

# Towards A Blockchain-based Decentralised Educational Landscape

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**Abstract**—Institutions in the current educational landscape operate independently. They exhibit reluctance in sharing their teaching and qualifications with others due to the fear of damaging individuality. This practice, however, is counterproductive for the students as they suffer from various difficulties and get deprived of certain benefits. In this paper, we explore the possibility of finding a solution to this deadlock. We argue that Blockchain-based decentralisation can offer a passageway where educational institutions get to keep their individuality but participate in collaborations to help overcome the problems students face. Our principal contribution in this paper is a conceptual educational landscape to show how institutions could potentially manage record-keeping, credential verifications, and continued career support in a decentralised environment.

**Keywords**—*blockchain; decentralisation; verification; education.*

## I. INTRODUCTION

The primary role of educational institutions is to offer governance, teaching, qualifications and support towards a successful career of their graduates in the post-study period. In this practice, they exhibit a standalone, scattered and remote model. They do not show interest in sharing their teaching methods or qualifications with others due to the fear of damaging their goodwills and reputation. The roles of the institutions can also vary broadly. Some provide both tuition and degrees while others only teach and the degree comes from issuing authorities who do not offer teachings. The practice of universities issuing qualifications for other institutions having no right to confer the degree on their own is not rare either. In addition to maintaining their individuality, the complex nature of types and roles heavily contributed against decoupling educational institutions from their standalone model, making the education system inherently isolated.

This current model is inadequate, backdated and sometimes damaging. It cannot see the full academic history of a student; hence, institutions fail to act appropriately. This model is also unsupportive towards lifelong learners and students receiving micro-credentials. Amongst many shortcomings, the following are three prominent problems that students frequently encounter. First, students need to verify their qualifications every time they join a new job or a new course, which is time-consuming and expensive. Second, the centralised governance puts students records in danger as such practice increases the chances of corruption, manipulation and privacy violation. Third, and finally, institutions fail to give adequate career

support, particularly for a more extended period when students achieve multiple qualifications from more than one institution.

While a universal institution is not a practical concept, students' miseries are genuine intricacies that need solving. In this paper, we show that employing Blockchain technology can help decentralising qualification verification, data governance and career support. We demonstrate how existing technologies and methods can be put together to offer a reasonable solution to these problems.

The remaining paper is organised into six sections. Section II presents the current educational landscape and identifies the problems, Section III reviews the technologies to be used in the proposal and Section IV describes potential decentralisation models. Finally, Section V presents the proposed Blockchain-based decentralised educational landscape before concluding the paper in Section VI.

## II. CURRENT EDUCATIONAL LANDSCAPE

Historically, education is an isolated system centred around teachers or teaching schools [1]. Before the establishment of formal institutions, pupils used to go to teachers' homes to receive an education. This practice gradually evolved, and both pupils and teachers started to gather at common locations, often at renowned places. This move began to establish the concept of school, although still not as a formal institution [2]. Raphael's celebrated fresco the School of Athens on the wall of Apostolic Palace in Vatican City is an excellent depiction of how the school used to look like in the ancient period (shown in Figure 1). Ancient Greece, Ancient Rome, Ancient India and Ancient China have well-documented histories of such schools [3]. By the time the University of Bologna opened its door to students in Europe roughly a millennium ago, the need for institutional education had echoed at different places across the continent and the universities of Paris, Oxford and Cambridge were established.

In this journey of evolution from teachers' home to formal institutions, one element remains common – the standalone and remote nature of the institutions. There are many lobby groups and collaborations between institutions for promoting their names and values, such as Ivy league (US), Russell Group (UK), U15 (Canada), G8 (Australia), Coimbra Group (Europe) and so on, but not many initiatives in giving joint teaching and degrees. Educational institutions have always been protective to safeguard their reputation as they fear sharing teaching



Figure 1. Raphael's celebrated fresco the School of Athens on the wall of Apostolic Palace in Vatican City.

practice and qualifications with others might put their goodwill in danger. Even institutions of the same status can have severe reluctance in joining such a union [4]. For instance, Imperial College London and University College London, two world-renowned universities from England, initiated a merger in a bid to form a large university capable of attracting twice the research fund universities such as Oxford or Cambridge can allure [5]. Although the alliance could help them achieve many benefits, it did not come through due to opposition from management and students of both universities [6].

In the present days, educational institutions play a broad role. Some provide governance, teaching, qualifications and career support. In contrast, others may provide a subset of these duties, such as awarding bodies confer qualifications while institutions without the right of giving their own degree contribute in teaching and governance. With the rise of the World Wide Web, online-based education and micro-credentials have recently become popular. Most of these qualifications come from distance learning and online institutions. The size and functional scope of these institutions are limited, making them provide slow verification assistance and almost no career support in the post-study period.

The current educational landscape shows us the practice has three broad problems. These are as follows:

#### A. Problem P1

It is a common practice that all educational institutions maintain individual databases of their own to store and hold students' records including their personal information. In most cases, students have no or limited control over their data and often remain oblivious to what exactly their institutions keep on their behalf. This centralised approach, in general, has been a subject of mounting concern as social awareness surrounding how users control their data continues to grow. Such an approach can cause alteration of data for numerous reasons including updates by mistakes, corruption and most importantly deliberate manipulation by the controlling administrators leading to tempering or removal of data without the owner's

consent or knowledge. Privacy could be another solicitude as data can be viewed, shared or sold by the possessors.

#### B. Problem P2

Educational institutions maintain an old tradition of carrying trust through badges, diplomas and certificates. It used to work when there were fewer institutions, and people recognised the certificate issued by a specific university or school. However, as time passed by, people started to lose faith in paper certificates due to the availability of handy technology that can produce fraudulent documents. Instead, it became a new trend for the bearers of certificates, transcripts and other educational records to establish the authenticity of their papers. Sometimes they need to send documents to another school or an employer using official email of the providers, while some test scores, such as the International English Language Testing System (IELTS) or Graduate Record Examinations (GRE) need to come directly from the issuers by post. What seems to be the biggest irony in the education sector is that even the educational institutions that once proudly developed the convention of issuing certified documents now do not trust them and ask for verification at the time of admitting new students.

#### C. Problem P3

The existing education system is mainly scattered, where educational institutions operate standalone failing to provide continued career support for their students. There indeed exists a practice of helping current students and alumni to obtain jobs through arranging networking sessions in universities and colleges. Still, the impact of such events is limited, and the process lasts for a few years in the post-graduation period. Furthermore, institutions generally have access to records and degree information of the qualification they provide only and cannot access or verify their students' skills and diplomas obtained from other institutions. This limitation prevents them from adequately assessing one's potentials and helping them to apply for the right job and guide them to their career paths.

### III. TECHNOLOGY REVIEW

While forming alliances amongst the universities sharing their student records, teaching, and qualification does not seem practical under the current landscape, the problems P1, P2 and P3 desperately need solving. We, therefore, argue that it is time to look for a resolution elsewhere and propose a solution in this paper using existing technologies, such as Blockchain, distributed storage and linked data. Before we present the explanation of how these technologies offer the answers to the problems, we introduce them briefly below.

#### A. Blockchain Technology

A Blockchain is an immutable distributed ledger secured by cryptographic techniques, as shown in Figure 2, and managed by a decentralised community over a peer-to-peer network through incentivisation [7]. Each member of the community is commonly known as *node* who distributedly maintains the storage of the Blockchain. No node has the authority to make changes unless agreed by the majority of the network. The process of this agreement is called *consensus* [8].

The transactions of a Blockchain are called *immutable* because once inserted, they become permanent and cannot be

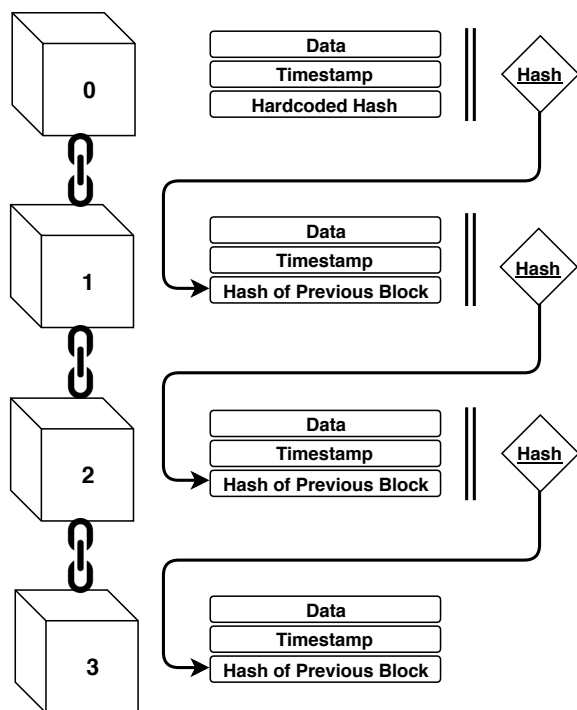


Figure 2. Each block in a Blockchain is chained to one another using cryptographic hashes creating the ultimate bond to develop the chain.

modified retroactively, not even by the authors, without the alteration of all subsequent transactions. The first block of the chain is called genesis block with subsequent blocks added through consensus between nodes. Various consensus methods, such as proof of work, proof of stake, proof of authority etc. are used in different protocols that allow nodes to compete for a pole position enabling them to insert the new block. The design of a Blockchain ensures that, once entered, contents of the blocks cannot be changed as long as no entities control more than 50% of the nodes. This property of Blockchain makes it trustworthy.

The progress in the development of Blockchain has taken the technology beyond the storage of records and includes distributed computing in the form of smart contracts. These are blocks of executable source code stored on a Blockchain with a published interface describing the methods and their parameters. The code gets executed when the corresponding transaction is added on the distributed ledger. Because the code fulfils the same requirements of the immutability of Blockchain data, smart contracts form trustworthy distributed computation [9].

### B. Linked Data

Linked Data is a form of structured data interlinked with other data to become useful through semantic queries of associative and contextual nature. It extends the capability of Web data originally meant for only human readers to share information in a way that can be read automatically by machines [10]. Linked Data plays a vital role in integrating data in the presence of multiple data sources, making them interoperable.

Sir Berners-Lee, the founder of the World Wide Web, first coined the term in his note Linked Data. He also outlined four

principles known as four rules for Linked Data. These rules state that Lined Data, i) Uses Uniform Resource Identifiers (URIs) as names of things, ii) Uses HTTP URIs to look up those names, iii) At the time of looking up a URI, provides useful information using the standards, such as Resource Description Framework (RDF) and SPARQL [11], and iv) Includes links to other URIs to discover more things [12].

### C. Distributed Storage

Distributed Storage is a decentralised approach of storing data in one or multiple servers. HyperText Transfer Protocol, or more commonly known as HTTP, is considered the biggest distributed database where peers can access particular data from anywhere in the world. HTTP became outdated due to its centralised nature. Peer to Peer (P2P) file system, such as BitTorrent, took its place. Although BitTorrent comes with a lot of advantages, several drawbacks, such as unstable downloading, unverified publisher and a lack of incentive mechanism restricted its use [13].

After the arrival of Blockchain, a combination of the distributed file system and Blockchain becomes a promising solution where the former provides the storage facilities while the latter ensures the integrity of the data and provides a way to achieve incentives. Interplanetary Filesystem (IPFS) [14], Swarm [15], and FileCoin [16] are some of these modern distributed storages.

### D. Solid: Social Linked Data

Sir Berners-Lee originally viewed the World Wide Web as a decentralised network. It was close to a peer-to-peer network assuming each user of the Web would be an active editor and contributor, creating and linking content to form an interconnected web of links [17]. The Internet, however, gradually turns out to be the opposite - an ideal example of the centralised paradigm. Sir Berners-Lee's response to this evolution of the World Wide Web is Solid. Solid, derived from **S**ocial **L**inked **D**ata, is a set of rules and tools for developing decentralised social applications based on Linked Data. It uses as much as possible the existing W3C standards and protocols [18].

Solid aims to modifying the centralised client-server paradigm, improving peer-to-peer networking in a manner that adds more control and performance features than its traditional concept, such as BitTorrent. Its central focus is to enable the discovery and sharing of information in a way that preserves privacy. It allows users to store personal data in Pods (Personal online data stores) hosted at the location of users' desire. They also have the flexibility to distribute data among several pods; allowing them to organise various types of data (personal, contact, health, financial) in multiple pods with varying degree of access control. In a nutshell, Solid allows users to retain complete ownership of their data, including where to store the data and who has permission to access it [19].

## IV. DECENTRALISED MODELS

Disintegrating educational institutions from their isolation does not necessarily have to come through sharing teaching or credentials. Decentralising their governance can potentially make them open to the authorised parties who can access information without any formal union. This approach establishes a trade-off where institutions get to keep their individuality

but participate in collaborations to help overcome the existing problems.

Decentralisation means the transfer of authority from one or more central controlling body to local representatives – in the context of web technology, these representatives are generally users. In an educational landscape, the institutions act as the central controlling bodies while students are users. Decentralisation gives students the authority over their data. They get to decide the storage location of their data and can grant access to specific entities while disallowing such access to others. There are several ways to achieve decentralisation. The following describes three models that can be used to decentralise the educational landscape.

#### A. Model M1: Pure Blockchain-based Decentralisation

Blockchain is decentralised by nature and a distributed ledger that can be used as data storage; hence, it acts as a useful tool for decentralisation. By design, data on a Blockchain are immutable; therefore, no further actions are required to ensure data integrity. There are different ways available to store data on Blockchain. The most efficient way of storing data on a Blockchain requires a smart contract. This model provides a fully distributed storage with a firm guarantee of data integrity. The tradeoff is, however, the cost as it requires payment for every contract deployment. The cost varies based on the size of the smart contract; the longer the contract, higher the fees required to deploy it. Amongst other shortcomings, lack of privacy is one that hinders its useability significantly. Besides, there exists various types of Blockchain, and depending on their kinds, advantages and disadvantages may differ. The following describes three major Blockchains, public, private and consortium, and their suitability.

1) *Public Blockchain (M1-A)*: A public Blockchain has absolutely no access restrictions. Anyone with an Internet connection can act as a participating node or send transactions. For a public Blockchain to keep operating, the platform provides some form of economic incentive or reward, often in the way of giving away some native currency, but it can be fees too.

A public Blockchain is more trustworthy due to being managed by a large community where no one has particular superiority over others in its governance and decision making. Nevertheless, it is not privacy-friendly due to being always open. This feature allows anyone to read its contents unless encrypted. Public Blockchains are expensive and storing and accessing data on this type of Blockchain can incur huge fees. In general, Blockchains do not come with built-in searching mechanisms, rather applications require developers to implement their own search functionalities. This inefficacy meets with another problem in public Blockchains. Their contents grow very fast, making the search even more difficult.

2) *Private Blockchain (M1-B)*: A private Blockchain is one that a single entity controls. Participating nodes require permission to join a private Blockchain and may have limited privileges. Because of access restrictions, private Blockchains offer some degrees of privacy and they do not grow as fast as public Blockchains. A big advantage of using private Blockchains is that they do not require *real money* to store and access data. However, they are not entirely trustworthy. The entity that controls their governance and operations may retain a superior power for tempering data.

3) *Consortium Blockchain (M1-C)*: A consortium Blockchain can have the best of both public and private Blockchains. It is sometimes referred to as a shared ledger or federated ledger because of multiple approved parties using it within a federated environment. These Blockchains are private Blockchains operated by a group or consortium and usually require permission. However, instead of a single body controlling it, various organisations can share governance. The administrators of a consortium Blockchain may restrict users' reading rights and allow a limited set of trusted nodes to execute the consensus protocol.

The main advantage of consortium Blockchains is they can bring the best of both public and private Blockchains. Because of having access restrictions (as only invited, and approved entities can join the Blockchain), they are more privacy-friendly than a public Blockchain. Besides, unlike a private Blockchain, a single entity may not hold control of the consortium Blockchains, making them more trustworthy. However, consortium Blockchains can still be vulnerable. Their number of controlling authority is likely to be limited, making it possible to group and a launch 51% attack quickly [8].

#### B. Model M2: Distributed Storage-based Decentralisation

Potential decentralisation strategies using distributed storage include two possible routes. The first is solely based on distributed storage, while the second option uses a combination of distributed storage and Blockchain.

1) *Distributed Storage Only (M2-A)*: Data can be distributed across multiple servers by duplication with anyone wishing to use the desired copy must know its precise location. This approach, however, fails to ensure the integrity of the data as there remains no straightforward way to identify if the data is altered. An improved method could be making the distributed storage to act as a filesystem for storing data with clients keeping copies of hashes of all files locally. Clients can then run the queries with these hashes to retrieve the data (e.g., IPFS). This technique helps to verify the integrity of the data because if the stored data gets altered, there will be a mismatch between the locally stored hash and the hash of the data, tearing apart the connection. In such cases, clients' query does not return the altered data, and in the event of no results, we can assume that either the data got tempered or went missing [20].

2) *Distributed Storage and Blockchain (M2-B)*: Instead of using distributed storage alone, another approach is to incorporate a Blockchain in the management of the data [21]. This use of a distributed storage with Blockchain can help to reduce the cost encountered while using pure Blockchain-based decentralisation. This model makes the decentralisation cost-effective but incorporates guaranteed data integrity. It also enables clients to avoid the need for maintaining the hashes locally; instead, data goes to a distributed storage while hashes and their associated timestamps stay as a trustworthy record on the distributed ledger [23].

#### C. Model M3: Solid-based Decentralisation

Solid can offer a third route to decentralisation. Solid pods are decentralised and give users full control of their data. They also ensure privacy as only approved entities can read and

access the data. There are two possible ways Solid can be used, standalone or in combination with a Blockchain.

1) *Solid-only Decentralisation (M3-A)*: The use of Solid is sufficient to introduce decentralisation. The ability of users while using Solid to store various types of data, such as personal, financial, educational, health, and so on, in different Solid pods makes way for creating customised privacy control. Users may give certain entities access to their personal and educational data but restrict access to financial and health data while using Solid. A significant shortcoming of Solid-only decentralisation is trust. Because of users having full control over their data, they can modify them anytime. Third parties having to rely on user data can find this model less prudent.

2) *Solid and Blockchain (M3-B)*: The use of a Blockchain with Solid pods is a type of decentralisation where Solid holds the data while a hash of it goes to the Blockchain, ensuring the integrity and trust of the user-controlled stored data. This strategy brings all the benefits that a Solid-only model can offer and solves the trust issues. Because a hash of the data goes to the Blockchain, third parties can quickly check the integrity by hashing the data stored on the pods and matching it with its Blockchain counterpart [22].

## V. PROPOSED EDUCATIONAL LANDSCAPE

In decentralising the educational landscape, we propose a four-layer architecture where Blockchain forms the first layer from the bottom. The design embraces three other layers on top of the Blockchain layer, namely data layer, verification layer and support layer – Figure 3, shows the architecture and the arrangement of the layers in the design.

Three problems, P1, P2 and P3, that we identified in Section 2 represent three broad areas of the educational landscape and form the top three layers in our design. P1 represents data management and governance and creates the data layer, P2 focuses on the credential verifications and forms verification layer, and finally, P3 states the continued career support for the students and produces the support layer.

### A. Blockchain Layer

The Blockchain layer forms the foundation of our proposed architecture. We recommend using a consortium Blockchain due to its ability to mimic the best of both private and public ledgers. In our architecture, participating institutions will join and govern this consortium Blockchain. The remaining three layers will operate over the Blockchain and will have the ability to access it directly or through other layers.

### B. Data Layer

The second layer in our architecture is the data layer responsible for data governance. It manages students data in a decentralised style. Institutions generally maintain a central database to hold all kinds of data, including students records and information. Data layer disintegrate this database and distribute its contents to various stakeholders, such as students, teachers and administrators. Amongst the suitable decentralised models, M1-C, M2-B and M3-B from Section IV look useful for developing this layer. However, due to lack of privacy, M1-C does not fit for sensitive data like personal information, students record and results; therefore, we prefer M2-B and M3-B, which means storing data on either IPFS or Solid with their hashes on the Blockchain. Between

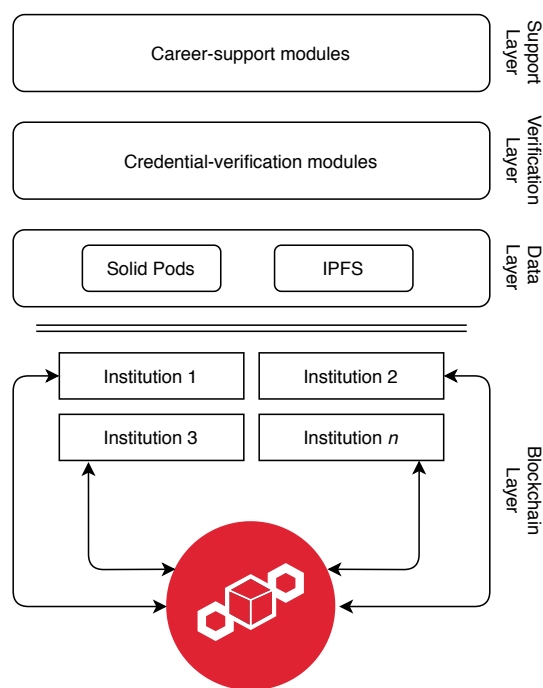


Figure 3. The layered architecture of the Blockchain-based proposed decentralised educational landscape

these two models, Solid offers added benefits in the form of advanced access control; hence, we use Solid while describing the remaining architecture.

The data layer consists of Solid pods managed by students, teachers and administrators. Students will have their personal information on their pod that they grant access to only their institutions. Administrators of the institutions can have some student data on their pods too, such as results and qualifications. In this case, they grant at least read access to students so that they can be aware of what data institutions hold on their behalf. This access may be time-dependent; for instance, results data will be made visible to students only when the results are announced. Teachers can have their pods to store and share students marks and initial results. They may only grant access to this data to administrators before the results are finalised. Institutions should have specific policies tailored to their practice concerning when to share data and how.

In a decentralised architecture, multiple sources can hold the data making it difficult to run queries using traditional methods. Linked Data and federated query can help to solve this problem. It works as follows: Each and every entity in a Solid pod are represented in the form of URIs. If the data stored in the Solid pods are expressed in RDF format, it can be queried using SPARQL, which is a query language for accessing linked data [11]. SPARQL can also be used to query data from multiple Solid pods as long as the query engine is granted access to the Solid pods [20].

The data layer solves P1. It gives students control over their data and allows them to see what their educational institution holds on their behalf. By employing Blockchain, data layer also ensures the integrity of the information contained by students and administrators.



### C. Verification Layer

The verification layer is responsible for verifying credentials. This layer helps students and lifelong learners to get their qualifications checked for potential employers and other educational institutions. All institutions that confer degrees or award micro-credentials must give students a badge or similar object that students keep in their Solid pods. Later at the time of applying for courses in other institutions or jobs in companies, they show the badge as a representative of their qualification certificate.

Badges are digital objects that students can temper. Therefore, to ensure the integrity of the data, issuing authorities insert hash of the issued badge to the consortium Blockchain. They also keep a record of the credentials to their Solid pods with students having access to it. An entity wishing to verify a particular credential does not have to go to the issuing authority. Again, Linked Data and federated query help us achieve this. The verifier can be a web application which seeks access to a Solid pod stored qualification badge, which then hashed by the web application. The badge hash is compared with the hash stored on the Blockchain which was previously uploaded by the badge issuer. If it matches, then the employer knows that the student badge is valid [24].

The verification layer solves P2. By making verification automated, it allows students to get their credentials verified at the expense of a few mouse clicks. It reduces time and saves money for both students and parties who check their credentials.

### D. Support Layer

The support layer paves the path for both educational and non-educational institutions to participate in providing career support to students and lifelong learners. These supports can come in various ways, including suggesting jobs, courses and preparing automated CVs.

Our architecture already showed how data are made accessible for approved entities through Linked Data and federated query engines. Educational institutions can run federated searches on the available job and qualifications of their graduates to pinpoint suitable employment for them. Potential employers can also benefit from this decentralised architecture as they can shortlist potential candidates on their own through verified qualification matching. Educational institutions can further suggest courses to students based on the qualifications they do not have but would help them land their preferred jobs. Institutions and commercial companies providing HR support can also use the data to offer students smart resumes where verified credentials and job information will be appended automatically.

The support layer solves P3 by opening data to approved parties. In a centralised and isolated system, educational institutions cannot see what qualification students have in addition to theirs. In this proposed architecture, institutions do so; hence can come up with job and course suggestions more precisely.

## VI. CONCLUSION

Educational institutions behave like islands – isolated and remote. Their reluctance in sharing teaching and credentials create sufferings for the students. In this paper, we try to find a trade-off proposing a decentralised educational landscape

where institutions do not have to lose their individuality but can still participate in collaborations. Using existing technologies, we showed how record-keeping, credential verifications and continued career support could be provided in a decentralised atmosphere.

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