A Preliminary Review of Blockchain-based Solutions in Higher Education

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Abstract. Blockchain technology is showing its potential to disrupt established business processes. Four types of blockchain initiatives have been identified: Record keeper, efficiency play, digital asset market, and blockchain disruptor. Many different applications have also been emerging within the educational domain, following a student or institution-centric approach. Student-centric solutions simplify the validation process of received credentials, while institution-centric solutions facilitate mainly operational activities of educational institutions. In this paper, we present several use cases addressing different aspects within the educational domain, such as streamlining the process of diploma verification, virtual lifetime learning passport, securing the issued certificates permanently, verifying the accreditation process, automatic recognition of credits, etc. A preliminary review and analysis of identified projects and initiatives show that most of them follow a student-centric approach while facilitating record-keeping.

Keywords: blockchain-based solution · higher education innovation · certificate management.

1 Introduction

Blockchain is an emerging technology that has the potential to optimize, transform and disrupt established and traditional business processes, products and services. Its key features provide space for innovative technological approaches, and differentiate it from others on multiple levels. Kandaswamy [17] identified four types of blockchain initiatives: (1) Blockchain disruptor, (2) Digital asset market, (3) Efficiency play, and (4) Record keeper. The "blockchain disruptor" initiative relies on a technology foundation in order to achieve decentralization of business. New markets that facilitate the creation and trading of new digital assets form part of a "digital asset market" initiative. "Efficiency play" is the

initiative which gathers those companies or industries that attempt to improve efficiency in their existing business processes using the blockchain technology. Finally, companies or institutions ensuring that records cannot be corrupted, and that they can be audited on demand, are gathered under the "record keeping" initiative. Blockchain technology is slowly integrating itself in different domains, such as logistics, energy, manufacturing, life sciences and healthcare, digital identities, retail, etc. One of the domains suitable for adopting blockchain technology is the Higher Education (HE) domain, where the principles of document authenticity, transparency, immutability, and trust, are the key advantages which make it a perfect match [12]. We have identified two basic types of approaches adopted when implementing blockchain-based solutions within the HE environment. The first one is a student-centric approach, which gives a student control over his/her data. The second one is an institution-centric approach, the primary goal of which is to facilitate and streamline activities of educational institutions. The aim of the paper is in presenting the differences between those two approaches, as well as to analyze and present key features of selected blockchain-based projects and initiatives within the educational domain. Additionally, projects will be classified considering the two types of approaches, as well as regarding the purpose of the solution provided and the impact it might have. Furthermore, we will present characteristics of our project, named EduCTX, as well as the implementation challenges that other implementers of blockchain-based solutions within the HE domain might also be facing.

The rest of the paper is organized as follows. Section 2 provides descriptions of different types of blockchain initiatives and solutions in HE. Analysis of existing use cases applying blockchain technology within the educational domain is presented in Section 3. The EduCTX initiative is detailed in Section 4, presenting the challenges faced during its implementation. Finally, Section 5 presents conclusions and directions for future work.

2 Blockchain initiatives and solutions in HE

This section provides a brief classification of blockchain-based solutions for HE, based on the entity focus and on the Kandaswamy classification. Student-centric blockchain-based solutions facilitate and simplify the student activities related to validation of received credentials, since blockchain-based services accelerate and facilitate administrative procedures where a validation process is required. Credentials are Certificates awarded to students in order to recognize achieved learning objectives, such as participation in formal or informal education, completion of courses or Study Programs (e.g., with ECTS (European Credit Transfer System) points awarded), completion of an apprenticeship or work-experience, etc. [12]. Blockchain-based student-centric solutions place the responsibility and control over received credentials on students, thus eliminating the need for a verification process by an intermediary (e.g., Higher Education Institution (HEI)). Consequently, the processes for stakeholders (e.g., potential employers) interested in the evidence of a student's achievements can be stream-

lined [25]. On the other hand, an institution-centric approach facilitates mainly management and operational activities of HEI for payment management (e.g., receipts of students' payments), international collaboration management (e.g., automatic recognition of awarded ECTS points), accreditation processes (e.g., a Certificate issued by government that the HEI is licensed to carry out specific tasks), etc. Blockchain-based institution-centric solutions can provide a wide range of benefits for HEIs. For example, the process of internationalization of HEIs through the Student Exchange Programs or joint degrees, can be facilitated avoiding long-lasting administrative procedures, which are a financial and time-consuming burden. Another example is blockchain-based gamification of learning, which would facilitate the management of the issued Certificates for the achievements of intermediate learning goals. Both approaches are faced with different challenges, e.g. organizational, legal, administrative, etc., whereby special attention should be placed on the data privacy challenge. Another classification of blockchain-based solutions within the educational domain can be provided considering the four types of blockchain initiatives identified by Kandaswamy [17]. Blockchain as a disruptor has the potential to be used as an education and academic publishing platform. Receiving students' payments, providing student funding and tokenized educational rewards are some use cases of the blockchain digital asset market initiative. Streamlining Diploma verification and virtual lifelong learning passport are use cases within the initiative for efficiency improvement. The blockchain record-keeping initiative for HEIs covers several use cases, such as securing the Certificates permanently, verifying the accreditation, automatic recognition of credits and intellectual property management [12, 25]. A good overview of current trends and existing implementations of blockchain for education can be found in [8, 15].

3 Analysis of existing blockchain-based solutions in HE

Taking into account the two previously described classifications, a preliminary literature review was performed related to the HE domain, and focusing on reports published by the European Commission [12] and Gartner [25]. We performed a detailed analysis of published articles, white papers and project web pages. The chosen applications are grouped considering four types of blockchain initiatives. There is a significant difference in the number of different projects, regarding their implications. For example, we detected many projects related to issuing new digital credentials, while just one dedicated to academic publishing. Nevertheless, here, we will present a few use cases considering different approaches taken for implementation of blockchain technology – ones related to the student-centric approach, and others to the institution-centric approach.

3.1 Selected use cases

As representatives of the student-centric approach related to issuing new digital credentials, the following universities can be considered due to their existing

projects on this topic: (1) University of Nicosia, (2) Massachusetts Institute of Technology (MIT) and (3) University of Maribor. The University of Nicosia presented a project on issuing a blockchain verifiable credential for completion of a digital currency course [23]. Blockchain-verifiable Diplomas were issued by MIT [21]. The University of Maribor presented a blockchain-based platform named EduCTX, which enables managing, assigning and presenting any type of digital micro-credentials [26]. Loci, Bernstein and Binded are projects addressing the field of Intellectual Property Management. Loci developed a blockchain-based platform for facilitating the invention process, where ideas can be verified as unique and could be claimed as one's own [20]. Bernstein provides a Blockchain-as-a-Service solution for registration of intellectual property assets [1], while Binded offers a blockchain-based copyright registration service for images [2]. All the above-mentioned projects form part of the "record keeping" blockchain initiative. Typical representatives of the "efficiency play" initiative with institution-centric approaches are a joint project of three Greek universities: Aristotle University of Thessaloniki, Democritus University of Thrace, and Athens University of Economics and Business, as well as a joint project of the Government of Dubai and EduChain. The first is addressing a process of streamlining Diplomas' verification [7], while the second is dealing with the creation of a lifelong academic passport [10]. King's College [18], the University of Nicosia [23], Simon Fraser University [6] and the University of Cumbria [31] are among educational institutions which accept bitcoin cryptocurrency for student payments [25]. Tokenized educational rewards are addressed by the Extra Credit and Bitcoin Homework projects. Extra Credit is a cryptocurrency learning platform [11], while Bitcoin Homework is designed as a learning portal for sharing ideas [3]. Use cases where a blockchain technology serves as a disruptor are Bitdegree, Woolf University and Ledger (University of Pittsburg). Bitdegree is an online education platform offering gamified learning experience and scholarships based on cryptocurrency [4]. Woolf University develops a platform where the relationship between students and professors is backed up with smart contracts and blockchain technology [30]. Finally, the only blockchain-based platform detected as an academic publishing use case is Ledger, which supports peer review process with published reviews, together with accepted manuscripts [19]. All those disruptor projects followed the institution-centric approach. Some additional projects are presented briefly in Table 1, and included in the final data analysis presented in Figures 1 and 2.

Table 1. Use cases in the educational domain.

Project	Owner	s-c	i-c	Initiative
Verifiable credential for completion of a digital currency course	University of Nicosia [23]	x		R
An open standard for applications that issue and verify blockchain-based Certificates (Blockcerts)	MIT Media Labs [5]	x		R
Blockchain-based Diplomas' verification	Malta College of Arts Science and Technology [12]	x		R
	MIT [21]			
	Univ. of Melbourne [28]			
	Southern New Hampshire University [24]			
	Central New Mexico Community College [29]			
	Ngee Ann Polytechnic [22]			
Managing, assigning and presenting any type of digital micro-credentials	University of Maribor [26]	x	x	R
Invention process; determining the uniqueness of an idea and providing a possibility to claim own ideas	Loci [20]	x	x	R
Registration of intellectual property assets	Bernstein [1]	x		R
Copyright registration service used for images	Binded [2]	x		R
Intellectual property rights for artists	Zhejiang University, Shenzhen University, Chinese Academy of Sciences [9]	x		R
Student Diplomas' verification	Three Greek universities [7]		x	E
Facilitating the creation of a lifelong academic passport	Government of Dubai and Educhain [10]	x	x	E
Accepting payment with bitcoins	King's College [18]	x	x	A
	University of Nicosia [23]			
	Simon Fraser Univ. [6]			
	University of Cumbria [31]			
Learning platform for cryptocurrency courses	Extra Credit [11]	x	x	A
Learning portal promoting a sharing of ideas	Bitcoin Homework [3]	x	x	A
Online education platform offering gamified learning experience and cryptocurrency-based scholarships	BitDegree [4]		x	D
A digital platform providing a complete record of everything ever learned	Ledger [14]	x	x	D
Platform connecting learners and educators	Woolf University [30]		x	D
Ledger - open publishing platform that supports the peer review process	Univ. of Pittsburgh [19]		x	D

s-c: Student-centric, i-c: Institution-centric
R: Record-keeping, E: Efficiency play, A: Digital asset market, D: Disruptor

3.2 Summary of preliminary analysis results

Overall, we have identified 25 projects, whereby 13 can be classified into a record-keeper blockchain initiative. Only two projects are part of the efficiency play. Six belong to the digital asset market, and four to the blockchain disruptor initiative. Only four out of 25 are detected as institution-centric, while 11 as only student-centric projects. Ten projects are following both approaches, student- and institution-centric. Most of the projects within the educational domain deal with record-keeping issues while taking student-centric approaches. Only four projects set up an institution-centric approach. Nine out of 25 projects follow both approaches – student- and institution-centric, which indicates the tendency of using blockchain additionally in order to support organizational processes within institutions.

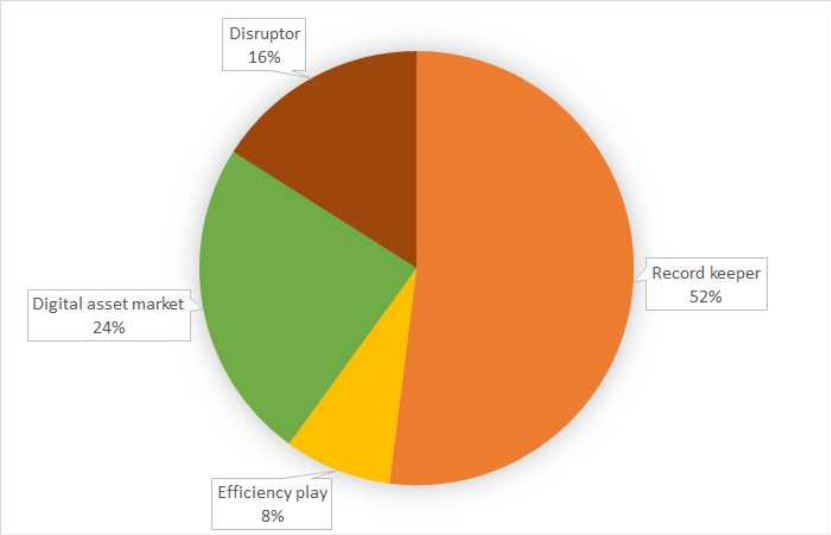

Fig. 1. The share of applications within the educational domain classified into four blockchain initiatives.

4 Characteristics and implementation challenges of the EduCTX project

In this section, we provide a detailed insight into the EduCTX project, which is a global decentralized blockchain-based platform that, primarily, follows a student-centric approach, while demonstrating a strong potential to solve organizational issues of HEIs. We will present the challenges that other implementers of blockchain-based solutions within the HE domain might also be facing. With

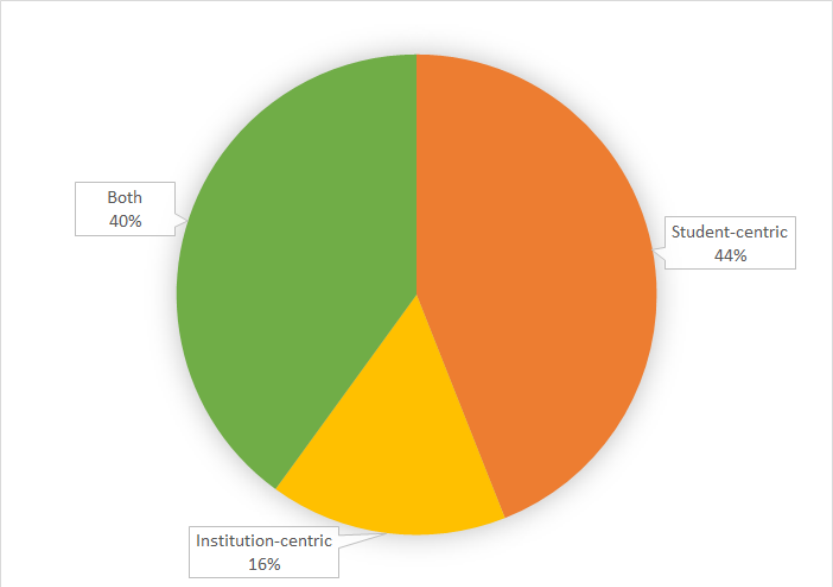

Fig. 2. The share of applications within the educational domain classified into two approaches to blockchain-based solutions.

its student-centric approach, EduCTX offers a comprehensive and unified digital environment for managing students' credentials, giving students control over which data to share [26]. Educational institutions, as well as other potential stakeholders such as companies, institutions, and organizations, are certified authorities issuing credentials. It aims at creating an effective and simplified digital environment to avoid linguistic and administrative barriers. It is a perfect solution to address internationalization challenges of HEIs, such as joint degrees, Student Exchange Programs, etc. Additionally, the platform contributes to the modernization of processes, and supports the development and deployment of innovative digital services. Through publicly accessible APIs, it provides organizations with the possibility to develop their own intelligent services in order to automate the evaluation of individuals' skills and knowledge, which can be used for ranking job candidates. A student sends the credential to the potential employer, which uses the publicly accessible API of the EduCTX platform to validate the content of the received credential. The validation process is time constrained by the student. We refer readers interested in more technical details to the original EduCTX articles [16, 26]. HEIs that use EduCTX do not have to devote resources for answering inquiries about their students' achievements. Instead, that data is publicly available to interested parties through reference provided by student. Using EduCTX educational organizations thus shorten this process that can be time-consuming, costly and burdensome. Therefore, it also shows the potential to be as well considered as an institution-centric solution.

Another important aspect of the platform lies in its social importance, as it enables individuals to have the equal possibility to share their competences with potential employers. Based on our experience, we have identified various challenges related to: (1) Addressing process-organizational aspects, (2) Assigning previously issued certificates, (3) Deciding on an adequate type of data storage, (4) Identity management, (5) GDPR compliance, and (6) Dealing with the immutability of blockchain records. Further, we present how the afore identified challenges were addressed within the EduCTX project. In order to develop and deploy blockchain-based solutions successfully, it is necessary to establish cooperation with the IT Departments of educational institutions to provide resources, network operation, etc. In addition, successful implementation of blockchain-based solutions is accompanied by innovations in existing business processes, thus requiring the collaboration of all involved actors inside and outside the HEI. Certain authorities (such as a Notary's office, a Ministry of Education, etc.) should be determined to deal with the challenge of assigning credentials issued in the past. This task could be attributed to the authority that issued a specific credential or, in the case that the issuing institution is no longer active, the task is passed to those general authorities which would verify the credential and assign it to the blockchain-based platform.

The new version of the EduCTX platform is implemented with Ethereum as the backbone and deployed on a consortium-based P2P network [16]. The platform manages ECTX tokens and transactions, which represent a trusted and transparent evidence of acquired skills and knowledge of individuals in the form of digital micro-credentials [13]. EduCTX enables all types of credentials to be stored in a JSON-format file, encrypted, and pushed into a distributed file system like IPFS, while storing the hash of such an encrypted file on the blockchain ledger. A student's certificate JSON file can only be decrypted by its owner. A student that wants to prove the possession of a certificate can download the decrypted version of the JSON file and send it to anyone. The recipient of the decrypted JSON file can verify its integrity and authenticity using the platform, where the decrypted JSON file can be uploaded, and the verification result obtained, i.e., the certificate is not valid (see Fig. 3). Furthermore, the platform also generates a user-friendly version of the certificate by generating its PDF version. The platform facilitates the anonymous storage of personal data, thus being compliant with the GDPR requirements, considering the right to be forgotten [27].

The EduCTX platform does not provide connectivity with identity management systems to support obtaining a student's identity. Therefore, anyone who wants to use the platform needs to create a classic Ethereum account, store the account keys and run a plugin for managing the account. Another important issue to deal with is the immutability of records within the blockchain network. Since an institution has the possibility to withdraw issued credentials for Degrees, Diplomas, Certificates, etc., this is inconvenient for a blockchain-based solution where none of the processed transactions could be deleted. In order to solve

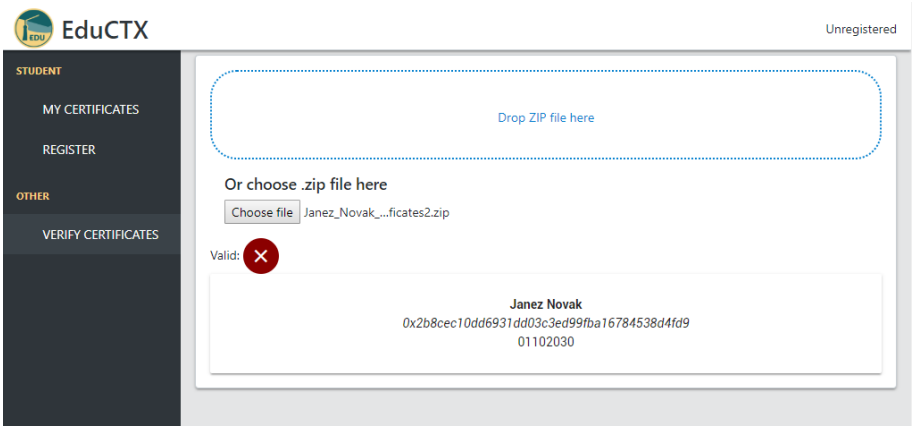

Fig. 3. Certificate verification process on the EduCTX platform.

this problem, the EduCTX platform enables issuing of annulled transactions i.e. credentials, which are bound automatically to existing revoked transactions.

Blockchain-based solutions should be a generic and global as possible in order to take advantage of the most important blockchain features. Those solutions should be integrated with existing Student Information Systems (SIS). Blockchain-based solutions are not supposed to substitute existing SIS, since there is no benefit of data replication, while additionally having to comply with privacy concerns. Therefore, EduCTX promotes itself as being only a blockchain-based platform for managing credentials, while enabling traditional SIS to integrate with it through publicly available APIs.

5 Conclusions and future work

In this paper, we have presented a thorough overview of blockchain initiatives and solutions in higher education. Main strengths and opportunities of this approach have been identified, as well as particular ongoing projects related to this domain. We have shown how blockchain is used to immutably store student achievement data, while making it available for authorized users. Through the systematic analysis of identified projects, we have been able to classify them into four blockchain initiatives and two approaches to blockchain-based solutions. This provides the basis for future research and development. Experience from implementation of EduCTX was used to identify and present main practical challenges. The identified challenges of EduCTX and the solutions for those, could help other researchers with their projects and enable further advances in blockchain projects for education.

Existing solutions and initiatives clearly demonstrate that Blockchain technology has enormous potential to disrupt current higher educational systems. Due to the nature of blockchain features (e.g., immutability, permanence), sev-

eral challenges need to be addressed for a successful implementation of blockchain-based services. Process-organizational and socio-cultural aspects are crucial for the successful introduction of any technology and IT-based services. The protection of sensitive personal data and the incorporation of the disruptive approach into settled organizational processes are the key technical and organizational challenges within the HE domain. In the future, we intend to contact the authors of identified projects through prepared questionnaires, in order to identify common challenges and issues on implementing blockchain-based solutions, and discover how different authors address them. In that manner, an initial set of best practices could be identified and documented, as well as possible reference models and architectures defined, including detailed implementation scenarios for blockchain-based solutions within HE environments.

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