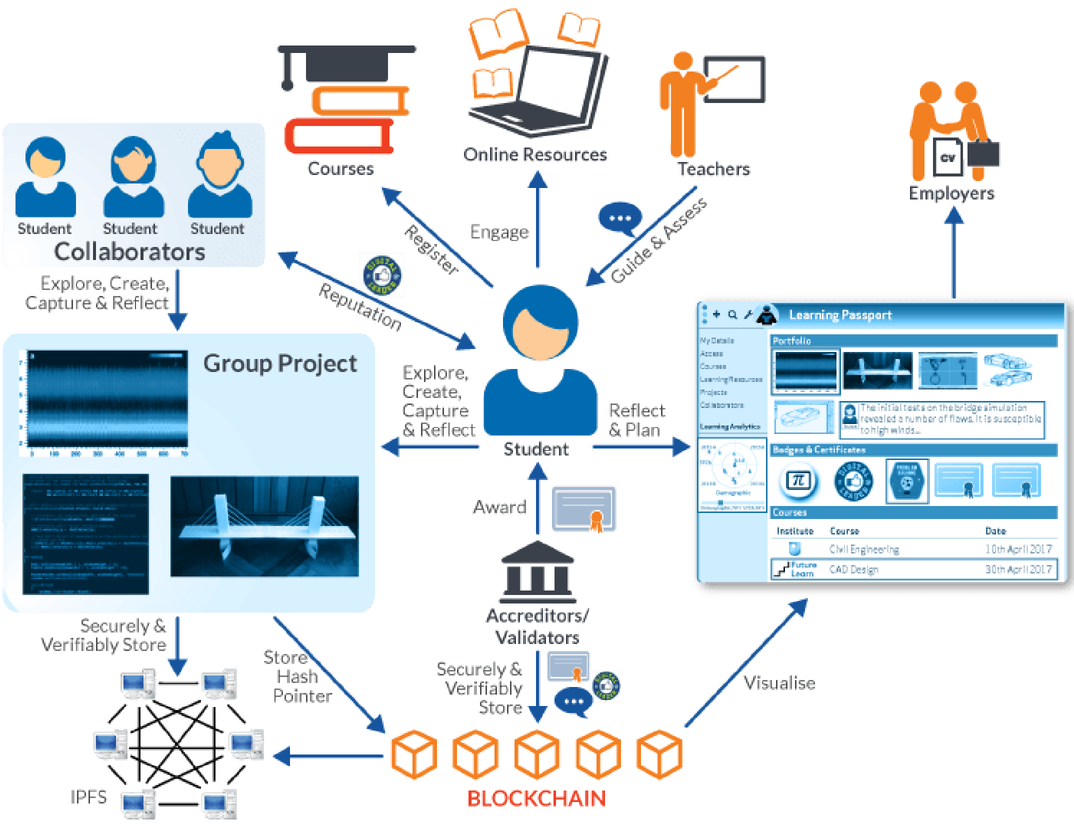

Fig. 2.5 A typical education scenario with the OpenLearn Blockchain(Open University, 2018)

2.4.3 OpenLearn Blockchain

The OpenLearn Blockchain project envisions the creation of blockchain based ePortfolios (See figure 2.5). They are currently demonstrating this with an experimental plugin for

Moodle, a popular course management system, with which achievement badges can be stored on the Ethereum blockchain. This system currently allows students to register for courses and receive badges which can be viewed in a student Learning Passport. The transactions are peer-to-peer: in principle no host institution is required for the awarding of accreditation. (Sharples and Domingue, 2016)

2.4.4 Novelty of the proposed project

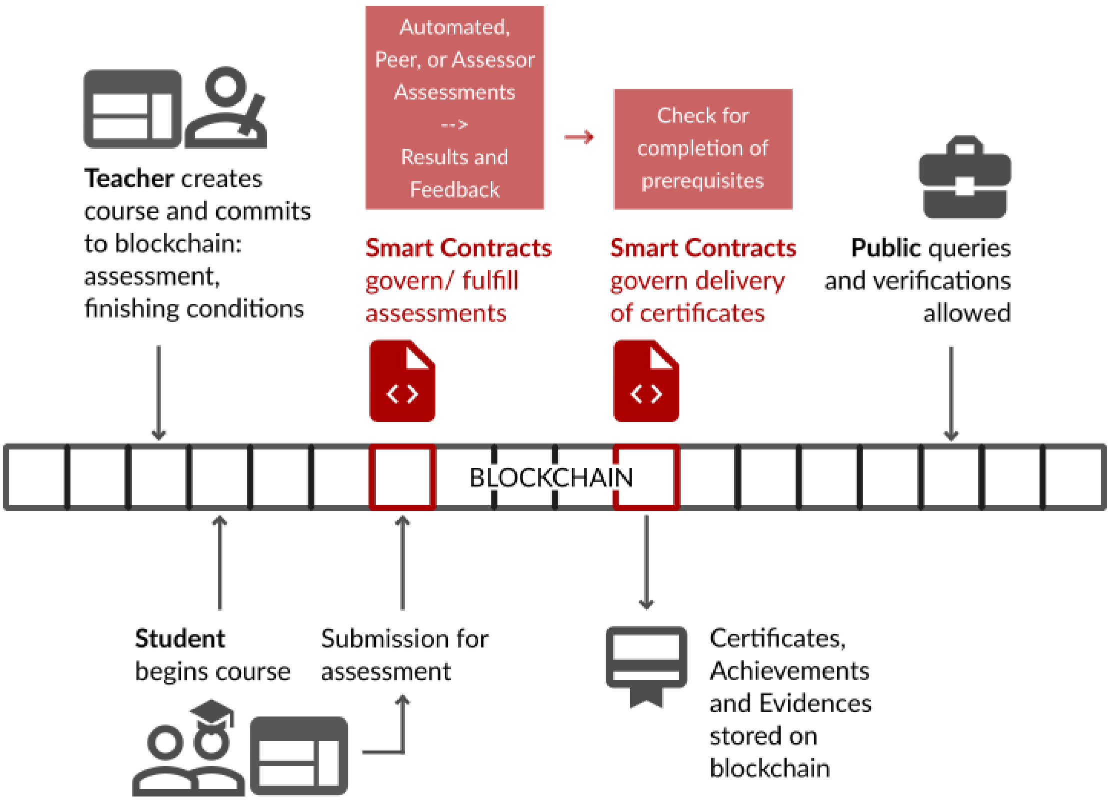

Fig. 2.6 Original diagram providing a high level view of how the project proposes automating assessments with smart contracts

All of the above three notable efforts focus on identity management and record keeping for education. This project will aim to extend these efforts by proposing smart contracts that automate assessments (See figure 2.6) and deliver personalised curricula.

The vision of this project will also be to create an e-Learning marketplace that teachers can use directly, instead of a blockchain network that education providers will have to consume through APIs. This makes for a lower cost of entrance in terms of technological know-how and investment.

2.5 Overview of Blockchain Development Toolkits

This project will involve the design of smart contracts for e-Learning transactions and building a demonstrator network and applications. A review of the popular blockchain implementations and development toolkits on the market is necessary. See table 2.2 for a overview and below for more commentary.

Table 2.2 Comparison of key blockchain implementations, adapted from IBM Blockchain (2018) and Valenta and Sandner (2017)

	Bitcoin	Ethereum	Hyperledger Fabric	R3 Corda
Crypto-currency	bitcoin	ether, user-created cryptocurrencies	none, user-created cryptocurrencies	none
Network	permissionless, public	permissionless, public or private	permissioned, private	permissioned, private
Transactions	anonymous	anonymous or private	public or confidential	
Consensus	proof of work	proof of work	PBFT	PBFT
Smart Contracts	none	yes (Solidity, Serpent, LLL)	yes (chaincode)	yes (chaincode)
Language	C++	Golang, C++, Python	Golang, Java, JavaScript	Kotlin, Java, legal prose

Bitcoin is included in the table only as a point of reference, building with the bitcoin blockchain is not considered for this project because of its lack of support for smart contracts (any kind of embedded logic or programmes).

Ethereum

Ethereum is famous for its Turing-complete smart contracts capabilities, which allows entire decentralised applications (dApps) to run autonomously on its blockchain. It has a build-in cryptocurrency "Ether", which is used to reward miners that contribute to consensus, and to pay transaction fees. Developers of dApps can also issue their own currency inside their smart contracts.

Valenta and Sandner (2017, p.3-4) noted that compared with Ethereum, which makes records accessible to all participants, permissioned blockchains such as Fabric and Corda provide "more fine-grained access control to records and thus enhance privacy". They also achieves higher performance due to a faster consensus mechanism that does not involve mining.

For this project, another crucial consideration against the adoption of the Ethereum environment is the lack of a central authority, which makes it impossible for the platform to kick unscrupulous actors off the blockchain.

Hyperledger Fabric

Valenta and Sandner (2017, p.7) described Fabric as a highly flexible "versatile toolbox". It has different roles for peers within the network, where they can act as clients (end users), peers (record keepers), endorsers (transaction verifiers), or orderers (transaction requester). The consensus mechanism is by default a Byzantine fault-tolerant (BFT) algorithm but can be customised. A cryptocurrency is not required, but could be developed with chaincode.

R3 Corda

Built following use cases in the financial industry, Corda notably augmented smart contracts with legal prose, making it a great tool for highly regulated environment. The development of a cryptocurrency is not intended or supported. (Valenta and Sandner, 2017)

Summary

Combining the recommendation from

Chapter 3

Approach

3.1 Scope

3.2 Agile Project Management

3.3 Software Development and Testing

Chapter 4

Requirements Elicitation

primary data

4.1 Methodology

4.2 Interviews with Education Professionals

And now I begin my third chapter here . . .

4.3 Interviews with Student Representatives

Chapter 5

Design

5.1 Choice of Blockchain Development Ecosystem

5.2 Participants, Assets and Transactions in the Blockchain Network

And now I begin my third chapter here ...

5.2.1 Access and Permissions on Assets

5.3 Logic and Events in Smart Contracts

5.4 User Interfaces for Client Applications

Chapter 6

Implementation

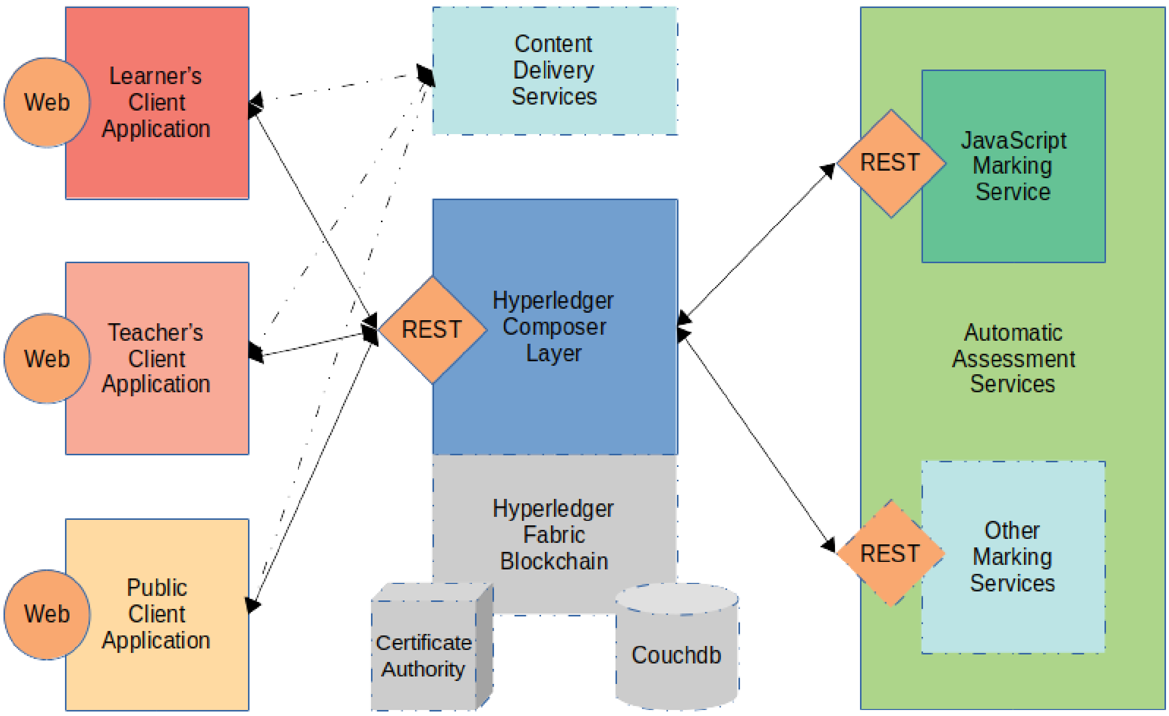

Fig. 6.1 Technical architecture overview for the demonstrator system built

6.1 CLI and API

6.2 Learner Client Application

6.3 Teacher Client Application

Chapter 7

Evaluation

purpose of eval

7.1 Methodology

instruments: appdx

sample

7.2 Interviews with Education Professionals

7.3 Interviews with Student Representatives

7.4 Analysis

7.5 Conclusion

Chapter 8

Conclusion

8.1 Future Work

- tests embedded in smart contracts instead of rest calls, which may not always be available

- consensus model for double marking, etc

-

and here I write more ...

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Appendix A

How to install LaTeX

Windows OS

TeXLive package - full version

1. Download the TeXLive ISO (2.2GB) from
   https://www.tug.org/texlive/
2. Download WinCDEmu (if you don't have a virtual drive) from
   http://wincdemu.sysprogs.org/download/
3. To install Windows CD Emulator follow the instructions at
   http://wincdemu.sysprogs.org/tutorials/install/
4. Right click the iso and mount it using the WinCDEmu as shown in
   http://wincdemu.sysprogs.org/tutorials/mount/
5. Open your virtual drive and run setup.pl

or

Basic MikTeX - TeX distribution

1. Download Basic-MiKTeX(32bit or 64bit) from
   http://miktex.org/download
2. Run the installer
3. To add a new package go to Start » All Programs » MikTex » Maintenance (Admin) and choose Package Manager

4. Select or search for packages to install

TexStudio - TEX editor

1. Download TexStudio from
   http://texstudio.sourceforge.net/#downloads

2. Run the installer

Mac OS X

MacTeX - TEX distribution

1. Download the file from
   https://www.tug.org/mactex/

2. Extract and double click to run the installer. It does the entire configuration, sit back and relax.

TexStudio - TEX editor

1. Download TexStudio from
   http://texstudio.sourceforge.net/#downloads

2. Extract and Start

Unix/Linux

TeXLive - TEX distribution

Getting the distribution:

1. TexLive can be downloaded from
   http://www.tug.org/texlive/acquire-netinstall.html.

2. TexLive is provided by most operating system you can use (rpm,apt-get or yum) to get TexLive distributions

Installation

1. Mount the ISO file in the mnt directory

   ```
   mount -t iso9660 -o ro,loop,noauto /your/texlive####.iso /mnt
   ```

2. Install wget on your OS (use rpm, apt-get or yum install)

3. Run the installer script install-tl.

   ```
   cd /your/download/directory
   ./install-tl
   ```

4. Enter command ‘i’ for installation

5. Post-Installation configuration:
   http://www.tug.org/texlive/doc/texlive-en/texlive-en.html#x1-320003.4.1

6. Set the path for the directory of TexLive binaries in your .bashrc file

For 32bit OS

For Bourne-compatible shells such as bash, and using Intel x86 GNU/Linux and a default directory setup as an example, the file to edit might be

```
edit $~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/i386-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;
export INFOPATH
```

For 64bit OS

```
edit $~/.bashrc file and add following lines
PATH=/usr/local/texlive/2011/bin/x86_64-linux:$PATH;
export PATH
MANPATH=/usr/local/texlive/2011/texmf/doc/man:$MANPATH;
export MANPATH
```

```
INFOPATH=/usr/local/texlive/2011/texmf/doc/info:$INFOPATH;
export INFOPATH
```

Fedora/RedHat/CentOS:

```
sudo yum install texlive
sudo yum install psutils
```

SUSE:

```
sudo zypper install texlive
```

Debian/Ubuntu:

```
sudo apt-get install texlive texlive-latex-extra
sudo apt-get install psutils
```

Appendix B

Installing the CUED class file

LaTeX.cls files can be accessed system-wide when they are placed in the <texmf>/tex/latex directory, where <texmf> is the root directory of the user's TeXinstallation. On systems that have a local texmf tree (<texmflocal>), which may be named "texmf-local" or "localtexmf", it may be advisable to install packages in <texmflocal>, rather than <texmf> as the contents of the former, unlike that of the latter, are preserved after the LaTeXsystem is reinstalled and/or upgraded.

It is recommended that the user create a subdirectory <texmf>/tex/latex/CUED for all CUED related LaTeXclass and package files. On some LaTeXsystems, the directory look-up tables will need to be refreshed after making additions or deletions to the system files. For TeXLive systems this is accomplished via executing "texhash" as root. MIKTeXusers can run "initexmf -u" to accomplish the same thing.

Users not willing or able to install the files system-wide can install them in their personal directories, but will then have to provide the path (full or relative) in addition to the filename when referring to them in LaTeX.