Decentralized Academic Platforms: The Future of Education in the Age of Blockchain

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ABSTRACT

Despite referring to two different phenomena, the phrases ”decentralized organization” and ”distributed organization” are sometimes used synonymously. I suggest separating distribution the dispersion of organizational decision-making from decentralization, which I define as the dispersion of organizational communications. The distribution of an organization does not necessarily imply its decentralization (and vice versa), because the presence of many management tiers impacts only distribution, not decentralization. Understanding the rise of digital platforms like Amazon.com, which control the global economy in the twenty-first century, has consequences for this proposed differentiation. Blockchain has arisen as an alternative technological framework. However, well-known platforms often use machine learning as their primary technology to translate inputs (such as data) into outputs (such as matchmaking services). I contend that machine learning encourages centralized communications and the concentration of decision-making, whereas blockchain provides platforms that are simultaneously decentralized and distributed (such as Bitcoin). This distinction has significant implications for antitrust policy, which, in my opinion, should instead concentrate on the data level for both its analysis and its target of action. My predictions for the future of competition between centralized and decentralized platforms, the development of governmental regulation, and broader ramifications for managers in the digital economy and the business schools responsible for their education are all based on the framework of this essay. I end by reflecting on the chance to renew cybernetic theory to stop a future where a small number of platform behemoths rule supreme.

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1. INTRODUCTION

Educational recognition such as degrees, certificates and academic records have long been considered a “job requirement” and a “universal medium of exchange” in enhancing career opportunities and social status in the labor market. OECD member countries allocate an average of 4.9% of their Gross Domestic Product (GDP) to the education sector, and individuals play an important role in financing higher education, contributing around 30% of total education investment. Despite these huge expenditures, students are still facing the ”qualifications inflation” trend revealed by the 2018 survey. Specifically, about 44% of employers have raised educational qualification requirements in the last five years, and 64% of them believe that the labor market is becoming more demanding more qualifications. In the face of soaring demand, educational qualifications have not only increased in volume (for example, the Credential Engine's 2021 report shows that 967,734 qualifications were issued in the US in one year), but also diversified in alternative forms. Qualifying publishers not only come from traditional institutions, but also engage a growing number of EdTech providers.

The increasing volume and variety of qualifications issued by different education providers from different education systems adds complexity to the education recognition ecosystem. Challenges such as qualification fraud, verification difficulties, and declining trust between stakeholders are exacerbated. These issues will be further detailed in the next section.

Blockchain technology has emerged as an innovative solution to address issues around educational recognition. It carries attributes such as data availability, verification, and trust. Research on this topic has been in demand since 2016, growing rapidly in 2018, and reaching its peak in 2019. However, similar to other sectors such as supply chain, health and smart cities, the adoption of blockchain technology in education has also experienced obstacles since 2019, with limited implementation and scale. The current studies can be grouped into two categories based on the research questions and the methodology used. First, a systematic literature review category that explores the potential of blockchain and its evolution over time. Second, the technical prototype design category that seeks to develop blockchain-based applications to address certain educational problems. However, these recent studies have tended to jump straight to the prototyping stage without closely investigating the existing educational landscape. Nonetheless, both provide limited insight into the factors that might hinder the adoption of blockchain technology in education.

As such, this research, which builds on previous studies, aims to fill this gap by exploring the potential barriers hindering blockchain adoption. This research serves as a reflective analysis and guide for future development. Contributions to this research include:

- Brief description of the education recognition workflow to provide an overview of the education landscape.
- Identification of the main challenges faced by key stakeholders, compiling the five attributes expected in an ideal recognition infrastructure, and emphasizing appropriate blockchain features to support these attributes.
- Introduction of a four-layered framework for comparing existing blockchain-based studies and discussing factors

2. LITERATURE REVIEW

The emergence of decentralized academic platforms and the integration of blockchain technology into education has attracted a lot of attention in recent years. This literature review explores the evolving landscape of decentralized education platforms and their potential impact on the future of education, all in the context of the transformative capabilities of blockchain technology. Traditional education systems have long been characterized by centralized control, often limiting access, and stifling innovation. However, the emergence of decentralized academic platforms aims to change this paradigm. The platform uses a blockchain decentralized ledger to enable direct interaction between students, educators and institutions. This shift promises increased accessibility, transparency and autonomy for all stakeholders. Decentralized platforms offer opportunities for lifelong learning, micro-credentials, and global collaboration, unencumbered by geographic constraints.

Blockchain, originally designed to support cryptocurrencies, has found applications outside the financial sector. In education, blockchain offers features such as immutability, transparency, and security. Student records, credentials, and achievements can be stored securely in tamper-resistant ledgers, reducing fraud and increasing trust in the education system. Additionally, blockchain can streamline administrative processes, simplify credit transfers, and facilitate qualification verification, thereby creating a more efficient and responsive education ecosystem. The integration of decentralized academic platforms and blockchain technology is in line with some of the leading trends in education. Lifelong learning is becoming a necessity as the job market is growing rapidly due to technological advances. The decentralized platform provides flexible and on-demand learning opportunities, empowering individuals to upskill and adapt to changing demands. Furthermore, a personalized and learner-centric approach gains prominence with a decentralized platform, which enables customized learning paths and adaptive content delivery.

While blockchain promises increased security, privacy concerns should not be overlooked. Educational institutions need to strike a balance between transparency and data protection. Blockchain's inherent transparency can pose challenges in safeguarding sensitive student information. Innovative cryptographic techniques, such as zero-knowledge proofs, can overcome this problem, enabling verification without disclosing personal data. A decentralized academic platform has implications for various stakeholders in the education ecosystem. Institutions should adapt their models to embrace decentralized learning environments and implement blockchain-based solutions for records management. Educators can leverage this platform to experiment with new teaching methods and access a global student pool. Students benefit from a borderless education marketplace, earning credentials that are recognized across jurisdictions.

The emergence of decentralized academic platforms along with blockchain technology presents a transformative potential for education. The combination of accessible and learner-centric media, secured with blockchain features, has the potential to reshape the education landscape. While challenges such as privacy and adoption remain, the future of education in the blockchain era is poised to become more inclusive, dynamic, and adaptive. As researchers and educators continue to explore and innovate, these platforms hold promise for a more democratic and effective education system.

3. RESEARCH METHODS

This research examines the effectiveness of integrating machine learning and artificial intelligence in education using a comprehensive survey approach to gather opinions from educators, administrators, and students. This study uses the SmartPLS program to uncover latent constructs, analyze complex relationships, and reveal the underlying relationships. To gain insight into the potential, challenges, and impact on learning outcomes, this research investigates the factors that influence successful AI integration. This research carefully explores the complex interplay between AI integration and learning outcomes, incorporating perspectives from teachers and students, all of which are analyzed using SmartPLS. This project leverages state-of-the-art SmartPLS software for data processing to assess perceptions, identify complex relationships and simulate complex interactions in education.

3.1. Data and Variables

For this study, 60 Indonesian students and teachers participated in the survey. The findings constitute important new research and a representative sample is required for the second phase of this study and therefore cannot be generalized to the entire statistical population of Indonesian students and teachers. This study does not apply a sample size limit because it is believed that learning aid technology should be applicable to various learning models. From Table 1, there are 16 different data points considered. These variables must be taken into account to ensure that the model best fits the data and produces accurate predictions. In addition, these characteristics are used in the research on which our research is based.

Code	Definition
DP1	The decentralized platform has increased my access to a wider range of educational resources.
DP2	The decentralized platform has increased my involvement and participation in online learning activities.
DP3	I found it easy to navigate and use the features offered by the decentralized platform.
DP4	The decentralized platform has had a positive impact on my learning outcomes and understanding of the subject.
DP5	Collaborative learning experiences on a decentralized platform have been invaluable to my education.
BE1	The integration of blockchain technology in education has increased the security of student data and records.
BE2	The use of blockchain technology has a positive impact on the transparency and integrity of academic achievement.
be3	The adoption of blockchain-baseds solutions has given students better control over their personal educational information.
BE4	Blockchain technology has simplified the process of verifying educational qualifications for employers and educational institutions.
BE5	The blockchain merger has fostered increased trust between students and educational entities.
FET1	New technologies, such as AI and VR, have the potential to increase student engagement and interaction in the learning process.
FET2	A blended learning model that combines online and face-to-face teaching provides a more flexible and effective learning experience.
FET3	Personalized learning paths, tailored to the needs of each student, are essential for improving educational outcomes.
FET4	Collaborative learning environments, both face-to-face and virtual, foster critical thinking and problem-solving skills.
FET5	Lifelong learning and continuous skills upgrading will be critical for individuals to remain competitive in a rapidly evolving job market.
SP1	Institutions effectively communicate their data privacy policies to students and staff.
SP2	The institution provides clear guidelines on how my personal data is collected, used and stored.
SP3	The agency actively seeks user input to improve security and privacy measures.
SP4	The institution's cybersecurity measures played an important role in my decision to get involved in online education.
SP5	I feel my privacy is respected when using digital learning platforms.
SI1	The proposed changes have had a positive impact on teaching methods and educator effectiveness.
SI2	The implementation of the proposed learning improvement strategy is sufficient to answer students' needs.
SI3	The improvements introduced increase collaboration and engagement among students.
SI4	New learning initiatives take into account the preferences and learning styles of a diverse student population.
SI5	The proposed strategy has the potential to increase the overall retention rate of students.

3.2. Research methodology

The analysis of the literature reveals some of the potential associated with Education in the Blockchain era to enhance personalized learning environments in education. This disclosure prompted us to adopt an exploratory strategy to learn more about enhancing personalized learning environments through the application of Blockchain in education. To assist education managers and authorities throughout Indonesia in adopting and utilizing Blockchain in education, we developed a survey. This research uses a survey of students and teachers in Indonesia to gain insight into their level of knowledge about Blockchain, as well as to explore their opportunities and concerns in this area. The findings regarding Blockchain, as presented in the study, formed the basis for subsequent academic research surveys.

- Hypothesis 1: Decentralized Platforms and Adoption of Educational Technology: The higher the acceptance of decentralized platforms, the higher the adoption rate of educational technology.
- Hypothesis 2: Use of Blockchain Technology and Educational Data Security. The use of blockchain technology has a positive impact on the level of security of educational data.
- Hypothesis 3: Linkage of Future Educational Trends and Use of Decentralized Platforms: Future education trends relate to the use of decentralized platforms.
- Hypothesis 4: Security and Privacy Effects of Blockchain Technology on Adoption: The level of security and privacy of blockchain technology has a positive effect on adoption.
- Hypothesis 5: Effect of Future Educational Trends on the Use of Blockchain Technology: Future educational trends have a positive influence on the use of blockchain technology.
- Hypothesis 6: The Effect of Using a Decentralized Platform on the Implications of Stakeholders: The use of decentralized platforms has positive implications for stakeholders in the education environment.
- Hypothesis 7: Effect of Security and Privacy of Blockchain Technology on Stakeholder Implications: The security and privacy of blockchain technology affects the positive implications of stakeholders.
- Hypothesis 8: Effect of Future Educational Trends on Stakeholder Implications: Future education trends have an influence on the positive implications of stakeholders in the educational context.
- Hypothesis 9: Effect of Using Blockchain Technology on Stakeholder Implications: The use of blockchain technology has positive implications for stakeholders in the educational environment.

4. RESULT AND DISCUSSION

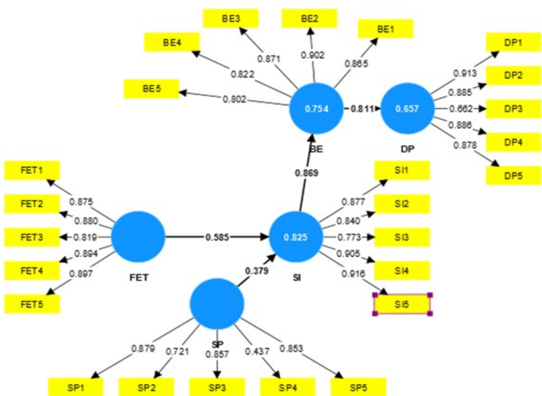

Figure 1. PLS Framework

A high value [¿0.7] of composite reliability indicates strong support for this hypothesis in the model. In the second stage of the analysis, Cronbach's Alpha was used to assess the applicability and consistency of the

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
BE	0.906	0.913	0.93	0.728
DP	0.901	0.917	0.928	0.722
DONE	0.922	0.924	0.941	0.763
AND	0.914	0.92	0.936	0.746
SP	0.81	0.854	0.872	0.589

survey. Since all the survey questions achieved an excellent Cronbach's Alpha score, it is clear that significant care has been taken in constructing the survey questions. A significant driving force behind this research and its added value, particularly in Indonesia, is the dearth of studies on how the future of education in the Blockchain era is used collectively to enhance customized learning environments. To evaluate the construct's internal reliability, Cronbach's Alpha calculations were also used. It consistently delivers results that support a high degree of internal consistency across all constructs. Although CR values provide a more reliable estimate of construct reliability, especially when the construct consists of multiple measurement items, it is important to note that Cronbach's Alpha is the statistic that is widely used. Furthermore, Average Variance Extracted (AVE) was used to assess construct validity by comparing the variance of the item measurements with the variance of the common factors. The AVE calculation produces a value that exceeds the required limit, which indicates that the measurement items in each construct collectively effectively assess each latent variable.

Composite Reliability calculation results, Cronbach alpha reliable shows that each construct has a value that exceeds the recommended threshold, which is ¿ 0.70 and AVE shows that each construct has a value ¿ 0.6. This fact indicates a strong internal linkage among all measurement elements in the construct, accurately reflecting the latent variable to be measured. This study emphasizes how consistent the internal constructs aremaintained, measured by specific items, provides support for the validity of the construct.

	R-square	R-square adjusted
BE	0.754	0.751
DP	0.657	0.653
AND	0.825	0.82

Convergent validity was determined because the average extracted variance (AVE) for each latent variable exceeded the allowable limit value of 0.5 for the following categories: BE (0.652), educational outcomes (0.728), DP (0.763), FET (0.763) , and SI (0.746). BE (0.751), DP (0.653), and SI (0.82) all have a correlation coefficient for each variable R square that is greater than the limit ¿0.5, while the Machine Learning Model (0.427) is the only variable that is below this limit . It can be assumed that these variables are indicators of interconnected constructs because the average validation procedures shown in Tables 2 and 3 do not rule out the hypotheses of artificial intelligence algorithms, educational outcomes, machine learning models, performance models, and personalized learning environments. With 5,000 samples and the SmartPLs software, which has a reliability level of 95% when using the bootstrapping approach, the significance of the variables is assessed. Figure 1 and Table 4 provide a general summary of the findings.

4.1. Facing Barriers in Traditional Credentialing Frameworks

This segment provides an overview of the educational credentialing landscape, identifies existing issues within the sector, and outlines the desirable attributes of an ideal credentialing infrastructure. While higher education systems share similarities, historical and legislative factors contribute to their distinctiveness. In the context of this paper, the Australian Qualifications Framework (AQF) was chosen as the basis for this investigation because of its integral role in Australian education quality assurance and its alignment with international frameworks.

A. Credential Landscape Mapping

An educational credential includes a series of evidence demonstrating a student's learning achievement during the credentialing process, including academic transcripts, certificates of placement, qualifications, and degrees. In general, credential scores increase with higher entry requirements and graduation thresholds. The modern educational credentialing process can be summarized in four steps to illustrate this complex landscape (see Figure 1):

1. redential Program: Students apply for accredited educational programs aligned with specific credentials offered by institutions such as Registered Training Organizations (RTO) or Institutions of Higher Education (HEI), in both traditional and online formats. Applicants must provide evidence of previous studies and relevant work experience to meet the entry criteria. Successful completion of the entrance assessment may lead to enrollment and commencement of the program.

2. Learning Credits or Micro Credentials: Students engage in learning activities and pass appropriate assessments to earn traditional learning credits or digital micro credentials issued by education providers. Microcredentials, a term that has gained prominence in recent years, function similarly to learning credits, representing smaller modules of learning that accumulate into larger credentials (eg degrees). Synonyms for micro-credentials include 'nano-degrees', 'learning badges', or 'endorsements'.

3. Educational Credentials: After collecting sufficient learning credits or micro-credentials from required subjects and meeting the passing criteria, students receive educational credentials from the provider. These credentials include transcripts, certificates of completion, and qualifications, which reflect student achievement.

4. Verifiable Credentials: After graduation, when students apply for jobs or advanced degrees, recruiters (i.e., employers) may request certified educational credentials. Many Australian universities recommend graduates use the My eQuals platform for verifiable credentials, presented as secure links or cryptographically signed PDF documents.

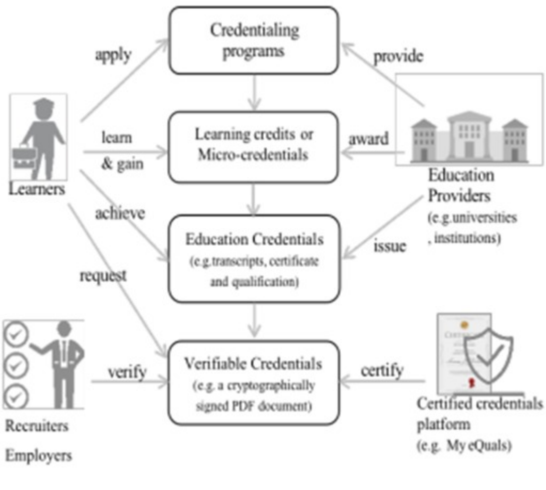

Figure 2. Crendentialing workflow and involved steakholders

This represents an ideal portrayal of the credentialing workflow, where credentials seamlessly connect various stakeholders, primarily for a comprehensive comprehension of the tertiary education landscape. However, as highlighted in Section I, the escalating issuance of credentials by diverse education providers exacerbates the complexity. Thus, in the subsequent part of this section, we delve into the challenges intertwined with credentialing within the increasingly intricate realm of tertiary education.

B. Emerging Challenges

1. Recognition Complexity of Credentials: Learners encounter arduous procedures in attaining recognition for their credentials when transitioning between different education providers. Particularly in the context of international transfers, individuals may need to pay substantial consulting fees to local agencies to

ensure successful educational transitions. Furthermore, education transitions contribute to the fragmentation of evidence regarding learning achievements. Schools are often unable to access a newly enrolled student's prior learning data, hindering the provision of personalized curricula and targeted teaching guidance.

2. Credentials Vulnerable to Damage or Tampering: Credentials are susceptible to accidental damage or intentional manipulation. When individuals deliberately modify their credentials through malicious actions, the verification process can confront significant challenges. An illustrative instance involves Mina Chang, a former senior administration officer of the U.S., who embellished her educational achievements, falsely claiming a Harvard degree. This misinformation was only brought to light after her resume was scrutinized, demonstrating the persistent issue of fabricated credentials. While governmental oversight was criticized for lax screening of appointed officials, the issue of falsified credentials remains unresolved, as long as verification heavily relies on human assessment.

3. Escalating Hiring and Screening Costs: Confronting the previously mentioned problem, enterprises are compelled to increase their expenses for recruitment and screening. The estimated average cost of hiring an employee hovers around US$17,000, and even this expenditure cannot shield companies from deceptive employees, as 75% of them have dealt with inappropriate hiring. This concern over negligent hiring has spawned a profitable market—employment screening services. Education and employment verification stand as the top two screening aspects. The global employment screening services market reached US$4,957 million in 2020 and is projected to reach US$9,917 million by 2028.

4. Eroding Trust and Value: Enterprises appear to be losing faith in the conventional credentialing system, attributed not only to fraudulent credentials but also to concerns about education quality. An emerging trend is that enterprises are establishing their own education credentialing systems. For instance, Google introduced an IT certificate program that enrolled 40,000 learners in 2018 and formed a consortium of 20 major companies to hire its graduates. This practice has been replicated by other major corporations like Amazon and EY. If businesses begin to supplant institutions in educating individuals, traditional higher education institutions must urgently reassess education quality and credentials' value.

5. Identity Theft: Notably, an educational credential signifies more than skills and knowledge; it also serves as ”tangible proof of identity” for individuals. A certificate contains an individual's real name and other authentic personal details, such as university names, faculty, and graduation years (which could potentially disclose a person's geographical location and networking information). In the U.S., the education sector ranked among the top three for social data breaches in 2017, with identity thieves targeting both adult learners (selling for around US$10-25 per person) and young children (selling for around US$300 per child).

6. Centralized Credentials Governance: The present credentialing system relies on centralized third-party verification providers to address these issues, but it fails to completely address trust and security concerns. For example, My eQuals is employed by 55 Australian and New Zealand universities to issue verifiable official credentials. However, My eQuals' data storage is situated in Australia, implying that the current database containing 1.6 million learners and over 4.8 million documents is housed in a single region. This centralized data storage could raise uncertainties regarding trust and data security when considering individual, national, and public interests. At the individual level, learners lack awareness about how their data is accessed and used. On a national scale, clients from diverse cultural or political backgrounds are compelled to trust a single centralized governance entity to manage their learning data. Publicly, a single point of failure or attack could jeopardize the entire system, leaving millions of learners' data vulnerable.

C. Characteristics of the Ideal Credentialing Framework

Drawing from the aforementioned understanding of the landscape and the prevailing challenges, we aspire to incorporate the subsequent attributes into an education credentials infrastructure:

- Empowering Learner Control: It is imperative that learners wield authority over their credentials, ensuring prevention of data manipulation or misuse, and diminishing the reliance on centralized third parties.

- Verification Simplicity: Credentials should possess a high degree of authenticity that can be swiftly verified through user-friendly methods. This verification process should be immune to the limitations of human intervention.
- Immutability Assurance: The integrity of credentials should be upheld, resisting any attempts at fraudulent alteration. Any modifications made should be promptly identifiable and traceable.
- Seamless Portability: Credentials must exhibit a remarkable level of flexibility, surmounting barriers associated with credentialing. They should be conveniently transportable, enabling learners to present them across various educational platforms and workplaces.
- Employability Focus: Credentials should cater to the demands of industries, equipping learners with the essential knowledge and skills required to maintain a competitive edge in the job market.

4.2. Revolutionizing Credentials Through Blockchain Technology

Utilization of blockchain technology, which serves as a substitute for decentralization, seems to uphold all of the aforementioned qualities. It has the potential to revolutionize the educational credential life cycle through multiple avenues. This segment underscores important elements that are critical to the context of educational credentials. Initially, we described the overarching properties of blockchain that have been discussed in various research studies, including decentralization and immutability. Next, we emphasize two additional attributes, namely self-sovereignty and tokenization. While not universally discussed in every study, these two attributes have significant potential to propel blockchain applications, commonly called DApps, to the next echelon. Other aspects such as different types of blockchains, smart contracts and data stores are discussed as comparative benchmarks among selected prototypes in Section IV.

A. Eternity

Immutability, the second important aspect of the blockchain, implies that once a learning credential has been documented on the blockchain, it becomes immune to modification by any party. Achieving immutability involves incorporating mechanisms within the blockchain such as timestamps, hash functions, consensus, and peer-to-peer networks. For example, learning credentials can be time-stamped, a unique chronological fingerprint to keep track of when students got credentials. Hash functions are used to convert credential documents, regardless of size and length, into a concise output called a ”digest”. Even minor changes to the original result in substantial modifications to the output, facilitating the identification of fraudulent acts. In addition, any change to the blockchain requires strict approval from network participants to reach consensus on a global scale. This attribute of blockchain technology provides a source of credentials, improves verification efficiency, and contributes to rebuilding trust between various stakeholders.

B. Tokenization

While tokenization has only been sparingly explored in related education studies, it has been successfully applied in certain real-world examples (eg, Student Coin), offering many prospects for future applications. Tokenization, defined as the process of converting data or digital assets into a new cryptographic form using blockchain technology, generating tokens, can be called ”tokenization”. This process is believed to be able to increase the efficiency of business processes and substantially expand the scope of DApps. Tokens can be categorized based on their function, into fungible tokens for exchangeable assets and non-fungible tokens (NFT) for non-divable assets. NFTs can prove ownership, protect intellectual property, and most importantly, prevent counterfeiting and fraud problems in practical scenarios. These distinctive attributes present a viable solution to existing credentialing challenges. Notably, certain pilot projects have used tokens to represent educational rewards (e.g., E2C-Chain), learning credits (e.g., EduCTX), and educational reputation (e.g., Kudos).

C. Decentralization

The distributed nature of data storage in the blockchain allows each node (ledger) in the system to have a verified data backup. These characteristics contribute to increased data security for student learning records, allowing individuals to access their education credentials from any node in the system. Even if a student makes the transition to an education system in another country or loses direct contact with the issuing institution, they still have the ability to regain or restore their learning credentials from anywhere in the world. In addition, the decentralized peer-to-peer network serves as a deterrent against fraudulent activity, as it becomes impossible to modify educational data across all archives in the network. This facilitates the verification process and reduces costs incurred by employers during recruitment screening.

D. Self-sovereignty

Blockchain provides resolutions to challenges such as learning discontinuities and identity theft by facilitating a new identity management paradigm called self-sovereign identity (SSI). SSI empowers individuals with absolute control over their data, enabling them to dictate the use and disclosure of their data without third party interference. Educational credentials implemented through SSI can integrate new attributes such as security, portability, and self-determination. Additionally, credential systems can inherit blockchain characteristics to not only ensure secure privacy sharing but also overcome geographic and political barriers. An illustrative example is the "Diploma Use Case" in the European Blockchain Services Infrastructure (EBSI), built on top of the European Self-Identity Framework. In this scenario, cryptographic proofs of digital diplomas are stored on the blockchain, and issued to the student's wallet, giving the user complete control over their identity and education-related data.

4.3. Assessing Different Approaches and Impact of Blockchain Solutions

Several academic and industry initiatives are currently underway or in their early phases. This study employs a snowballing approach, rooted in software engineering principles, based on a "start set" of recent systematic literature review studies, to identify representative studies. The selection of representative studies involves the utilization of Connected Papers to assess the relevance and significance of each study. Our review encompasses not only peer-reviewed papers but also official websites and white papers to acquire the most precise and up-to-date information. Exclusion criteria involve studies lacking experimental prototypes and testing outcomes. In cases where two studies propose similar concepts, the initial presentation of the creative idea is chosen. Ultimately, our objective is to aggregate the focused application scenarios of the selected projects to encompass all the credentialing processes discussed in Section II-A. The chosen use cases are arranged chronologically from 2016 to 2021 to analyze the evolution of blockchain-based credentialing solutions.

1. Blockcerts (2016), developed collaboratively by the MIT Media Lab and Learning Machine, represents the world's pioneering and widely adopted blockchain-based education credentialing platform. Its primary function involves supporting the issuance and verification of credentials.

2. EduCTX (2018), the inaugural project to align with the European Credit Transfer and Accumulation System (ECTS) framework, generates tokens as learning credits to facilitate their transfer, accumulation, and verification.

3. E2C-Chain (2019), introducing an incentive model for peer-to-peer verification of education and employment skills, uniquely emphasizes social welfare maximization. This project employs ZK-SNARK to safeguard learners' sensitive data.

4. BOLL (2019), known as the Blockchain of Learning Log, relies on three smart contract types to monitor learners' learning records and facilitate transitions between institutions.

5. QualiChain (2019), a prominent Pan-European digital education credential infrastructure funded by the European Union, addresses four distinct application scenarios aimed at different client groups. These scenarios encompass lifelong learning for learners, curriculum design for schools, public sector staffing, and HR consultancy for enterprises.

6. ocs Chain (2020), pioneers the integration of Internet of Things (IoT) devices, supporting the uploading of traditional paper credentials onto the blockchain.

7. TolFob (2021), by introducing a conceptual learning application model and undergoing extensive testing, represents the first initiative to undergo comprehensive testing involving 98,181 teachers and students, 38 courses, and a total of 40,708 learning activities.

This study does not aim to provide an exhaustive literature review but rather conducts a cross-project analysis to identify potential barriers hindering widespread adoption. We introduce a four-layer comparison framework, integrating the "blockchain within a software architecture" design pattern [33], [34], with the system architectures of selected education use cases, to offer guidance for blockchain-based education application development. The framework comprises four layers: the prerequisite layer, application layer, interoperability layer, and blockchain layer (refer to Figure 2).

A. Prerequisite Layer

This layer underscores fundamental knowledge essential prior to commencing system design. Activities encompass understanding the landscape, identifying users, observing and evaluating users' behaviors, and specifying users' requirements. Engaging users in the design process enhances the likelihood of user acceptance and adoption [35]. However, to date, this layer has received inadequate attention. Weaknesses include discrepancies between design assumptions and users' actual habits. Practical user involvement strategies should be implemented to understand users' requirements, values, and habits within real-world contexts.

B. Application Layer

The application layer enables users to leverage blockchain technology's benefits through interactions with the DApps. This layer focuses on formalizing performances and functions within DApps to meet specific user requirements. The execution of functions within the blockchain scope is typically supported by smart contracts. However, a majority of current projects develop their functional structures in isolation. Collaborative ecosystem-building across different initiatives is recommended for greater resource efficiency and advancement.

C. Interoperability Layer

Interoperability within education settings involves enhancing interoperation and data exchange among various education entities. Achieving interoperability promotes application portability, cooperation between different DApps, and integration within the education ecosystem. While interoperability remains a complex challenge, strategies such as standardizing building blocks, adopting standardized data models, and leveraging existing interoperability-supporting tools can enhance blockchain adoption.

D. Blockchain Layer

This section compares selected solutions within the blockchain layer based on aspects like blockchain types, smart contracts, data storage, and economic feasibility. The choice of blockchain types, the utilization of smart contracts, on-chain or off-chain data storage, and economic factors are critical considerations during the implementation of blockchain solutions. It's worth noting that the practical considerations extend beyond the aforementioned aspects, including incentives mechanisms, privacy protection, signature authorization, and asynchronous network effects. These multifaceted factors collectively shape the feasibility and success of blockchain adoption within various applications.

5. CONCLUSION

Through examining the educational credentialing landscape, we uncover the challenges that exist within this sector and their relation to the potential for blockchain adoption. Next, we evaluate and research selected initiatives using the four-layer framework suggested in this paper. The results of this research have the ability to raise awareness and provide guidance for the future endeavors of blockchain experts and educational researchers. We must be aware of the limitations of this study. This is done with a limited number of cases, so it cannot cover the entire spectrum of blockchain application development. In addition, they are also reluctant to introduce new solutions, not only because of space constraints but also in line with their original purpose as a baseline study to pave the way for further investigations. Future phases of this effort will include: (i) increasing user engagement and support through a co-design strategy, and (ii) designing adaptable and customized blockchain prototypes while overcoming the technical barriers mentioned above, to ensure compatibility with other blockchain solutions.

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