Chapter 2
Blockchain Applications in Lifelong Learning and the Role of the Semantic Blockchain

Alexander Mikroyannidis
https://orcid.org/0000-0002-9518-1443
The Open University, UK

Allan Third
https://orcid.org/0000-0002-0386-1936
The Open University, UK

John Domingue
The Open University, UK

Michelle Bachler
The Open University, UK

Kevin Quick
The Open University, UK

ABSTRACT

The emergence of the blockchain promises to revolutionise not only the financial world but also lifelong learning in various ways. Blockchain technology offers opportunities to thoroughly rethink how we find educational content and tutoring services online, how we register and pay for them, as well as how we get accredited for what we have learned and how this accreditation affects our career trajectory. This chapter explores the different aspects of lifelong learning that are affected by this new paradigm and describes an ecosystem that places the learner at the centre

DOI: 10.4018/978-1-5225-9478-9.ch002

of the learning process and its associated data. This chapter also discusses the possibilities that will be afforded by the combination of trustworthy educational data enhanced with meaningful web-accessible linked data, and what these developments will mean for learners, educators, and the employment market.

INTRODUCTION

Education today is still controlled mostly by educational institutions, which offer quality, credibility, governance, and administrative functions. This model is not flexible enough and poses difficulties in recognising the achievements of a lifelong learner in informal and non-formal types of education. As a result, a lifelong learner's transition from formal to informal education and vice versa can be hindered, as the achievements acquired in one type of education are not easily transferable to another (Harris & Wihak, 2017; Lundvall & Rasmussen, 2016; Mayombe, 2017; Müller et al., 2015). Generally, lifelong learners have limited control and ownership over their learning process and the data associated with their learning. This indicates the need for a learner-centred model across all types of education, offering learners with a framework for fully controlling how they are learning, how they acquire qualifications and how they share their qualifications and other learning data with third parties, such as educational institutions or employers.

The Blockchain is best known as the technological underpinning for the Bitcoin cryptocurrency. Blockchain technology, which can be thought of as a public distributed ledger, promises to revolutionise the financial world. A World Economic Forum survey in 2015 found that those polled believe that there will be a tipping point for the government use of Blockchain by 2023 (Rizzo, 2015). Governments, large banks, software vendors and companies involved in stock exchanges, especially the Nasdaq stock exchange, are investing heavily in the area. For example, the UK Government recently announced that it is investing £10 million into Blockchain research (Das, 2020) and Santander have identified 20-25 internal use cases for the technology and predict a reduction of banks' infrastructure costs by up to £12.8 billion a year (Williams-Grut, 2015)

Blockchain technology offers a decentralised peer-to-peer infrastructure where privacy, secure archiving, consensual ownership, transparency, accountability, identity management, and trust are built in at the software and infrastructure levels. As such, the Blockchain has the potential to revolutionise education in a number of ways. In this chapter, we explore some of the applications that the Blockchain can have on certain aspects of lifelong learning, including Smart Badges, ePortfolios and tutoring. We discuss the innovative paradigms introduced by each of these applications, with the goal of building a learner-centred ecosystem for lifelong learning.

One of the key advantages of Blockchain technology is that it is decentralised, with access, and the ability to participate and publish data, open to anyone with the capacity to join a network. It is important to remember, however, that there is an existing infrastructure with *some* of the same features: the Web. Blockchain brings immutability and trust, among other additions, but we should take advantage of the vast wealth of existing data and standards for decentralised data publication and consumption on the Web too. In particular, one of the core design principles of the Semantic Web is the assumption that data can be published anywhere online, and by anyone, and that it should be possible to query and integrate that data without aggregating it all into a central location. We argue here that a *Semantic Blockchain*, encouraging interoperability between Blockchain platforms and the Semantic Web, is essential to get the most out of both technologies. This is especially important in the education sphere, where learning experiences and accreditation can be acquired from diverse independent sources and according to different learning approaches, contexts and standards, but which still need to be drawn together to form a coherent and understandable picture of an individual's lifelong learning. We discuss approaches to the Semantic Blockchain and their applications to education in this chapter.

The remainder of this chapter is organised as follows. First, we present the state of the art, regarding the Blockchain, distributed ledgers, the Ethereum platform, as well as Smart Contracts, and we discuss in which cases the Blockchain technology should be used and what it offers. We then present a scenario showcasing the impact that the Blockchain can have on lifelong learning. Subsequently, we present various Blockchain applications on lifelong learning, focusing on Smart Badges, ePortfolios and tutoring. We then proceed to discuss the different approaches to the Semantic Blockchain and their applications to education. Finally, the chapter is concluded and its main points are summarised.

STATE OF THE ART

Distributed Ledgers and Blockchains

It is important to distinguish between the terms 'distributed ledgers' and 'blockchains', which are often incorrectly used as synonyms. Distributed ledgers are replicated, shared and synchronised digital data geographically dispersed over multiple sites possibly including multiple institutions. A peer-to-peer network is required for communication and a consensus algorithm to ensure replication and synchronisation across multiple nodes.

It is important to emphasise the key differences between applications that run on standard platforms and those that run on top of distributed ledgers. Rather than connecting from a device (e.g. a mobile phone) to a central server, which holds all the required data (possibly including private customer data), every player or volunteer in the network gets a complete copy of all the data. This changes a fundamental dynamic. The notion of centralised control disappears completely, rather data and computation is evenly owned, controlled and shared across the peer network.

A Blockchain is a specific type of distributed ledger where an ever-growing list of records, called blocks, are linked together to form a chain – hence the term 'Blockchain'. The first Blockchain was conceived by (Nakamoto, 2008) as the basis for Bitcoin the most famous Blockchain based crypto-currency. The main idea behind Bitcoin was to create a currency specifically for the Internet rather than (as is the case in all fiat currencies) mapping an originally physical currency to the global communications infrastructure.

The first issue that arises with internet-based currencies is what is called the 'double spend problem ("Double spending" 2019). This is the case when a digital 'coin' is spent, by an individual, for some service or good, and then the same coin is spent again by the same individual, for example by copying or duplicating the relevant data. The Blockchain addresses this problem by providing an immutable public ledger of all historical transactions. Once processed and stored within a block, a transaction cannot be altered even by the transaction owners.

Within a Blockchain, immutability is provided through a number of related mechanisms:

- **Timestamp**: Each block has a unique timestamp.
- **Cryptographic Hash**: Each block is linked to the previous block through a crypto-graphic hash. ("Cryptographic hash function", 2019). A cryptographic hash function is a hash function that takes an input of any size and returns a string of fixed size. Small changes in the input result in large changes in the output. It is this last feature that guarantees that changes to the input can be easily detected, as the hash function will no longer be verifiable. Additionally, it is not easy to regenerate the input from any given output. This aids in use cases involving an element of privacy or security.
- **Cryptographic Puzzle:** In order to gain the right to create the next block, a participant (often called a 'miner') has to be the first to solve a cryptographic puzzle. This feature prevents a malicious attack aiming to re-write the history of a set of transactions, since this would require many cryptographic puzzles to be solved, as the hash of each block would have to be altered.

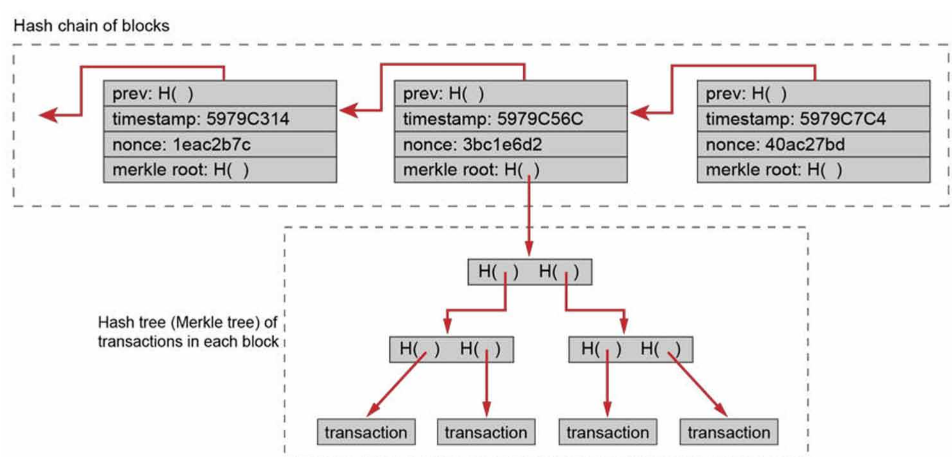
- **Participant Network:** Since the data related to all the transactions are copied across all participants (miners) in the network, all miners are able to check if any protocols or rules have been violated.

Figure 1 shows a Blockchain containing three blocks. Starting from the right, which is the newest block, each block points to its predecessor using a hash function. Additionally, each block contains the solution to the cryptographic puzzle, termed ‘nonce’ and a timestamp. Transactions are stored in a Merkle Tree (Merkle, 1980) - a tree of hashes - where the leaf nodes contain the transactions. This structure allows for efficient retrieval and ensures the veracity of the individual transactions in addition to the block, i.e. if a transaction is altered then the hash will no longer be valid.

The proof of work consensus mechanism, which involves solving the cryptographic puzzle before anyone else, has led to the growth of the computing power and electrical consumption associated with Blockchain networks. Estimates are that by 2020 the Bitcoin network will expend as much electricity as the whole country of Denmark (Deetman, 2016). This has led to several Blockchain platforms exploring other consensus mechanisms, such as:

- **Proof of Stake** (“Proof-of-stake”, 2019): Where the chances of being selected to produce the next block depend on the value of a ‘stake’ stored by a miner in a specific location. Variants of this take into account the ‘age’ of the stake.

Figure 1. A Blockchain with three blocks



- **Proof of Capacity**: Rather than the chances of being selected being related to the amount of computing power, as for proof of work, here the probability is related to the amount of storage a miner holds.
- **Proof of Burn**: Sending coins to an irretrievable address ('burn') gives one the right to be selected. The chances of being selected to mine the next block are related to the value of the burn.
- **Proof of Elapsed Time**: Intel has produced a special processor capability to implement this mechanism which relates elapsed time to the probability of being selected (Hertig, 2016).

Ethereum and Smart Contracts

After the Bitcoin, Ethereum (Buterin, 2013) is the best known Blockchain platform. Rather than serving as a platform for a crypto currency, the underlying aim for Ethereum is to be an open Blockchain platform to support the development and use of decentralised applications. Unlike Bitcoin, the programming language available on the Ethereum platform is Turing complete so that general applications can be run on what the founders call a 'world computer'.

At the core of the Ethereum concept are two types of accounts:

- *Externally Owned Accounts (EOAs),* which are controlled by private keys. A private key is a cryptographic mechanism allowing for individuals to unlock data that has been secured by a corresponding public key. EOAs are controlled by individual users or organisations.
- *Contract Accounts*, also termed 'Smart Contracts', which can be defined as "automatable and enforceable agreements" (Clack, Bakshi, & Braine, 2016). Smart Contracts constitute one of the main features of current Blockchain platforms, such as Ethereum. They are controlled by contract code and are activated by EOAs.

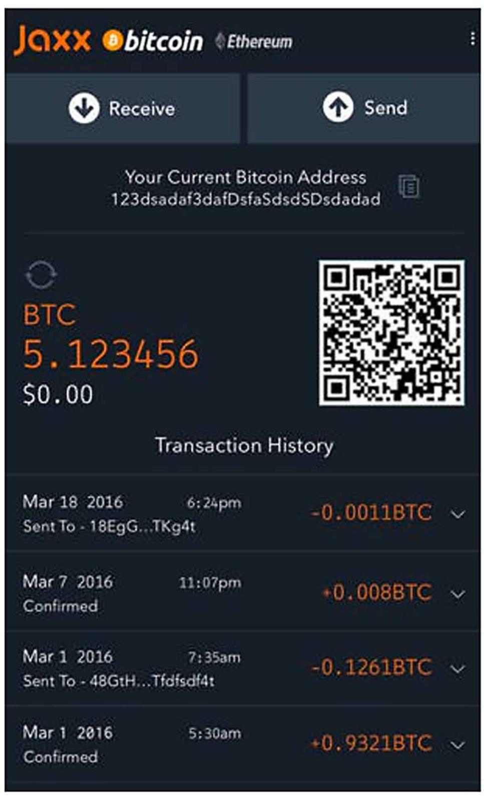
When ether, the currency used within Ethereum, is sent from an EOA to a Contract Account, the contained program is executed. This can result in further transactions and payments and additional Smart Contracts being invoked. Through these chains of invocation, connected Smart Contracts form the basis of Ethereum applications which are called 'DApps' (short for 'Distributed Applications'). A number of high-level languages exist for writing Smart Contracts, including Solidity (similar to C and JavaScript), Serpent (similar to Python) and LLL (a low-level lisp-like language).

From and end-user point of view, Ethereum, like Bitcoin, can be accessed through a number of implementations. It should be noted that the term 'Ethereum Client' includes software able to create transactions and mine new blocks, as well as wallets that manage private and public keys associated with an EOA. A screen snapshot of such a wallet that can be used for both Ethereum and Bitcoin is shown in Figure 2. As in many banking apps, users of this wallet are able to select accounts, view balances and transfer funds to other accounts. Other wallets also allow DApps to be managed in a fashion similar to Apple's iTunes application.

Gas and Off-Chain Storage

One of the first main problems that Ethereum faced was how to prevent arbitrary programs hogging the combined computational power of the mining community. A developer may inadvertently or maliciously create a program that never halts or eats up CPU or space resources. The solution to this is a transaction pricing mechanism, based on the concept of 'gas'. Every transaction request must be accompanied by a

Figure 2. A screen snapshot of a Jaxx wallet which can be used for both Bitcoin and Ethereum
Source: https://www.bitcoin.com/choose-your-wallet/jaxx



maximum amount of gas that a user is willing to be spent on a transaction. Miners execute transactions until they complete, or the gas runs out. Insufficient gas will result in a failed transaction and all of the fee lost. Otherwise the remaining gas is returned to the user. Gas is paid for in ether with the purchase price fixed by the Ethereum mining community.

Because of the associated costs, large data files are not stored on the Ethereum platform. Typically, large files are stored elsewhere (off-chain) and referenced using a cryptographic hash. This solution enables the validity of a document to be checked (by comparison with its hash), whilst dramatically reducing storage costs. The peer-to-peer storage system IPFS (Inter Planetary File System) is often used in conjunction with Ethereum. Ethereum's own storage system, Swarm, is currently under development.

When Should Distributed Ledgers be Used?

As with any new technology that receives a lot of attention, one needs to be careful to ensure that it is appropriately applied. Distributed ledgers are a technology primarily designed to store data, for which many stable, tested, scalable commercial systems exist. The decentralisation properties are useful in certain contexts only. In (Greenspan, 2015) the author articulates the contexts in which Blockchains are useful, which we outline below:

- **Shared Database**: There should be a need for data to be shared. If this is not the case, then standard relational databases can be used.
- **Multiple Writers**: More than one entity, individual or organization should need to write data. Mobile banking, where many customers alter their account data by transferring or spending funds from their smartphones or laptops, is a good example of this.
- **Absence of Trust**: This means that the multiple writers do not trust each other sufficiently to accept reports of data changes without evidence nor to allow access to internal data infrastructures.
- **Disintermediation**: Blockchains provide a route for removing trusted intermediaries, such as a bank or legal body, leading to reduced costs and increased speed and efficiency. There should be a need to either remove or reduce the role of the intermediary.
- **Transaction Interaction**: A significant benefit for Blockchains can be found when the transactions are not isolated. For example, the current funds of a bank account depend on all of the previous transactions to the account.
- **Set Rules**: A consequence of the fact that transactions between non-trusting parties alters an overall state is that transactions need to abide by rules

restricting how data can be added. All nodes in a Blockchain network check new transactions and will reject blocks containing any transactions that are invalid.

- **Validators:** For any functioning Blockchain, there will need to be a set of nodes that act as validators of all transactions. This group, whether open or not, will have the power to permanently exclude transactions (ideally because the transaction is violates a rule) and to determine which block should be added next in the case of conflicts (e.g. if two miners produce a block at nearly the same time). This power is far less than any owner of a standard database would have. Validators cannot act in violation of the defined rules, nor fake a transaction.
- **Asset Backing**: The transactions will result in the creation and movement of assets which should have a real-world backer. Besides financial transactions, other examples have included luxury goods, such as diamonds, and energy.

We argue that the above also applies in the educational context. Credentials and other evidence of learning is created, managed, shared and used by multiple parties where there is an absence of trust. In 2007, a Dean at MIT had to resign after it was found that she had none of the degrees from US universities that she had claimed to have for nearly 30 years (Lewin, 2007). In 2016, a prolonged argument involved India's Prime Minister over whether he had lied about his academic qualifications ("PM Modi lied., 2016). A 2015 survey of more than 2,500 hiring managers found that 62% of respondents had been caught embellishing skills or capabilities (White, 2015). In the online world, MOOC companies today use a variety of methods for identity verification, including live interviews, typing patterns, and photographs. A recent study (Northcutt, Ho, & Chuang, 2016) found an online specific method of cheating emerged, whereby students create multiple accounts, so that they can collect supplied correct answers (using a 'Show Answer' button) from a 'harvester' account and use these answers in a second 'master' account. The study found that this method was responsible for 1.3% of certificates awarded generally across 115 MOOCs with 1.9 million course participants and for 25% of certificates awarded to students having more than 20 certificates.

An academic CV is composed of related evidence. Passing a series of individual courses may lead to a significant qualification, such as a degree. Awarded qualifications are backed by organisations, such as universities, or companies like Microsoft and Cisco, each of which have a variety of validation mechanisms.

With Smart Contracts, the Ethereum platform extends the decentralised framework beyond data to include decentralised computation. Trusted decentralised computation offers the opportunity to automate educational transaction costs. Education is an expensive business. Two-thirds of college students in the US graduate with college debt and that debt now tops $1.2 trillion (Terner, n.d.) Fees for students in England are now £9,250 per year and student loan debt has risen to more than £100 billion. Students starting now in England will graduate with an average debt of £50,800. In this context, anything that lowers costs associated with running educational institutions has the potential to provide significant benefits both for individual learners and across society.

A Lifelong Learning Scenario

The following scenario demonstrates the potential impact of Blockchain technology on lifelong learning. Let us consider Jane, who works as a Junior Data Analyst in a London-based company. She is 30 years old and holds a B.Sc. in Computer Science. She is keen to advance her career in the field of Data Science; however, her demanding work schedule and daily commute do not allow her to return to full-time education for acquiring further qualifications. She is interested in informal and non-formal methods of learning, but she also seeks to acquire some type of accreditation for her learning.

Jane creates her personal Learning Passport (shown in Figure 3), which is powered by Blockchain technologies and offers, among other things, a learning portfolio, smart badges, as well as opportunities for social learning and peer mentoring. We can see in Figure 3 that the top main panel (labelled 'Portfolio') contains artefacts that Jane has created with her peers during her courses. Selecting the top left item – the output of a simulation program – causes related feedback received ("The initial tests…"), associated badges or certificates, and relevant courses (the CAD Design course), within the list of current and completed courses in the bottom panel (labelled 'Courses') all to be highlighted.

Jane enrols to relevant open online courses offered by Higher Education Institutions (HEIs) in the UK and abroad, as well as relevant Massive Open Online Courses (MOOCs). Upon completion of these courses, she acquires certifications in the form of smart badges, which are added to her Learning Passport. Apart from just evidence of learning, the smart badges that Jane has earned can be used as dynamic accreditations in a number of ways, thus helping Jane in achieving the following goals:

- Finding new courses based on the gap between Jane's current skills and her desired jobs
- Finding new job opportunities that match Jane's qualifications
- Acquiring job promotions based on the new skills that Jane has mastered
- Networking with other professionals and learners with similar backgrounds and learning goals as Jane

Figure 3. Example of a Learning Passport.

- Identifying other learners that Jane can mentor and tutor in exchange for money or reputation points

Jane is building her learning portfolio, which consists of the courses she has enrolled to, her assignments and the results of other exercises she has completed such as quizzes, as well as the smart badges she has earned. All data in this portfolio is owned by Jane, who can also encrypt it or select subsets of it for release to others for a fixed duration. For example, Jane can release parts of her portfolio to potential employers two weeks before an interview. She may also offer access to HEIs, educators / trainers and other learners that follow a similar learning journey.

All transactions associated with Jane's Learning Passport are signed and time-stamped. The fact that the transactional record is visible to all and immutable resolves many of the problems associated with identity and fraud. As all data is permanently accessible, different consensual mechanisms can be put in place to link learner work to formal feedback and assessment. If desired, any principles underlying formal statements can be encoded in Smart Contracts, which allow the encoding of organisational rules, so as to be explicit for any interested party.

Jane finds micro-courses that have been produced by independent tutors and gains access to them via micro-payments, similar to purchasing an app on her smartphone. She studies these micro-courses and offers her feedback via ratings that count as reputation points for the authors of these learning materials. Other tutors can also reuse and repurpose these learning materials, upon agreement with the original authors. Jane decides to produce a free micro-course on the R programming language, based on what she has learned, in order to earn reputation points and enrich her portfolio.

Additionally, Jane has access to a network of learners that study together online and mentor each other. She chooses to mentor an early career data scientist in basic data analytics methodologies. She thus gains reputation points for acting as a mentor in this field. In return, she receives tutoring by an expert in Machine Learning and offers reputation points to her mentor. All these transactions are stored on the Blockchain, thus enabling easy transfer between units or organisations if needed and the automatic detection of any abuse of the system (e.g. pairs or small groups of employees favouring each other).

Jane is gradually building a strong portfolio in Data Science, with proof that she has gained advanced knowledge based on her earned badges, reputation points, as well as her learning activities and produced artefacts, all of which are recorded and stored in her Learning Passport. Even though she has not returned to formal education, she is now in a much better position to seek a promotion and advance her career.

Towards a Learner-Centred Ecosystem

We envisage a learner-centred ecosystem of educational transactions, as shown in Figure 4. Within their educational context, learners create single authored or shared artefacts with their peers. At the same time, learners are enrolled on a number of courses and are making use of additional learning resources. Tutors and other teaching staff are providing informal and formal feedback as the learners complete summative and formative assessment. Central administration bodies are issuing formal certificates according to institutional processes.

We layer on top of these processes a reputational ecosystem with the learner at the centre. Learners can rate courses, online resources and teachers in terms of ease of understanding and attributes related to their specific learning goals. Learners can also rate each other on a range of qualities including, for example, organisational and communication skills. Our early work in applying this approach to academic reputation can be found at (Sharples & Domingue, 2016).

All data about learners' accreditation, work, ratings, formal and informal feedback are stored within a framework where everything is verifiable via the Blockchain. Because of the associated costs, large data files are usually not stored on the Blockchain. Typically, large files are stored elsewhere (off-chain) and referenced using a cryptographic hash. The ecosystem depicted in Figure 4 uses IPFS for storing the learner's documents. This solution reduces storage costs and, at the same time, enables the validity of a document to be checked.

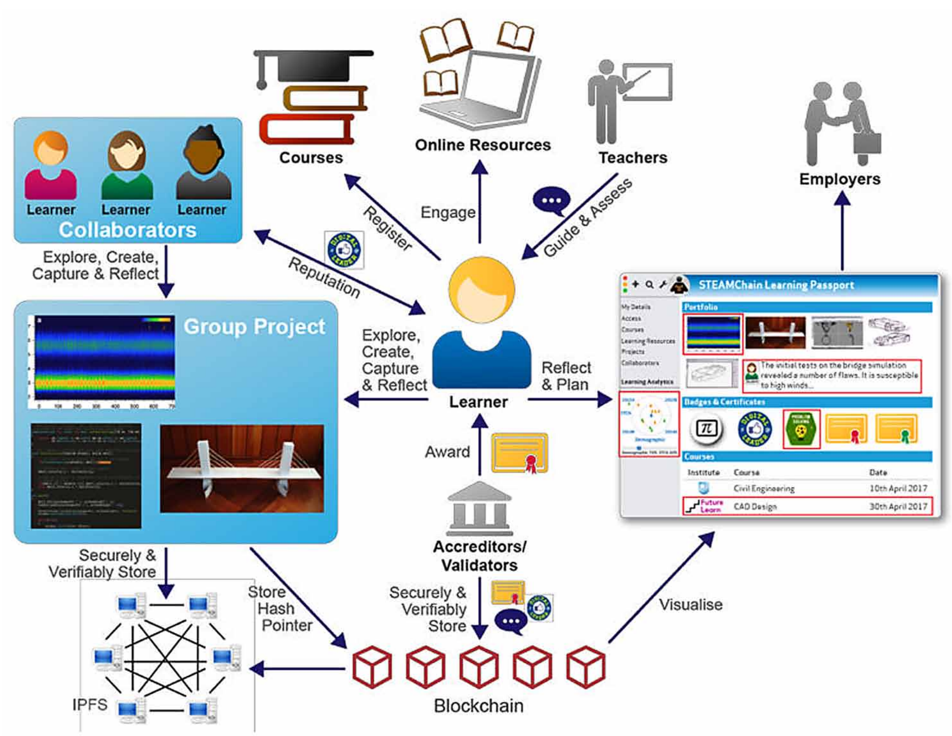
The following sections outline in more detail the core elements of this ecosystem. In particular, we describe how ePortfolios, accreditation and tutoring can be enhanced by Blockchain technology within this ecosystem and the new opportunities that arise for learners, educators and academic institutions.

Smart Badges

Smart Badges are dynamic records of accreditation that follow the same principles as Open Badges (Mozilla Foundation, Peer 2 Peer University, & The MacArthur Foundation, 2010) and offer the same benefits in recording accreditation. However, the key difference and novelty of Smart Badges lies in their dynamic features. For example, apart from just recording a learning achievement, a Smart Badge can also offer recommendations to the learner about jobs or courses. These dynamic features are implemented in the Blockchain as Smart Contracts.

Learners that study online or offline courses can earn Smart Badges upon reaching certain milestones in their studies, e.g. completing part of a course or a whole course. These badges are stored on the Blockchain and include data about

Figure 4. A learner-centred ecosystem of educational transactions.

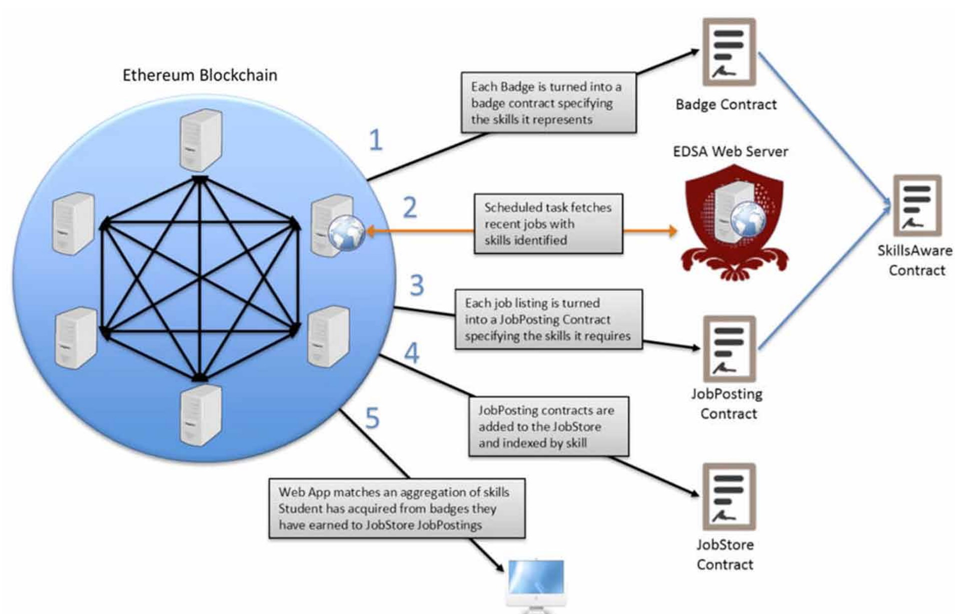


the key skills that learners have acquired upon obtaining these badges. As learners continue to earn Smart Badges, they start receiving automated recommendations for the latest job offers that match the skills they have earned. In the case that a job they are interested in requires additional skills, learners can also receive recommendations about courses that will offer them these additional skills. In this way, someone can adopt a more efficient and targeted approach to their learning, towards achieving their desired career trajectory.

Figure 5 shows our implementation of a process for generating Smart Badges by matching the learner's skills with job offerings (Mikroyannidis, Domingue, Bachler, & Quick, 2018). This implementation is based on the use of Smart Contracts for the Ethereum Blockchain platform. Datasets of current job offers and their associated skills are being harvested from a job aggregator that has been developed by the EDSA project (Dadzie, Sibarani, Novalija, & Scerri, 2017). These datasets are then placed in contracts on the Blockchain, which are used for matching jobs with a learner's badge-based skills. In this way, the awarded badges are smart, in the sense that they are being used to offer recommendations to learners.

In our current Smart Badges implementation, we have generated the following types of Smart Contracts:

Figure 5. Generating Smart Badges by matching the learner's skills with job offerings



- **Badge Contract**: It stores the details of a badge that can be awarded upon completion of a course. It contains data like title, description, issuer, criteria for awarding the badge, etc.
- **SkillsAware Contract:** It is used to store a unique list of all the skills that are required to gain badges. This contract also stores all the skills required by jobs harvested from the EDSA job aggregator.
- **JobPosting Contract:** It holds the details of a particular job post that has been harvested from the EDSA job aggregator, e.g. title, description, country, organisation, location, etc.
- **JobStore Contract**: It maps JobPosting contracts to skills. It contains a list of pointers to map all the JobPosting contracts (i.e. individual jobs) to the corresponding skills held in the SkillsAware contracts.

Through this process, we are able to generate job recommendations based on the badges that the learner acquires. In order to generate these job recommendations, we aggregate the skills from Badge contracts and request matching jobs from the JobStore contract. For those jobs that there is a partial skills match, we request suitable courses from the EDSA job aggregator. The implementation process and the associated scenario are demonstrated in a short movie available online.[1]

Smart Badges bear a number of significant benefits to learners, by supporting them in shaping their learning path in order to achieve their career goals. More specifically, we foresee the following applications of Smart Badges in different aspects of education:

- **Job Hunting**: As described in our scenario, Smart Badges can be used to link accreditations to jobs through the matching of badges to job profiles.
- **Promotion**: Similarly to job hunting, Smart Badges can be used to match acquired badges to organisational roles for internal promotion.
- **Mandatory CPD Training**: Workers in a variety of professions are obliged to take CPD training annually in order to be able to continue to practice. For example, solicitors in the UK are required to plan suitable learning activities, complete and evaluate their learning, record how the process was carried out and make an annual declaration on their overall actions. Other professions such as banking and healthcare have similar obligations (Thomas & Qiu, 2013). Smart Badges, coupled to a reasoning system based on Linked Data (Berners-Lee, 2006), will enable compliance with regulatory CPD training to be checked by relevant authorities and non-compliance to be automatically signalled.
- **Networking:** Can be achieved using inference-based matches of acquired skills as represented by Smart Badges. Networking may be with peers within

a specific sector, by general seniority, by geography and also with workers who are less or more senior for mentor-based relationships.

- **Courses**: Can be automatically recommended based on the gap between current skills and desired jobs (with higher salary or status). Recommendations may be for a single course or a small set of courses. This has also been demonstrated in our data science education scenario.
- **Reconfiguration**: With the right granularity, badges can be reconfigured to align with sector specific qualifications. For example, a combination of computing badges aligned to a company specific qualification.

ePortfolios

The primary benefit brought by the Blockchain to ePortfolios is the disaggregation between the activities that learners have been engaged in and the accreditation gained. Facilitating the representation of both learner work within ePortfolios and accreditation will allow all educational stakeholders to engage in this. The use of the Blockchain also addresses the following issues:

- **Hosting and Scalability**: As an issue is removed as data is copied and hosted throughout the peer network. Due to its distributed nature, the Blockchain is also resilient to scalability.
- **Ownership:** Following the peer-to-peer principles of the Blockchain, there is no single data owner. Instead, ownership resides in the participating community that provides a consensual framework of control. As a consequence, all data in the ePortfolios are owned by the learners, who also control access to their ePortfolios.
- **Privacy and Security**: Can be provided through two main routes. Firstly, all sensitive data can be stored off-chain with parties digitally signing hashes of the data as required. Secondly, data can be encrypted with the keys held by the relevant stakeholder such as the learner.
- **Interoperability and Transportability**: All data on the Blockchain are shared across the peer network and transactions are visible to all. In essence, an educational Blockchain acts as a global source of truth across the participating organisations and individuals. Therefore, the interoperability and transportability issues are solved at a data level.
- **Immutability and Reliability**: Are ensured as Blockchain transactions are immutable records that are signed and can be multiply signed, for example by a host institution and an individual course assessor.

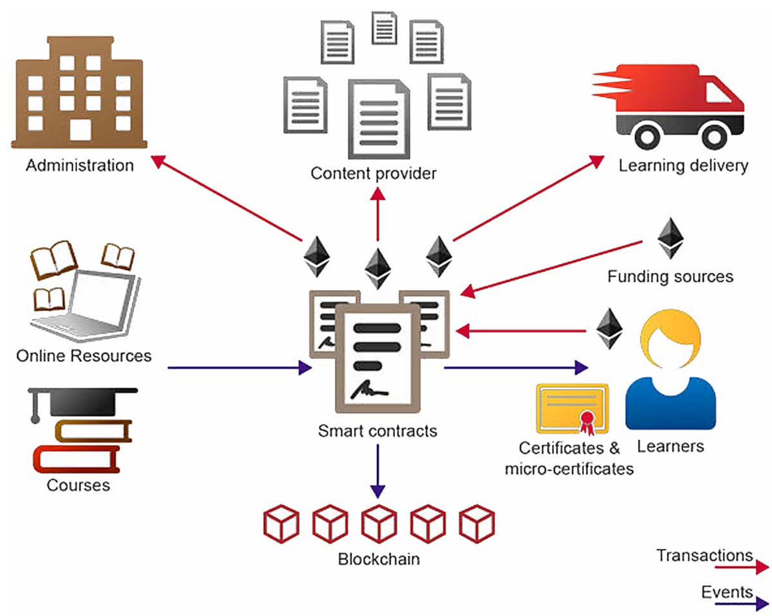
Tutoring

As shown in Figure 6, a university can be thought of very simplistically as a set of transactions between learners, authors of learning materials, content providers, learning delivery teams and administration departments. Normally, these services are aggregated into a single institution.

When the Open University was setup in the UK in the late 1960s, one of its primary innovations was to disaggregate the production of learning materials from the delivery of teaching. Rather than a university professor developing and presenting materials face to face, collaborative course teams of up to 30 staff spend up to two years developing a suite of materials (e.g. radio broadcasts, experimental kits) which are then delivered by external academics hired on a part time basis. The Open University can thus be thought of as a preliminary 'Uber' style model 20 years before the invention of the Web.

The blogpost "Uber-U is Already Here" (2016) describes how an Uber style university could be created using a combination of Blockchain for credentialing, online assessments, a fee charging and tracking system and an app for connecting tutors to learners. In such a university, micro-payments from learners could be transferred automatically to the authors of any learning materials viewed online. Additionally, tutors could accumulate ratings from learners for the quality of their

Figure 6. A university seen as a very simple transaction system.



teaching and feedback. Learners could also rate courses and institutions for their effectiveness and value for money.

A number of companies now exist for connecting tutors online to learners. Typically, these companies advertise for both tutors and learners and act as a broker between the two. For example, MyTutor pays up to £24 per hour to tutors. Synkers is a start-up based in Lebanon which instantaneously connects learners to qualified private tutors via a smartphone app. A future version of their platform will be integrated into a Blockchain.

More recently, Oxford academics have launched the world's first 'Blockchain University' (Broggi et al., 2018). Woolf University will not have a physical presence, but instead will be based exclusively on an app, which will allow academics to advertise their expertise to prospective learners. Learners will be using the app to select courses that suit their needs and interests. Blockchain Smart Contracts will be used in order to regulate registrations and payments, thus automating administrative processes and reducing overhead costs. The platform will be open for individual academics and academic institutions to join and offer their services to learners.

The Semantic Blockchain

The Web is ubiquitous and provides one of the primary interfaces for humans to interact with digital data. By combining technologies especially from the Semantic Web with the Blockchain, the resulting *Semantic Blockchain* has the potential to promote highly interoperable trusted data, with significant applications to education.

The Semantic Web is a collection of technologies and standards for the publication and consumption of machine-interpretable data at Web scale and according to the decentralised Web publication model. In particular, Linked Data, most commonly using the RDF data model, is intended to serve as a standard for self-describing Web data, encapsulated by the Linked Data principles (quoted here from a W3C design note by the Web's creator, Sir Tim Berners-Lee[2]):

1. Use URIs as names for things
2. Use HTTP URIs so that people can look up those names.
3. When someone looks up a URI, provide useful information, using the standards (RDF*, SPARQL)
4. Include links to other URIs. so that they can discover more things.

By using shared *vocabularies* or *ontologies* -- Web documents which can establish shared URIs for common concepts and the semantic relationships between them -- Linked Data can be published in such a way that the *meaning* of data from independent sources can be interpreted by human or software consumers with little need for manual data alignment. Recent developments in the Semantic Web include the advent of decentralised “data pods” in software such as Solid, from Sir Tim Berners-Lee, which aims to build a user-centred “human-friendly” Web by, in part, supporting individual hosting and control of one’s own data. Complementary developments towards user-centredness in the Blockchain sphere include work on *self-sovereign identity* (Baars, 2016): technical solutions using Blockchains to manage digital identity in a way which gives users control over their online identity without needing to store personal information in a third-party facility.

The strength of the Semantic Web is in providing an easy framework for *combining* data from multiple sources. Applications of the Semantic Web in education include the Learning Object Metadata for annotation of digital educational material, Open Badges, (from version 1.1 onwards, Open Badges are Linked Data), the ESCO ontology for annotation of skills, competencies and occupations and Linked Data harvesting of employment opportunities. Initiatives such as these enable new opportunities, particularly for lifelong learning. For example, an individual planning their future career moves could use Linked Data resources based on the skill requirements of job postings and their existing set of qualifications to identify, automatically, learning materials and opportunities which would be relevant to add to their learning portfolio in order to reach a desired goal. However, the issue of *trust* becomes relevant when data is being drawn from multiple independent sources, particularly when it is valuable. Because of the consequences of one’s educational record on career, lifestyle and travel opportunities, there is a strong potential motivation for fraud, for example. How are we to know whether a particular source of data is trustworthy with regard to its contents and history?

We can distinguish different kinds of trust. Let us start with the example of an educational qualification. In order to be able to accept a presented qualification as accurate, it is important to know where it came from - which institution, for example, for which learning opportunity; to whom it applies - the learner identity; and that the qualification presented is the same qualification that was originally issued. In brief, we need to have trust in *provenance*, trust in *identity*, and trust in *integrity.*

Provenance in educational data covers a number of factors. These include: the history of a piece of education-related material or of certification - when was it created, what was the learning context, what or who endorses it, and so on; the identity of learners and of issuing bodies - is the person presenting, or claiming to be the subject of, some educational data the same as the person it is actually about or from; and integrity - after publication, has the data been altered in anyway? For example, has a qualification been altered to show that it was of a higher level than it actually is?

These trust concerns apply generically outside the education sector as well and require a generic solution. The idea of the Semantic Blockchain is to add a trust layer to the Semantic Web in general, motivated initially by our work and applications in the realm of education.

There are a number of different ways in which Blockchain technology can be used to verify the integrity of data. The core idea remains the same: by publishing data on a Blockchain, a transaction is recorded on the distributed ledger. The transaction record will show the data along with a timestamp showing when it was published. By the nature of the Blockchain, this record is immutable, and anyone with access to the chain can verify that the transaction, its timestamp, and its data contents, have not been altered since that time. Anyone carrying out such a check can be assured that data integrity has been maintained: if the data being presented for verification has been tampered with, it will be possible to detect this and to prove that tampering took place. (Third & Domingue, 2017) present a survey of different specific approaches to making data distributed and trusted, varied along several dimensions, from the degree of data replication, to the levels of integrity guarantee provided, to the cost. The simplest model - in which all data is stored on-chain - has a number of disadvantages. One of these is expense - adding data to a public Blockchain costs money - but even without a cost factor, this poses data protection issues. Educational data contains at least some personal data, and it contravenes good data protection practice and law to store such data in a public space, particularly one which does not allow it to be edited/corrected or deleted. As a result, it is preferable to methods which keep actual data elsewhere, and store only verification data on-chain: something such as a cryptographic hash, which takes up little space and which can only be calculated from the actual data it represents, and which cannot be used to recreate that data. Distributed storage networks such as the Interplanetary File System (IPFS) are a practical match for Blockchains, being based on similar hashing mechanisms.

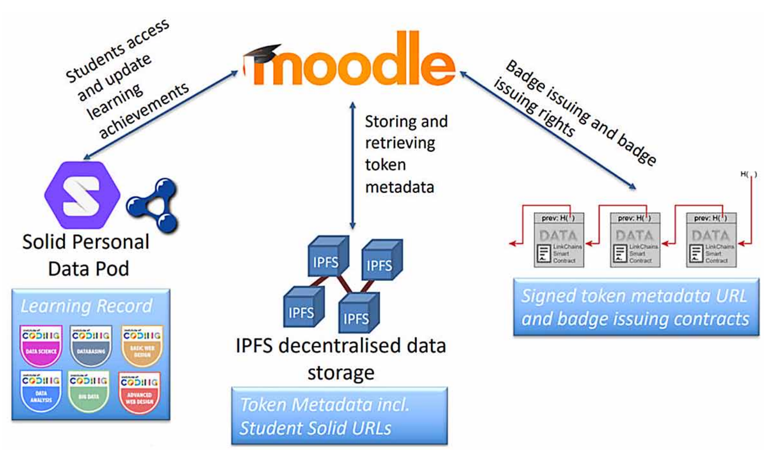
To build a Semantic Blockchain, then, we can integrate personal semantic data pods in Solid, using the IPFS network for larger storage, and with both components connected to a Blockchain infrastructure to provide integrity guarantees. *Provenance* is given by immutable timestamped records (as Linked Data) stored alongside the data and which can be cryptographically proven to be associated with that data. *Identity* (including data access control) is provided by self-sovereign identity systems, and *integrity* is provided by the Blockchain itself. Collectively, these support *trust* in the data. By using Linked Data throughout, we ensure the maximum potential for learners and educators to connect their data with that from other sources, and so to get the maximum use from their own data; by particularly using Solid data pods, we ensure that data remains under user control. Figure 7 shows the main components of the Semantic Blockchain approach we are pioneering in ongoing work, known as *LinkChains*.

The focus on personal interoperable trusted data opens up new possibilities for pedagogical technology and approaches. One of the most exciting is the potential for *lifelong learning analytics*. Instead of learning activity data being collected, and analysed, solely within a specific institution, leading to data silos relating to the same learner being spread across multiple institutions across a lifetime of learning, by storing this data with the user and trustable under user control, it becomes possible to perform learning analytics over time and in diverse educational contexts. Tools can be developed to support learners in understanding their own learning approaches from their own data, as well as supporting wider learning analytics carried out across populations, with user consent. The use of Semantic Blockchains makes this possible; without the security and trust, and the common data models enabled by Linked Data, it would be considerably more difficult to carry this out.

CONCLUSION

This chapter has presented the different applications and impact of Blockchain technology on lifelong learning. We have presented an ecosystem that places the learner at the centre of the learning process and its associated data, with emphasis on the way Smart Badges, ePortfolios and tutoring are augmented with the introduction of Blockchain technology. This approach enables learners to plan their learning journey more efficiently based on their desired career trajectory and offers them full control and ownership over their learning artefacts and processes.

Figure 7. A Learning Management System (Moodle) communicating with the three main components of a Semantic Blockchain



This chapter has also discussed various approaches to the Semantic Blockchain and their applications to education. The Semantic Blockchain encourages interoperability between the Blockchain and the Semantic Web, by taking advantage of the vast wealth of existing data and standards for decentralised data publication and consumption on the Web. Impact on lifelong learning is significant, as learning experiences and accreditation can be acquired from diverse independent sources and according to different learning approaches, contexts and standards. The Semantic Blockchain offers a solution for bringing together all acquired learning experiences and accreditation, in order to form a coherent picture of an individual's lifelong learning.

REFERENCES

Baars, D. (2016). *Towards self-sovereign identity using blockchain technology*. University of Twente.

Berners-Lee, T. (2006). *Linked Data - Design Issues*. Retrieved from http://www.w3.org/DesignIssues/LinkedData.html

Broggi, J. D., Gallagher, M. A., Lilly, J., Duquette, J., Nimura, C., Pattenden, M., . . . Winkler, A. (2018). *Woolf - Building the first Blockchain University*. Retrieved from https://woolf.university/assets/doc/whitepaper.pdf

Buterin, V. (2013). Ethereum white paper. *GitHub repository*. Retrieved from https://github.com/ethereum/wiki/wiki/White-Paper

Clack, C. D., Bakshi, V. A., & Braine, L. (2016). *Smart contract templates: foundations, design landscape and research directions.* arXiv preprint arXiv:1608.00771

Cryptographic hash function. (2019). Retrieved from https://simple.wikipedia.org/wiki/Cryptographic_hash_function

Dadzie, A.-S., Sibarani, E., Novalija, I., & Scerri, S. (2017). Structuring visual exploratory analysis of skill demand. *Journal of Web Semantics*.

Das, S. (2020). *The UK Treasury Is Embracing Block Chain, Digital Currencies and Big Data Research*. Retrieved from https://www.cryptocoinsnews.com/the-uk-treasury-is-embracing-block-chain-digital-currencies-and-big-data-research/

Deetman, S. (2016, March 29). *Bitcoin Could Consume as Much Electricity as Denmark by 2020*. Retrieved from https://www.vice.com/en_us/article/aek3za/bitcoin-could-consume-as-much-electricity-as-denmark-by-2020

Double-spending. (2019). Retrieved from https://en.wikipedia.org/wiki/Double-spending

Greenspan, G. (2015). *Avoiding the pointless blockchain project.* Online at https://www. multichain. com/blog/2015/11/avoiding-pointless-blockchain-project

Harris, J., & Wihak, C. (2017). To what extent do discipline, knowledge domain and curriculum affect the feasibility of the Recognition of Prior Learning (RPL) in higher education? *International Journal of Lifelong Education*, *36*(6), 1–17. doi:10.1080/02601370.2017.1379564

Hertig, A. (2016). *Intel is Winning Over Blockchain Critics By Reimagining Bitcoin's DNA*. Retrieved from https://www.coindesk.com/intel-winning-blockchain-critics-reimagining-bitcoins-dna/

Lewin, T. (2007). *Dean at M.I.T. Resigns, Ending a 28-Year Lie*. Retrieved from https://www.nytimes.com/2007/04/27/us/27mit.html

Lundvall, B.-Å., & Rasmussen, P. (2016). Challenges for adult skill formation in the globalising learning economy–a European perspective. *International Journal of Lifelong Education*, *35*(4), 448–464. doi:10.1080/02601370.2016.1203364

Mayombe, C. (2017). An assessment of non-formal education and training centres' linkages with role-players for adult employment in South Africa. *International Journal of Lifelong Education*, *36*(3), 339–358. doi:10.1080/02601370.2016.1246486

Merkle, R. C. (1980). *Protocols for public key cryptosystems.* Paper presented at the Security and Privacy, 1980 IEEE Symposium on. 10.1109/SP.1980.10006

Mikroyannidis, A., Domingue, J., Bachler, M., & Quick, K. (2018). *Smart Blockchain Badges for Data Science Education.* Paper presented at the IEEE Frontiers in Education Conference (FIE), San Jose, CA. 10.1109/FIE.2018.8659012

Mozilla Foundation, Peer 2 Peer University, & The MacArthur Foundation. (2010). *Open Badges for Lifelong Learning*. Retrieved from https://wiki.mozilla.org/images/5/59/OpenBadges-Working-Paper_012312.pdf

Müller, R., Remdisch, S., Köhler, K., Marr, L., Repo, S., & Yndigegn, C. (2015). Easing access for lifelong learners: A comparison of European models for university lifelong learning. *International Journal of Lifelong Education*, *34*(5), 530–550. doi:10.1080/02601370.2015.1030350

Nakamoto, S. (2008). *Bitcoin: A peer-to-peer electronic cash system.* Academic Press.

Northcutt, C. G., Ho, A. D., & Chuang, I. L. (2016). Detecting and preventing "multiple-account" cheating in massive open online courses. *Computers & Education*, *100*, 71–80. doi:10.1016/j.compedu.2016.04.008

PM Modi lied to people about his BA degree, alleges Arvind Kejriwal. (2016). Retrieved from https://indianexpress.com/article/india/politics/pm-modi-ba-degree-du-cheated-people-arvind-kejriwal-2788004/

Proof-of-stake. (2019, June 10). Retrieved from https://en.wikipedia.org/wiki/Proof-of-stake

Rizzo, P. (2015). *World Economic Forum Survey Projects Blockchain 'Tipping Point' by 2023*. Retrieved from https://www.coindesk.com/world-economic-forum-governments-blockchain

Sharples, M., & Domingue, J. (2016). *The blockchain and kudos: A distributed system for educational record, reputation and reward.* Paper presented at the 11th European Conference on Technology Enhanced Learning (EC-TEL), Lyon, France. 10.1007/978-3-319-45153-4_48

Third, A., & Domingue, J. (2017). *LinkChains: Exploring the space of decentralised trustworthy Linked Data*. Paper presented at the Decentralising the Semantic Web, Vienna, Austria. http://oro.open.ac.uk/52928/

Thomas, H., & Qiu, T. (2013). Continuing professional development: Accountability, autonomy, efficiency and equity in five professions. *British Journal of Educational Studies*, *61*(2), 161–186. doi:10.1080/00071005.2012.756445

Turner, G. (n.d.). *College Access and Affordability: USA vs. the World*. Retrieved from https://www.valuecolleges.com/collegecosts/

Uber-U is Already Here. (2016, May). Retrieved from https://teachonline.ca/tools-trends/exploring-future-education/uber-u-already-here

White, M. C. (2015). *You Won't Believe How Many People Lie on Their Resumes*. Retrieved from https://money.com/how-many-people-lie-resumes/

Williams-Grut, O. (2015). *Santander is experimenting with bitcoin and close to investing in a blockchain startup*. Retrieved from http://uk.businessinsider.com/santander-has-20-25-use-cases-for-bitcoins-blockchain-technology-everyday-banking-2015-6

KEY TERMS AND DEFINITIONS

Blockchain: A blockchain is a specific type of distributed ledger, where an ever-growing list of records, called blocks, are linked together to form a chain.

Distributed Ledger: Distributed ledgers are replicated, shared and synchronised digital data geographically dispersed over multiple sites, possibly including multiple institutions.

ePortfolio: An ePortfolio holds the learning record of a learner, providing evidence of learning achievement via a collection of digital artefacts associated with learning outcomes, such as learning assignments, badges, etc.

Hash Function: A mathematical function which, regardless of the size of its input, always gives a fixed size output, with the property that a particular output (a hash) can only be generated by exactly one input, and which is one-way. That is, there is no way to compute the input given only the output.

IPFS: A distributed filesystem in which files are indexed by a cryptographic hash of their contents; known therefore as a content-addressable filesystem.

Linked Data: A model for representing data semantically using web standards. Entities are identified by URLs and data publishers are encouraged to use shared URLs with common meanings for shared concepts. The main data model for the Semantic Web.

Open Badge: Open badges allow for detailed recording of accreditation in digital form from both formal and informal learning contexts.

Self-Sovereign Identity: An approach to digital identity, authentication, and data access control which is based on users controlling their own identity. Often uses distributed ledger technology to provide trust.

Semantic Web: A set of technical standards and processes designed to encourage a Web of data which is not only machine-readable but machine comprehensible.

Smart Badge: Smart badges are dynamic records of accreditation that follow the same principles as Open Badges with additional dynamic features, e.g. apart from just recording a learning achievement, a Smart Badge can also offer job or course recommendations.

Smart Contract: Smart contracts are automatable and enforceable agreements, allowing for trackable and credible transactions on the Blockchain without the need for verification via third parties.

Solid: A decentralised linked data platform intended to serve as a personalised linked data store.

ENDNOTE

[1] http://blockchain7.kmi.open.ac.uk/movies/movies/course-jobs2.mp4