Blockchain in E-Learning Platform to Enhance Trustworthy and Sharing of Micro-Credentials *

Alessandro Bigiotti[1][0000−0002−6183−1719], Maria Paola Francesca Bottoni[2][0000−0002−6397−297X], and Giacomo Nalli[3][0000−0002−5667−3429]

[1] Division of Computer Science, University of Camerino, Via Madonna delle Carceri, 9, Camerino, 62032, Italy
alessandro.bigiotti@unicam.it
[2] Legal and Social Science, International School of Advanced Studies, University of Camerino, Via Andrea D'Accorso, 16, Camerino, 62032 Italy
mariapaolafrancesca.bottoni@unicam.it
[3] Computer Science, School of Science and Technology, Middlesex University London, The Burroughs, London, NW4 4BT, United Kingdom
g.nalli@mdx.ac.uk

Abstract. Blockchain is a disruptive technology and interest in its adoption is growing across many market sectors in Industry 4.0. However, the blockchain adoption is limited by the difficulty in managing private keys and wallets to interact therein. This paper describes the integration of a consortium blockchain within e-learning platforms. The adoption of blockchain in the e-learning platform maximises the reliability, verifiability and sharing of micro-credentials. The proposed solution aims at eliminating the difficulties of managing keys and wallets. The enhancement in the reliability of micro-credentials is particularly important in learning environments and in companies that want a guarantee of effective training of employees. The present article, in line with the European privacy framework, exploits the potential of blockchain without compromising user data protection.

Keywords: blockchain · smart contract · online learning · micro-credential · industry 4.0

1 Introduction

Industry 4.0 was launched in 2010 by the German government as a strategic initiative aiming to integrate new technologies derived from "Information and Communication Technologies" into the industrial environment [29]. Among the technologies of interest in Industry 4.0 we find artificial intelligence, the Internet of Things and certainly the blockchain. In particular, the blockchain is an

* This research was funded by Ministero dell'Università e della Ricerca (MUR), issue D.M. 351/2022 "Borse di Dottorato" - Dottorato di Ricerca di Interesse Nazionale in "Blockchain & Distributed Ledger Technology", under the National Recovery and Resilience Plan (NRRP).

emerging and potentially disruptive technology due to its transparency, decentralisation, and security properties. The significant features of blockchain technology are the use of cryptographic primitives, to manage authentication and data integrity, and the use of distributed algorithms, to conduct peer-to-peer communications. The adoption of blockchain technology in Industry 4.0 was favoured by the introduction of so-called smart contracts, digital contracts executed within the blockchain [2]. The blockchain began as a public peer-to-peer network, used as a public distributed ledger without restrictions. However, the lack of restrictions is problematic in corporations where privacy requirements and access control mechanisms are needed. To fill this gap, recently advanced frameworks have been implemented to build private blockchains such as Hyperledger Fabric and Hyperledger Besu [8] which are capable of meeting privacy and access control requirements. The adoption of private blockchain allows the application of blockchain in Industry 4.0 and generates several benefits in many sectors.

For instance, the blockchain in the energy market can streamline energy production and consumption, helping to monitor pollution levels while promoting a peer-to-peer energy market [5]. In the manufacturing sector, the blockchain along with the integration of IoT devices, can optimise production processes. In agribusiness, the adoption of blockchain can help to monitor the food supply chain and guarantee access to healthy food, in terms of secure and safety food [17]. Similarly, blockchain adoption could have some beneficial impacts in the educational field and specifically in the e-learning platforms, e.g. Learning Management Systems (LMS) and Course Management Systems (CMS), used for professional training in several different companies that adopted the Industry 4.0 policies. Industry 4.0 requires specialising professionals with specific skills and knowledge of their job sector. Many researchers observe the lack of trained employees with adequate training, including lifelong learning, creates the risk of a transition from technological unemployment to structural unemployment [19]. To train their employees, many institutions and many businesses offer them online training courses and digital technologies designed for distance education, and remote and online learning. However, the use of online training courses can lead to the risk of counterfeiting of the results [26]. Moreover, the methods used for the verification process can be cumbersome and too slow [23]. In this way, the adoption of blockchain technology in the business oriented to the Industry 4.0 policies can produce several benefits, e.g. the increasing the trustworthiness of the certificates issued and to accelerate the verification process, facilitating the sharing of the certificates itself.

This paper aims to explore the potential of integrating blockchain with micro-credentials in online courses delivered through e-learning platforms, to increase the trustworthiness of the certificates in the labour market and the education system. The paper is structured as follows: Section 2 describes the main features of micro-credentials and blockchain, followed by some related works. Section 3 deeps the potential of micro-credentials through a case study of an e-learning platform. Section 4 proposes the adoption of blockchain in the e-learning environ-

ment as a tool to improve the reliability of certificates, simplify their verification and improve sharing. Section 5 demonstrates that the smart contract-driven approach implemented aims to run the blockchain invisibly to the end user while also protecting user privacy. Finally, section 6 by the European regulatory framework in this field summarises the reasons for the adoption of micro-credential in Industry 4.0 and illustrates the conclusion.

2 Background, Related Work and Contribution

2.1 Micro-Credentials

The wide increase of Massive Online Open Courses (MOOC) and the innovation in online learning led to the development of micro-credentials. Micro-credentials represent small-scale learning programmes aimed at acquiring specific knowledge and skills in selected topics that meet the needs of learners to increase their abilities in specific sectors that can involve not only professional development but also personal, social and cultural goals. The need to attract specialists in the new emerging technologies and the rapid potential problems of unemployment make the Micro-credentials particularly suitable for the Industry 4.0. Indeed, the micro-credential provides specific knowledge, skills and competencies that meet labour market needs [20] and offer to both provider learners and provider employers, the assurance that the promised learning outcomes will be achieved. The European Union (EU) adopts the micro-credential approach for lifelong learning and employability to develop quality education and implement a vocational training policy. Additionally, the EU recommends certifying learning objectives, such as short e-training courses, through the adoption of micro-credentials. Micro-credentials can help individuals fill skill gaps necessary for success in a fast-changing environment, without replacing traditional qualifications. Various providers could design and issue these credentials in different learning settings, including e-learning courses. Despite the EU sponsoring the adoption as a tool to acquire new professional knowledge and skills and despite their increasing use [9], in the legal field and IT area, there is no common definition or standard for micro-credentials in Europe. This lack of clarity limits the understanding and uptake of micro-credentials, undermining their potential to facilitate flexible learning and career pathways. The increasing and diverse use of micro-credentials raises a debate on evaluating, certifying, and ensuring micro-credentials. The current debate throughout Europe is centred on the incorporation of micro-credentials into national qualifications systems and frameworks, as well as the establishment of conditions for their recognition. However, in the Member European States, there are notable differences in approaches, with varying national perspectives on the description and assessment of qualifications.

2.2 Blockchain

The blockchain is a disruptive technology that aims at maximising the transparency, traceability and security properties of the actions carried out by the

participants of the blockchain itself. The cornerstones of the blockchain lie, firstly in the use of distributed algorithms to manage peer-to-peer communications between network participants, and then in the use of cryptographic primitives that guarantee authentication in the interaction and integrity of the data. Given these characteristics, the blockchain is an ideal technology to overcome the validity criticism of the certificates provided by e-learning platforms [4].

Furthermore, the advent of smart contacts allows to extend the basic functionality of the blockchain, making it possible to define complex logics that go beyond the simple movement of an asset. However, although several types of blockchains exist today and frameworks for building custom blockchains suitable for corporate and private contexts are also emerging, at the same time the adoption of blockchain in numerous contexts faces several barriers. The barriers are technical, due to the lack of experts to support the management of the blockchain, and functional, as users do not have the necessary knowledge to understand the functioning of the blockchain and the management of public and private keys, and wallets needed to interact with the blockchain itself [27].

The public blockchains are distributed databases that seek to achieve decentralisation by replacing a unitary actor with many different users. In this mean, for private blockchains is easier than their public counterparts to comply with some aspects of General Data Protection Regulation (GDPR) [13, 12].

2.3 Related Work

The authors in [10] propose a feasible integration of the Ethereum public blockchain with an educational institution in order to register the students' achievements and verify it through a QR code. Similarly, the authors in [15] propose the architecture of a feasible model that aims at integrating the blockchain with an education system. The architecture aims to make the educational process more transparent, traceable and easily verifiable by companies or other interested parties.
The authors in [22] propose a possible integration of the Moodle platform with the public Ethereum blockchain for the validation of the documents produced by the platform itself, storing the hash of the documents produced on the blockchain. In the same way, the authors in [18] propose the integration of the Moodle platform with the Ethereum blockchain to store the metadata associated with the digital certificates produced by the platform, while the authors in [21] provide an integration of the blockchain for the verification of the badge as a certification.
Regarding micro-credentials, the authors in [16] propose EduCTX, a system in which users interact directly with the blockchain and keep their skills as points obtained via ERC20 tokens.
We did not find other works with concrete proposals, but only surveys that partially inspired the present work [3, 1].

In the examined approaches, the use of blockchain has been proposed for maintaining the metadata relating to any certificates. In many of the works

presented, the integration of a public blockchain was proposed and the issues of costs and privacy were not adequately expressed or were not expressed at all.

2.4 Contribution

Our approach involves implementing a consortium blockchain that enables users to interact with the blockchain without managing private keys and wallets, maintaining user privacy. Moreover, the skills gained by the users are kept in specific smart contracts that aim to be real CVs. The main outcomes of this study can be summarised as follows:

1. Integrate a consortium blockchain in e-learning education systems, specifically applied to Micro-Credentials, to maximise the trustworthiness of the certificates and speed up their verification processes.
2. Present the design of smart contracts to make digital certificate verification faster, transparent and accessible, and enable end users to interact with the blockchain indirectly.
3. Propose a system for recording and sharing training curricula based on the micro-credentials certificates collected by users, safeguarding the privacy of the individuals involved.

3 E-learning platform and Micro-Credentials

In the field of e-learning platforms related to micro-credentials, a consortium of organisations offers online courses aimed at acquiring specific knowledge and skills required in the labour market, in line with the needs of Industry 4.0. The platforms offering online services, the institutions registered, the courses provided by the institutions and the candidates wishing to improve their knowledge are the main actors currently involved in e-learning platforms based on micro-credentials. Different institutions can co-exist in a single platform. Each institution offers specific short-term training online courses aiming at helping people to develop specific knowledge and skills, allowing users to tailor their learning to the topics they are interested in and to open up the training available from different countries. Several instructional designers during the design of the micro-credentials consult the learners to find out what topics meet their professional learning needs [30] according to the vision of Web 2.0 pedagogy that allows the learners to become more active and co-producers of the teaching material. The design of micro-credentials based on LMS, indeed, is usually characterised by features that encourage the applications of pedagogical strategies such as the peer learning and wiki [24]. These features can include not only traditional text documents but it can also include exercises, quizzes blogs, discussion board [25]. The actors involved in the e-learning consortium are represented by the institutions and the learners, identified as “candidates”.

Figure 1 (left side) shows the main actions that an institution can perform within an e-learning platform. Institutions can register their affiliation with the

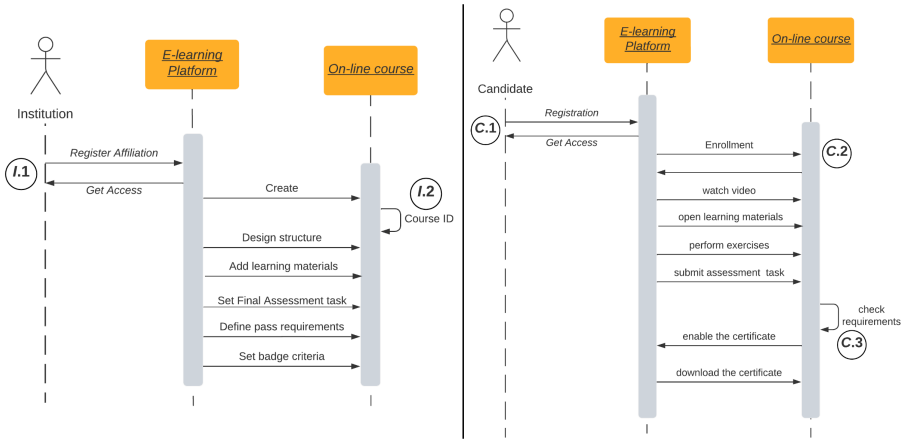

Fig. 1. The sequence diagram shows the interactions and operations that an institution (on the left) and a candidate (on the right) can carry out on e-learning platforms for Micro-Credentials.

e-learning consortium and then they can create new courses including learning contents, provide a final assessment and set badges criteria. The on-line courses have been designed as self-learning, without the need for instructors to be involved in assessments or issuing certificates.

Figure 1 (right side) shows the main actions that a candidate can perform within an e-learning platform. The learners, once registered, can improve their knowledge and skills by enrolling in new courses, attending the course in self-learning and completing the required tests to obtain the certificate that represents the acquisition of new skills. The certificate can be downloaded from the platform.

However, LMS platforms are still managed by humans and the risk of counterfeiting certificates remains a concern [14], although the issue of fake diplomas has increased in recent years thanks to advanced graphics editing software. Because of the increasing certification demand and the fake qualifications in the labour market, today it needs major control on the credentials [7]. The verification process could depend on the staff's experience in investigating credentials and a trusted network of professionals who may have knowledge of how to verify the documents. In addition and unfortunately, it is possible that some staff members in different institutions such as administrators, instructors, and office employees may be involved in the production of fake certificates and diplomas [28]. The combination of these factors demonstrate the need to develop tools able to combine credibility and agility in labour market data. Furthermore, the qualifications held by various students generally become fragmented and difficult to share efficiently. The next section explores blockchain integration, aimed to increase the trustworthiness of the certificates issued, speed up the verification processes and simplify the shareability of the qualifications held by students.

4 Consortium Blockchain within E-Learning Platforms

The integration of a consortium blockchain within e-learning platforms represents a possible solution to overcome the issues described in the previous section. The proposed solution aims at facilitating the management of private keys and wallets for end-users when interacting with the blockchain. This task is delegated to the e-learning platform which is the first manager of the blockchain. Once registered, institutions can request to participate in the management of the blockchain, making it more decentralised. In this way the security of the proposed solution and the credibility of all the actors involved should be increased. Figure 2 shows the structure of the smart contracts implemented to increase the trustworthiness of the certificates issued by the different institutions and to speed up the verification of the qualifications obtained by the different candidates. The relationships between the smart contracts shown in Figure 2 represent the actions of the institutions ($I.1$, $I.2$) and the actions of the candidates ($C.1$, $C.2$, $C.3$) in the case study illustrated in Figure 1. The management of smart contracts follows a tree structure. The smart contract placed at the root of the tree is the only access point to the blockchain, and therefore the only access to all other smart contracts. The other smart contracts are dynamically assigned and managed by the *ELearningPlatform.sol* smart contract, allowing the registration of institutions *Institution.sol* and candidates *Candidate.sol*. An institution sends a request to the platform when it wants to make the registration on the platform. Once the platform receives the request, it registers the institution on the *ELearningPlatform.sol* which dynamically allocates a new smart contract. Each institute is placed at the first level of the tree and can create new courses. When an institute adds a new course, it is registered to its *Institution.sol* smart contract, which dynamically allocates a new *Course.sol* smart contract. The smart contracts located at the second level of the tree, identified as leaves of the

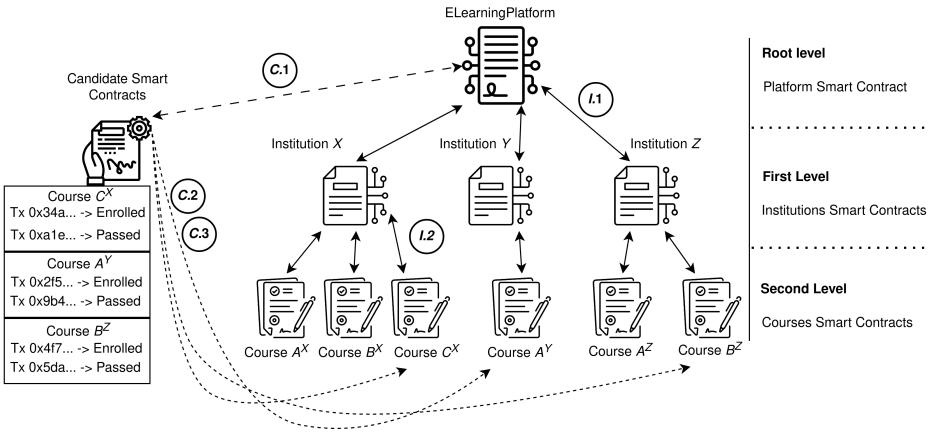

Fig. 2. Smart Contracts architecture.

tree, represent the various courses created. The main actions performed by the *ELearningPlatform.sol* are listed below:

Register an institution (*I.1*): This action allows the registration of a new institution.

Register a course (*I.2*): This action allows an institution to create a new course.

Register a candidate (*C.1*): This action allows the registration of a new candidate.

Course subscription (*C.2*): This action enables the enrolment of a candidate into a course.

Course passed (*C.3*): This action enables a candidate to complete the assessment and obtain a certificate upon passing the exam.

Course verification : This action aims to simplify the verification process. The verification process requires the involvement of both the platform and a third party to verify the certificate obtained by the candidate. The third party checks the candidate's skills through a simple query to the e-learning platform providing the candidate identifier, the institution identifier, and the course identifier.

The interaction between the user and the blockchain must be invisible. In particular, the user continues to interact with the platform as if the blockchain doesn't exist. A Solidity implementation of all smart contracts shown in Figure 2, along with relevant details, can be inspected thoroughly in a dedicated repository[4].

The proposed approach is designed for a consortium blockchain that might be implemented using Hyperledger Besu [8]. This solution is not feasible for public blockchains due to the size of the byte-code of the *ELearningPlatform.sol*, which requires specific customisation. Furthermore, a public blockchain approach could discourage participants due to privacy issues and high transaction costs.

The *Candidate.sol* smart contract represents a starting point for creating an effective curriculum vitae recorded on the blockchain. This approach increases the credibility and verifiability of Micro-Credentials obtained by candidates. Candidates can easily be shared between different institutions via the *ELearningPlatform.sol*. Two actions are taken to preserve privacy. Firstly, during the registration phase (Figure 1 - $C.1$), the user's sensitive data is kept off-chain within the e-learning platform. Secondly, only one identifier is stored in the *Candidate.sol* smart contract (Figure 2 - $C.1$).

4.1 Institutions and Candidates Actions

The main actions performed by an institution consist of the registration into the e-learning platform and the creation of new courses. The initial operation that an institution can take is the registration on a platform ($I.1$). Then, the

[4] https://github.com/alessandrobigiotti/micro-credentials-smart-contracts

e-learning platform needs to associate the institution's access credentials with a pair of keys. The pair of keys allows the identification of the institution within the blockchain. The platform uses the newly created keys to invoke the function `registerInstitution` through the *ELearningPlatform.sol* smart contact. This smart contract dynamically allocates a new *Institution.sol* smart contract, owned by the institution and registered on the platform. After the registration phase, the institutions can create new courses ($I.2$) available for various candidates. When a new course is created, the platform invokes the `registerCourse` function using the credentials associated with the specific institution. This institution dynamically allocates a new smart contract *Course.sol* associated with the specific institution.

The *Candidate.sol* smart contract aims to be an effective digital curriculum vitae because it collects all the qualifications and skills acquired by each candidate. When a user registers on the platform ($C.1$), the system invokes the function `registerCandidate` via the *ELearningPlatform.sol* smart contract, which dynamically allocates a *Candidate.sol* smart contract. The user registration phase is a sensitive process as it involves sharing personal information such as name, surname, address, and tax code, or other data depending on the platform's requirements. In this study, all sensitive data is kept off-chain within the platform. A unique code that identifies the student is kept within the blockchain and no sensitive data is shared. The *Candidate.sol* smart contract tracks the activities carried out by the candidate during its interactions with the platform. After the candidate registration, the main actions needed to be maintained on the blockchain are the enrolment in a course ($C.2$) and the final test to issue the certificate ($C.3$). When a candidate enrols in a course, the platform sends a transaction. This transaction updates the status of the smart contract *Candidate.sol*, and indicates the enrolment in a new course through the `courseSubscription` function. Similarly, the platform updates the status of the same smart contract by recording a transaction indicating the successful completion of the selected course through the `passCourse` function.

5 Discussion

The use of blockchain technology in the education sector raises several challenges. According to the authors in [11], a big challenge is the functional adoption of the blockchain technology. The involvement of trainees, educators, instructors and managers in the use of blockchain is not currently easy and sustainable. Therefore, this study aims to enable users to interact with the blockchain indirectly with a silent integration of this technology into e-learning platforms. However, in the future each user will need to manage their own keys, as if they are the access credentials to the e-learning platform.

Other challenges to consider are the verification of the authenticity of a certificate and the need to use third parties solutions [31]. In this work, the blockchain acts as a validator for the certificates held by candidates, without the need to implement third parties. The e-learning platform must guarantee the reading

access to the blockchain, linking sensitive data with the related smart contracts, allowing third parties to carry out checks on the status of the certificates held by the various candidates. This feature makes the verification process fast and efficient. Moreover, the *Candidate.sol* smart contract acts as a collector of all the certificates received by the candidate. It also eliminates the fragmentation of the different certificates and facilitates their sharing with any interested third party. Furthermore, based on recent research involving interoperability protocols between blockchains [6], this smart contract implementation can allow the sharing of students between different platforms. It can also improve the sharing of candidate training data and overcome the fragmentation criticism potentially associated with micro-credentials.

This case study presents a crucial aspect in terms of user privacy, paying attention to the privacy of the final users [11, 31]. In fact, sensitive candidate data is not stored within the blockchain, but is saved off-chain and managed directly by the platform. Candidates have a unique identifier that will be stored within the blockchain, creating a link to the user's sensitive data. This approach permits to track the certifications held and holdable by candidates without keeping sensitive data on the blockchain. The main advantage of this approach is the real data protection, because those using micro-credentials in the blockchain do not use or share sensitive data, but use an anonymous identifier. The results illustrate the significant impact of blockchain to enhance the reliability of micro-credential in the light of the European regulatory framework. Similar results need synergetic work between lawyers, computer scientists and institutions to create a specific regulatory framework for a disruptive technology, such as blockchain.

6 Conclusion

In this work, a consortium blockchain is integrated with micro-credentials through an e-learning platform to increase the trustworthiness, verifiability and sharing of completion certificates. The proposed solution aims to make the interaction with the blockchain invisible to the users involved, facilitating its adoption. In addition, the solution proposes a new approach that allows the collection of micro-credentials to realise a certified curriculum vitae, validated by the blockchain. The adoption of blockchain technology ensures that the value of micro-credentials is known, understood and recognised both in the labour market and the education system such as stable, reliable material. In this way, the knowledge and skills of learners and the employers' proposals strengthen their validity and increase the user's trust. Currently, the European Commission is developing tools, software and services that will form part of the European Digital Credentials (EDCI) Infrastructure and the experimentation of the blockchain in the micro-credentials field can be a good way to implement the vocational training policy (IGG), combining credibility and agility in labour market.

References

1. Ahsan, K., Akbar, S., Kam, B., Abdulrahman, M.D.A.: Implementation of micro-credentials in higher education: A systematic literature review. Education and Information Technologies **28**(10), 13505–13540 (Oct 2023). https://doi.org/10.1007/s10639-023-11739-z
2. Alharby, M., Aldweesh, A., Moorsel, A.v.: Blockchain-based smart contracts: A systematic mapping study of academic research (2018). In: 2018 International Conference on Cloud Computing, Big Data and Blockchain (ICCBB). pp. 1–6 (2018). https://doi.org/10.1109/ICCBB.2018.8756390
3. Alsobhi, H.A., Alakhtar, R.A., Ubaid, A., Hussain, O.K., Hussain, F.K.: Blockchain-based micro-credentialing system in higher education institutions: Systematic literature review. Knowledge-Based Systems **265**, 110238 (2023). https://doi.org/https://doi.org/10.1016/j.knosys.2022.110238
4. Ayub Khan, A., Laghari, A.A., et al.: Educational blockchain: A secure degree attestation and verification traceability architecture for higher education commission. Applied Sciences **11**(22) (2021). https://doi.org/10.3390/app112210917
5. Bigiotti, A., Mostarda, L., Navarra, A.: Blockchain and iot integration for air pollution control. In: Barolli, L. (ed.) Advances on P2P, Parallel, Grid, Cloud and Internet Computing. pp. 27–38. Springer Nature Switzerland, Cham (2024)
6. Bigiotti, A., Mostarda, L., Navarra, A., Pinna, A., Tonelli, R., Vaccargiu, M.: Interoperability between evm-based blockchains. In: Barolli, L. (ed.) Advanced Information Networking and Applications. pp. 98–109. Springer Nature Switzerland, Cham (2024)
7. Brown, G.M.: Degrees of doubt: Legitimate, real and fake qualifications in a global market. Journal of Higher Education Policy and Management **28**(1), 71–79 (2006)
8. Capocasale, V., Gotta, D., Perboli, G.: Comparative analysis of permissioned blockchain frameworks for industrial applications. Blockchain: Research and Applications **4**(1), 100113 (2023). https://doi.org/https://doi.org/10.1016/j.bcra.2022.100113
9. Cedefop: Microcredentials: Striving to combine credibility and agility. Publications Office of the European Union (2024), https://data.europa.eu/doi/10.2801/966682
10. Cheng, J.C., Lee, N.Y., Chi, C., Chen, Y.H.: Blockchain and smart contract for digital certificate. In: 2018 IEEE International Conference on Applied System Invention (ICASI). pp. 1046–1051 (2018). https://doi.org/10.1109/ICASI.2018.8394455
11. El Koshiry, A., Eliwa, E., Abd El-Hafeez, T., Shams, M.Y.: Unlocking the power of blockchain in education: An overview of innovations and outcomes. Blockchain: Research and Applications **4**(4), 100165 (2023), https://doi.org/10.1016/j.bcra.2023.100165
12. European Parliamentary Research Service: Blockchain and the general data protection regulation: Can distributed ledgers be squared with european data protection law? Tech. rep., European Parliment (2019)
13. Filvà, D.A., García-Peñalvo, e.a.: Privacy and identity management in learning analytics processes with blockchain. In: Proceedings of TEEM 2018. p. 997–1003. Association for Computing Machinery (2018), https://doi.org/10.1145/3284179.3284354
14. Go, A.: Stopping fake certificates and transcripts – is digital and blockchain technology the answer? In: An Anthology of Selected Papers of APQN Annual Academic Conference. pp. 191–201. Asia-Pacific Quality Network (APQN) and Eduvalue Pte Ltd, Singapore (2021)

15. Han, M., Li, Z., He, J.S., Wu, D., Xie, Y., Baba, A.: A novel blockchain-based education records verification solution. In: Proceedings of the 19th Annual SIG Conference on Information Technology Education. p. 178–183. SIGITE '18, Association for Computing Machinery (2018). https://doi.org/10.1145/3241815.3241870
16. Hölbl, M., Kamisalić, A., Turkanović, M., Kompara, M., Podgorelec, B., Herićko, M.: Eductx: An ecosystem for managing digital micro-credentials. In: 2018 28th EAEEIE Annual Conference (EAEEIE). pp. 1–9 (2018). https://doi.org/10.1109/EAEEIE.2018.8534284
17. Javaid, M., Haleem, A., Pratap Singh, R., Khan, S., Suman, R.: Blockchain technology applications for industry 4.0: A literature-based review. Blockchain: Research and Applications **2**(4), 100027 (2021). https://doi.org/https://doi.org/10.1016/j.bcra.2021.100027
18. KARATAŞ, E.: Developing ethereum blockchain-based document verification smart contract for moodle learning management system. Bilişim Teknolojileri Dergisi **11**(4), 399–406 (2018). https://doi.org/10.17671/gazibtd.452686
19. Kuzior, A.: Technological unemployment in the perspective of industry 4.0. Virtual Economics **5**(1), 7–23 (Apr 2022). https://doi.org/10.34021/ve.2022.05.01(1), https://virtual-economics.eu/index.php/VE/article/view/140
20. Kušić, S., Vrcelj, S., Zovko, A.: Micro-credentials – improvement or fragmentation in higher education? Education and New Developments 2022 – Volume 2 (2022). https://doi.org/10.36315/2022v2end033
21. Mikroyannidis, A., Domingue, J., Bachler, M., Quick, K.: Smart blockchain badges for data science education. In: 2018 IEEE Frontiers in Education Conference (FIE). pp. 1–5 (2018). https://doi.org/10.1109/FIE.2018.8659012
22. Morais, A.M.d., Correia Neto, J.d.S., Medeiros, R.W.A.d., Nóbrega, O.d.O., Lins, F.A.A.: A solution for integrating virtual learning environments with blockchain. Research, Society and Development **10**(12), e210101220354 (Sep 2021). https://doi.org/10.33448/rsd-v10i12.20354
23. Mudiyanselage, A.K., Pan, L.: Security test moodle: a penetration testing case study. International Journal of Computers and Applications **42**(4), 372–382 (2020)
24. Nalli, G., Amendola, D., Smith, S.: Artificial intelligence to improve learning outcomes through online collaborative activities. In: European Conference on e-Learning. vol. 21, pp. 475–479 (2022)
25. Nalli, G., Culmone, R., Perali, A., Amendola, D.: Online tutoring system for programming courses to improve exam pass rate. Journal of e-Learning and Knowledge Society **19**(1), 27–35 (2023)
26. Perera, P., Sirisuriya, S., Gunathilake, H.: Security vulnerabilities and security elements of frequently used e-learning platforms: A review (2022)
27. Prewett, K.W., Prescott, G.L., Phillips, K.: Blockchain adoption is inevitable—barriers and risks remain. Journal of Corporate accounting & finance **31**(2), 21–28 (2020)
28. Sayed, R.H.: Potential of blockchain technology to solve fake diploma problem (2019)
29. Silva, T.B.d., Morais, E.S.d., Almeida, L.F.F.d., Rosa Righi, R.d., Alberti, A.M.: Blockchain and Industry 4.0: Overview, Convergence, and Analysis, pp. 27–58. Springer Singapore (2020), https://doi.org/10.1007/978-981-15-1137-0_2
30. White, S.: Developing credit based micro-credentials for the teaching profession: An australian descriptive case study. Teachers and Teaching **27**(7), 696–711 (2021)
31. Yumna, H., Khan, M.M., Ikram, M., Ilyas, S.: Use of blockchain in education: A systematic literature review. In: Intelligent Information and Database Systems. pp. 191–202. Springer International Publishing, Cham (2019)