

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 distributed ledger 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 distributed ledger 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 reference 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.

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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 distributed ledger systems and smart contracts.

A distributed ledger is a type of database that is spread across multiple sites, such as different institutions, companies or participants. Validators or operators of this ledger are trusted not to collude and defraud actors in a transaction. The technology enabling this

distributed ledger is popularly known as a blockchain, where a block of records is chained to the next with a cryptographic signature, creating immutable records through a consensus corroborated by all the operators. (Walport, 2016, p.17) The security, immutability and verifiability of all actions on a blockchain makes systems inherently transparent, whereas a ledger 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 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).

There are two types of blockchains: one being a public and permissionless blockchain, and the other a private and permissioned blockchain (Wüst and Gervais, 2017, p.1). These two types of blockchain each provide varying degrees of the following properties:

- **Public Verifiability**

Permissionless blockchains provide a maximal degree of public verifiability, because every addition to the blockchain is confirmed by verifiers/ miners, and any observers can verify the state of the blockchain.

Permissioned blockchains are more centralised with an amount of trust required for a central authority that acts as an administrator for all peer servers. Additions to the blockchain is achieved by an agreed consensus mechanism.

- **Privacy**

Permissionless blockchains provide maximal verifiability and transparency, but could

- Integrity
- Redundancy

(Wüst and Gervais, 2017, p.2)

Impossible to collude: executed by transparent code, increase trust and enables reputation building for even new entrants to the education market Protects learner: guaranteed records and rewards Administration costs of higher education Smart Contract: secure and cutting the middleman

Public v. Private

Permissionless v. Permissioned

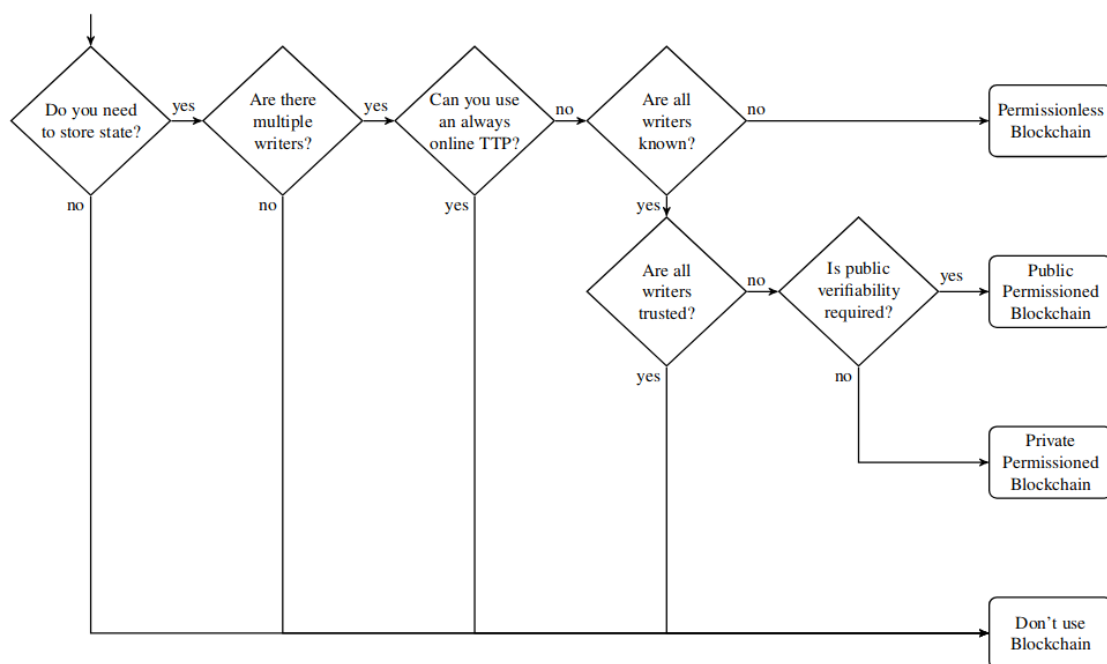


Fig. 2.1 Do you need a blockchain? flowchart (Wüst and Gervais, 2017, p.3)

Characteristics of a blockchain ledger such as Hyperledger: 1. Shared Ledger: shared across education and government authorities 2. Smart Contract: Swan (2015, p.62) proposed that “rules embedded in learning smart contracts could automatically confirm the completion of learning modules through standardized online tests”. 3. Privacy: a. Appropriate Visibility

b. Transactions are secure, authenticated and verifiable 4. Consensus: All shared ledger parties agree to transactions

Openness and transparency of online courses and online assessments is encouraged: using an interpreted language, instead of a compiled one, to write the smart contract, so the actual code is visible on the blockchain and can be easily inspected be removed or altered Resilient to loss of infrastructure: records are distributed over a network of participating computers

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 also 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

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

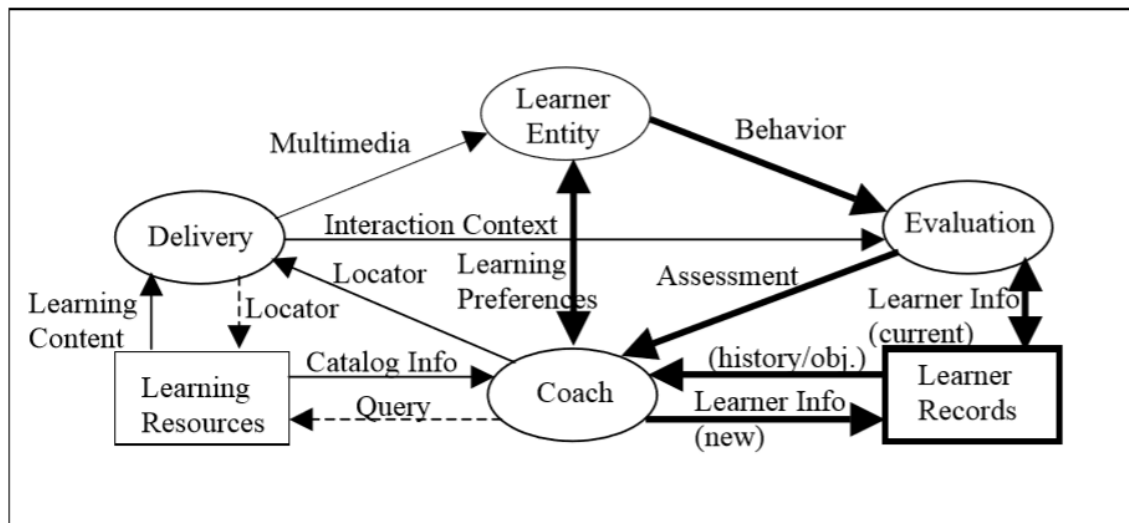


Fig. 2.2 Learning Technology Systems Architecture, IEEE P1484.1/D9 (Farance and Tonkel, 1999)

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 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)

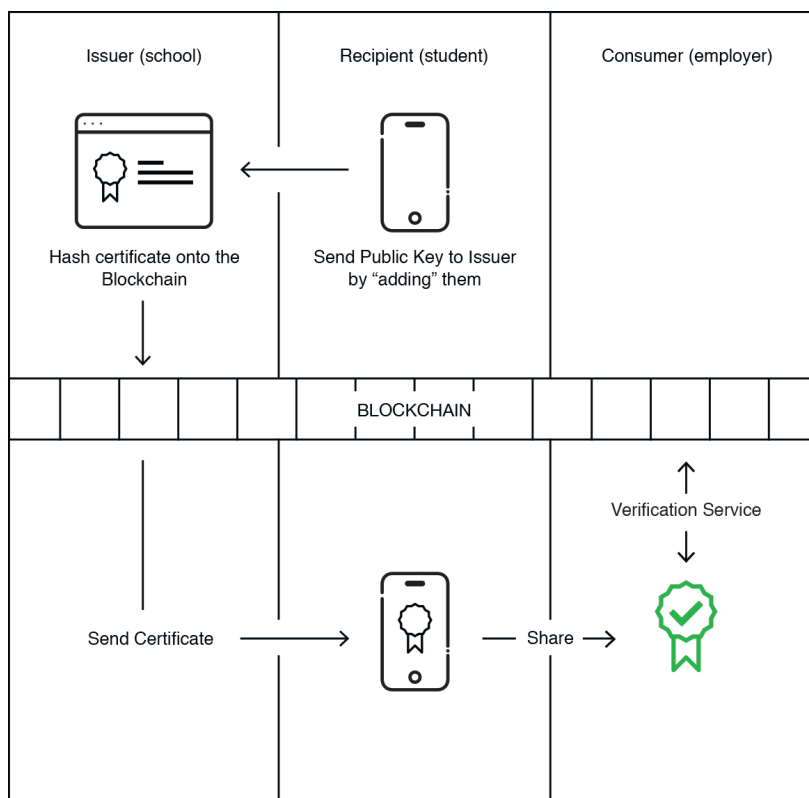


Fig. 2.3 How Blockcerts work (blockcerts.org, 2018)

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)

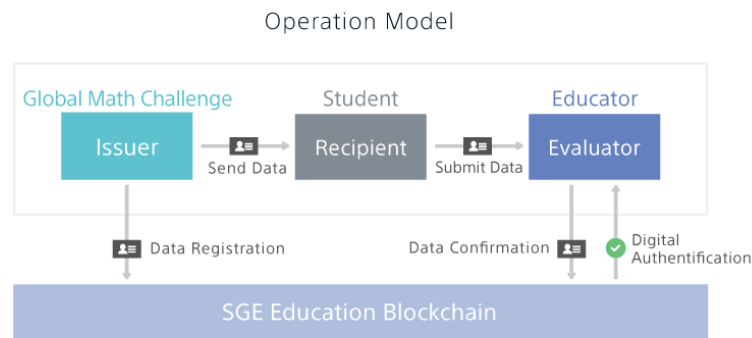


Fig. 2.4 Operation Example of the Sony Global Education Blockchain (Sony Global Education, 2017)

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

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.

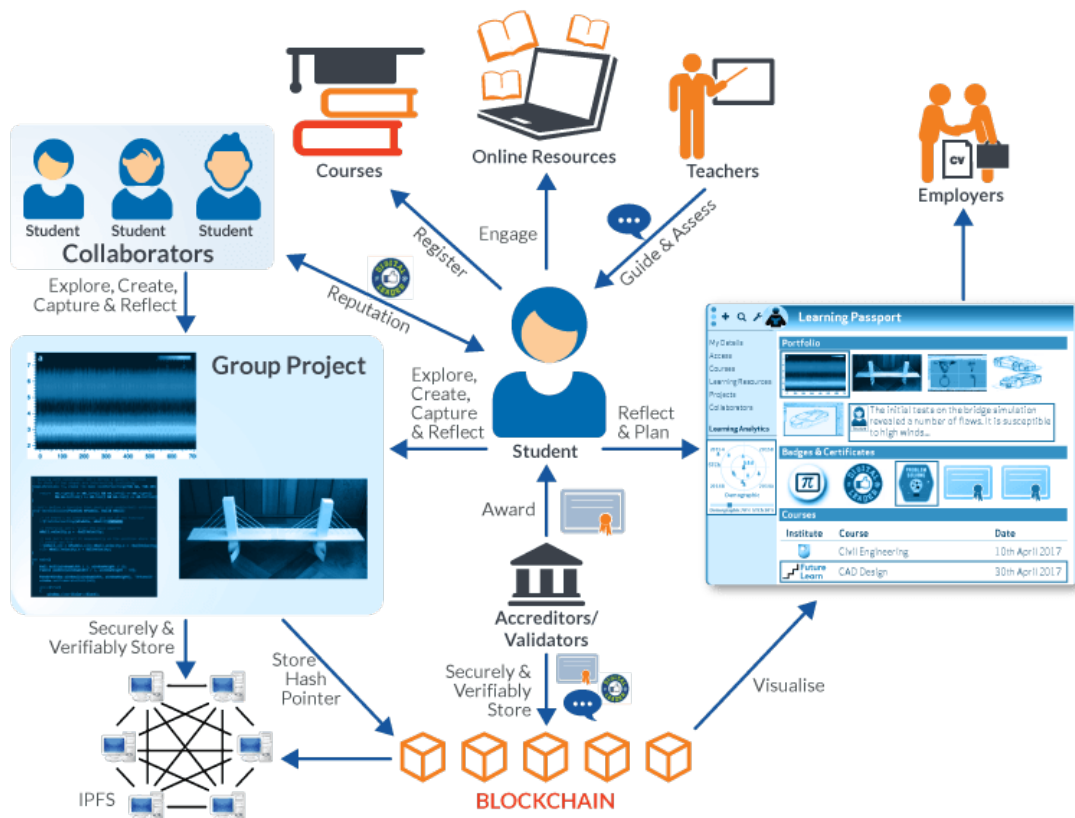


Fig. 2.5 A typical education scenario with the OpenLearn Blockchain(Open University, 2018)

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 2.1 for a overview and below for more commentary.

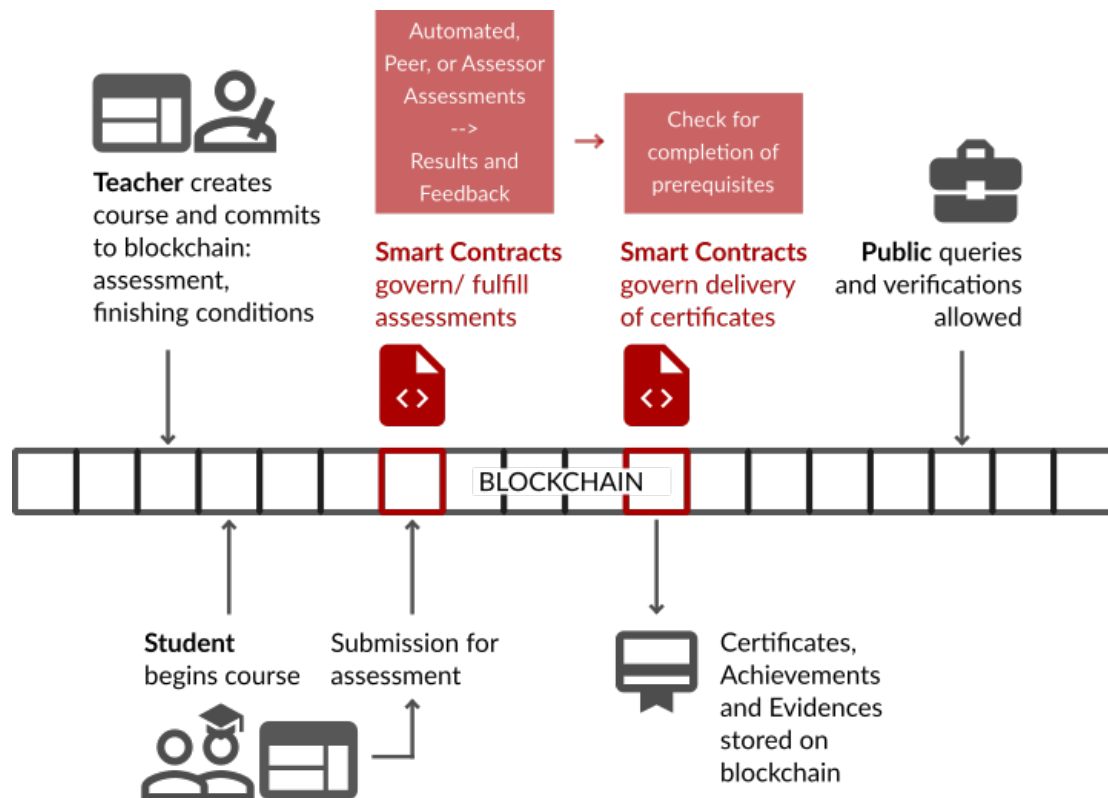


Fig. 2.6 Original diagram providing a high level view of how the project proposes automating assessments with smart contracts

Table 2.1 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

Hyperledger Fabric

R3 Corda

Built following use cases in the financial industry,

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

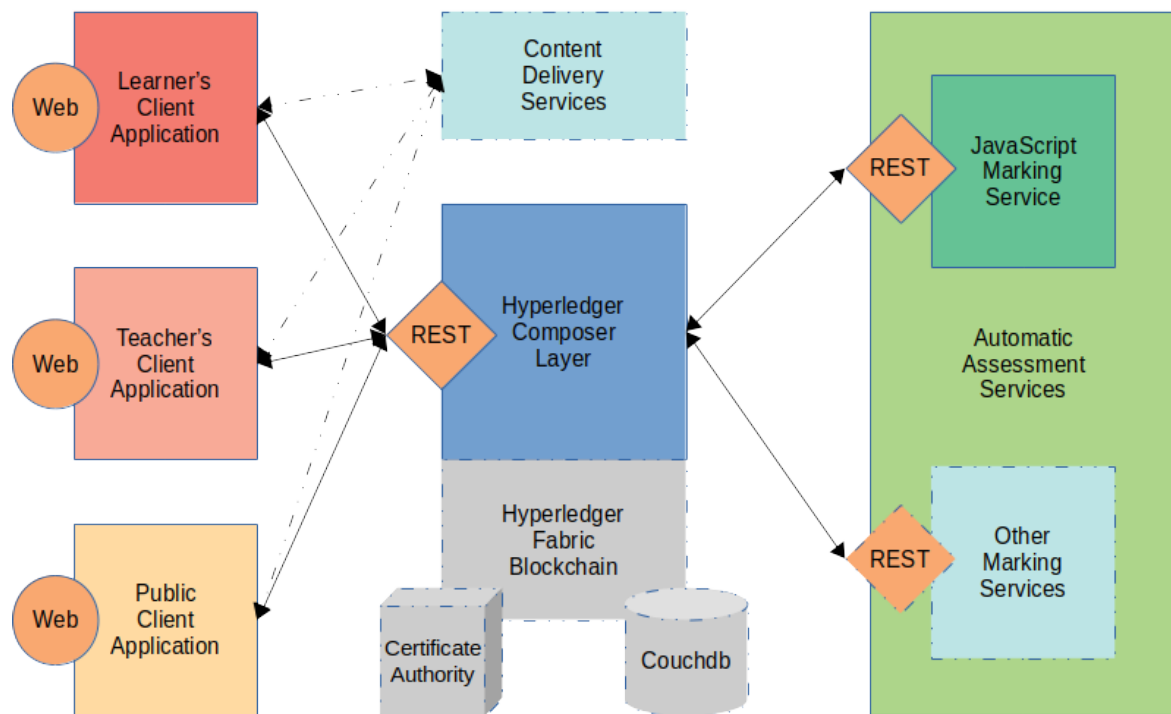


Fig. 6.1 Technical architecture overview for the demonstrator system built

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 . . .

References

- Ali, S. (2005). Effective teaching pedagogies for undergraduate computer science. *Mathematics and Computer Education*, 39(3):243.
- Bessonov, A. (2017). Five trends impacted by blockchain technology. [online] <https://www.forbes.com/sites/forbestechcouncil/2017/09/20/five-trends-impacted-by-blockchain-technology>.
- blockcerts.org (2018). Faq - blockcerts : The open initiative for blockchain certificates. [online] <https://www.blockcerts.org/guide/faq.html>.
- Brown Jr, J. (1999). *Assessment matters in higher education*. McGraw-Hill Education (UK).
- Campbell, A. (2010). Digital forms of assessment: Assessing what counts, the performance. *Curriculum, technology & transformation for an unknown future. Proceedings ascilite Sydney*, 2010.
- Condie, R. and Munro, B. (2007). The impact of ict in schools: Landscape review.
- Denham, E. (2017). Gdpr – sorting the fact from the fiction. [online] <https://iconewsblog.org.uk/2017/08/09/gdpr-sorting-the-fact-from-the-fiction/>.
- El-Khatib, K., Korba, L., Xu, Y., and Yee, G. (2003). Privacy and security in e-learning. *International Journal of Distance Education Technologies (IJDET)*, 1(4):1–19.
- Farance, F. and Tonkel, J. (1999). Learning technology systems architecture (Itsa). *IEEE Learning Technology Standards Committee (LTSC), IEEE P*, 1484.
- Garrison, D. R. (2011). *E-learning in the 21st century: A framework for research and practice*. Taylor & Francis.
- Gulhane, I. (2017). Create and execute blockchain smart contracts - ibm code.
- IBM Blockchain (2018). Ibm blockchain based on hyperledger fabric from the linux foundation. [online] <https://www.ibm.com/blockchain/hyperledger.html>.
- Open University (2018). Open blockchain. [online] <http://blockchain.open.ac.uk/>.
- Opsecmonkey (2017). Edmodo education platform hit by hacker, 77m account details stolen. [online] <http://opsecmonkey.com/edmodo-education-platform-hit-by-hacker-77m-account-details-stolen/>.

- Pantò, E. and Comas-Quinn, A. (2013). The challenge of open education. *Journal of E-learning and Knowledge Society*, 9(1):11–22.
- Sharples, M. and Domingue, J. (2016). The blockchain and kudos: A distributed system for educational record, reputation and reward. In *European Conference on Technology Enhanced Learning*, pages 490–496. Springer.
- Sony Global Education (2017). Sge education blockchain. [online] <https://blockchain.sonyged.com/>.
- Suhre, C. J., Jansen, E. P., and Torenbeek, M. (2013). Determinants of timely completion: the impact of bachelor's degree programme characteristics and student motivation on study progress. *Higher Education Research & Development*, 32(3):479–492.
- Swan, M. (2015). *Blockchain: Blueprint for a new economy*. " O'Reilly Media, Inc."
- Valenta, M. and Sandner, P. (2017). Comparison of ethereum, hyperledger fabric and corda. Technical report, FSBC Working Paper.
- Walport, M. (2016). Distributed ledger technology: beyond block chain. *UK Government Office for Science*.
- Wüst, K. and Gervais, A. (2017). Do you need a blockchain? *IACR Cryptology ePrint Archive*, 2017:375.

Appendix A

How to install L^AT_EX

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 - T_EX distribution

1. Download Basic-MiK_TE_X(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 - T_EX editor

1. Download TexStudio from
<http://texstudio.sourceforge.net/#downloads>
2. Run the installer

Mac OS X

MacTeX - T_EX 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 - T_EX editor

1. Download TexStudio from
<http://texstudio.sourceforge.net/#downloads>
2. Extract and Start

Unix/Linux

TeXLive - T_EX 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 $\langle\text{texmf}\rangle/\text{tex}/\text{latex}$ directory, where $\langle\text{texmf}\rangle$ is the root directory of the user's \TeX installation. On systems that have a local texmf tree ($\langle\text{texmflocal}\rangle$), which may be named “ texmf-local ” or “ localtexmf ”, it may be advisable to install packages in $\langle\text{texmflocal}\rangle$, rather than $\langle\text{texmf}\rangle$ as the contents of the former, unlike that of the latter, are preserved after the \LaTeX system is reinstalled and/or upgraded.

It is recommended that the user create a subdirectory $\langle\text{texmf}\rangle/\text{tex}/\text{latex}/\text{CUED}$ for all CUED related \LaTeX class and package files. On some \LaTeX systems, the directory look-up tables will need to be refreshed after making additions or deletions to the system files. For \TeX Live systems this is accomplished via executing “ texhash ” as root. MikTeX users 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 .