A Life-Long Learning Education Passport Powered by Blockchain Technology and Verifiable Digital Credentials: The BlockAdemiC Project

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Abstract. The academic and business domains are in constant transformation due to the technological advances. In this context, proof of knowledge, skills and training are becoming crucial for the students and employees. In a competitive environment like that, forgery of diplomas and certificates is a frequent problem that has not been faced properly yet. Additionally, the lack of a formal representation and acknowledgment of informal and life-long learning outcomes costs to all educational stakeholders and employee seekers. By using open source blockchain technology as a game changer throughout the educational process, security, privacy, integrity and immutability of the data related to diplomas, certificates and skills acquired by learners can be guaranteed. The result of building a system supported by blockchain for life-long learning, a positive impact in trust and transparency of the education achievements, institutions, students and companies is achieved.

Keywords: Education · Blockchain · Verifiable credentials · Anti-forgery · Digital identity

1 Introduction

The business world is facing a surge in demand for technical skills as it becomes more digitized and it finds it difficult to hire qualified and trained personnel [1]. In this environment, proof of skills, training and education are important in order to get hired by companies. This proof is mainly provided in forms of diplomas and certificates which include information for the candidate's educational and knowledge background. Unfortunately, the forgery of diplomas and certificates is a well-known problem in the academic sector leading universities and other institutions to even stop issuing them in paper [2]. At the same time, there are many informal ways of being educated and trained apart from universities. Life-long learning

A. Cerone et al. (Eds.): SEFM 2021 Workshops, LNCS 13230, pp. 249–263, 2022.
https://doi.org/10.1007/978-3-031-12429-7_18

(LLL) and digital education courses help to acquire microcredentials - which are a representation of the smaller units of knowledge that are not included in a standard diploma or degree - and are not currently represented in national qualification frameworks [3] and thus they lack a formal proof, though they represent skills that are needed for certain job positions. Massive Open Online Courses (MOOCS) for example have evolved from single-course into multi-course with associated degrees, such as the XSeries degree by Coursera and the Nanodegree by Udacity, accredited with microcredentials to prove the skills and training [4] someone has achieved after successfully completing them.

In parallel, the academic world is also being further digitized than just in the administrative tasks. Especially after the pandemic of Covid-19 in many EU countries the educational processes are taking place either fully online or in hybrid mode both in physical and digital presence. This comes with the opportunity to capture learners' interactions through the learning management systems (LMS) and monitor their learning outcomes in order to assign fine-grained badges and microcredentials to them. These microcredentials can then be combined with or accompany the student's diploma to demonstrate the upskill achieved. When speaking about diplomas and microcredentials representation in this paper, we are always referring to their digital format, unless noted otherwise.

Since proof of education and skills is often used to apply for subsequent studies to other national or international education institutions and for job vacancies at companies as well, it is crucial to eliminate any chances of this proof being counterfeit. Blockchain (BC) technology can be used to sustain availability of such credentials while preventing the forgery of the digital records that are stored on it. This is possible because of BC's principal characteristics which include a decentralized append-only database type called ledger, with its records - called transactions - being timestamped, digitally signed, added to blocks connected as a merkle-tree forming the ledger and written only after a consensus among the participating servers - which are called nodes - has been achieved [5]. Taking advantage of open source BC technologies and their features, the BlockAdemiC (BCA) project will create a digital cybersecure system (platform) for certifying and verifying educational activities, diplomas, certificates and skills in higher education (HE) and LLL domains. This system is supporting a cryptographically secured wallet that cannot be tampered, for safe storing all the digital credentials (DC) related to a person's education and training, forming a digital education passport (EDP). BCA differentiates from all other projects that support storing DCs because it goes a step further to record, apart from diplomas and certificates, the educational activities covering special skills - such as scientific and technical - and general skills. Thus, by adding a lower level of student activity recording, it achieves to capture specific actions that lead to acquiring these special and general skills, and stores them immutably on the BC ledger, making them integral part of the EDP. The rest of this paper is separated in three subsections describing a) the BCA potential and the problems it attempts to solve, b) what is blockchain and how it helps to solve the described problem, c) expected impact after piloting the platform, and d) conclusions and future work.

2 The BlockAdemiC Project

2.1 BlockAdemiC Overview

BCA as a project provides a decentralized immutable lifelong cybersecure EDP. To this direction it adopts the European Credit Transfer and Accumulation System (ECTS) for HE institutions' (HEI) students to represent learning outcomes and make academic qualifications recognized across EU countries [6]. The platform that has been developed will be applied at the Aristotle University of Thessaloniki, the largest university in Greece, and at least three more educational institutions in Greece and abroad. Students registered through the BCA will hold a student's digital wallet, that will be used as the EDP, to store their DCs such as diplomas and certificates. By utilizing BC technology HEIs and LLL institutions (LLLI) will issue digital tokens to store soft and hard skills as DCs. A token is an educational credit that reflects in the qualifications that learners have acquired after completing a learning activity.

Qualifications according to the Greek National Qualifications Framework [7] take the form of learning outcomes classified into predefined levels. Learning outcomes - for example what the person knows, understands and can do after completing a learning process - are categorized into knowledge, skills and abilities. A wallet in BC technology is a permanent digital personal storage and in BCA can be held on-chain or off-chain. The difference between the two types is that when stored on-chain this wallet is decentralized hosted on the BC network, when stored off-chain it is hosted on the user's personal computer storage. BCA's goal as a project goes beyond previous BC based education platforms such as Blockcerts and BCdiploma that only store the diplomas [8,9] or EduCTX that uses as a learning unit only the results of written exams to calculate the total ECTS earned by the students [10]. What differentiates BCA is its ambition to capture the total effort of the overall activities that students have on LMS and that can be expressed in ECTS and qualifications. This perspective makes the learning measurement unit more precise than just a single exam result.

Special care has been taken to protect the BCA users' personal and sensitive information by choosing open source technologies supporting the platform to form a private BC network where only registered users can participate. This also differentiates BCA from other education platforms that use public BCs, such as the Ethereum network [11,12], not only in terms of privacy, but also in terms of lowering the costs for storing information and operating the network, having better response times and storage speed, while maintaining security, decentralization, immutability and transparency. This way, information exchange processes between the participating institutions is being reinforced and secured at the same time by the BC technology. The same applies for all the other participants on this network, namely students, alumni and companies offering job opportunities. All of the participants are able to exchange information only after being authenticated and authorized. After research, four main roles - called actors - have been identified at BCA's design stages to be the end users of the system, and their interactions have been defined. After defining the roles, their interac-

tions formed the use case scenarios that would be supported by the system. The actors are

- The educational institutions, which include the HEIs and the LLLIs
- The teachers that are part of the educational institutions
- The students and alumni of the educational institutions
- The companies that are offering job opportunities and are interested in trained personnel with special skills and knowledge

The actions that each of these actors can perform are the following

- Educational Institutions and Teachers
  - HE Institutions
    * Register for an institution account for authentication and authorization
    * Issue verifiable DCs (diplomas, degrees, certificates)
    * Verify DCs issued by any educational institution
  - LLL Institutions
    * Register for an institution account for authentication and authorization
    * Issue verifiable DCs (certificates)
    * Verify DCs issued by any educational institution
  - Teachers
    * Register for a personal teacher's account for authentication and authorization
    * Issue verifiable DCs (microcredentials)
- Students
  - Register for a personal student or alumni account for authentication and authorization
  - Hold a life-long EDP
  - Participate to activities and courses in order to earn DCs (diplomas, degrees, certificates, microcredentials)
  - Present their EDP to HEIs and LLIs for subsequent studies or to employers looking for personnel
- Companies/Employers
  - Register for a company account for authentication and authorization
  - Announce job vacancies and define additional special skills needed to apply
  - Search with specific criteria for alumni in order to offer job opportunities
  - Verify DCs issued by any educational institution

The specific use case scenarios covered by the common interactions between the above mentioned actors are explained next.

The first scenario BCA covers is the need for issuing DCs like diplomas and certificates and capturing microcredentials all along the educational process. Furthermore, by storing the verifiable DCs on the immutable BC ledger, BCA prohibits tampering of all kinds of DC tokens contained in the EDP addressing the fraud of diplomas and certificates forgery. Furthermore, BCA confronts

not only the forgery of diplomas and microcredentials, but also makes them auto-verifiable by other users of the BC network using complicate cryptographic techniques covered in detail at Sect. 2.3. The actors interacting in this use case are HEIs, teachers and students. Figure 1 demonstrates the high level steps for storing a token as a verifiable DC on the BC representing a microcredential or a diploma. BC hosts the student's wallet on-chain in this case, which serves as the storage for the DCs which formulate as explained before the EDP. The wallet, and by that the EDP, is accessible by the students and they can have an overview of the complete list of DCs they have acquired throughout their learning journey.

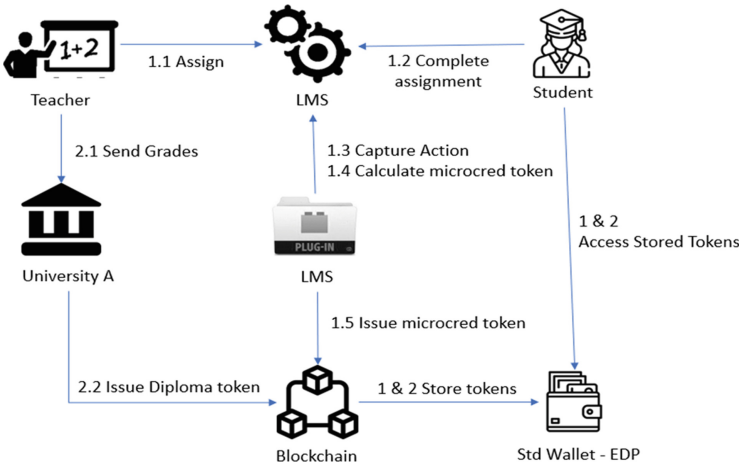

Fig. 1. Issue tokens as verifiable digital credentials

The second scenario BCA covers is the students' need for subsequent studies at other HEIs than the one they received their degree and therefor the assistance of students' mobility between EU countries, or even worldwide. Students' mobility is a priority in EU, and special programmes, like the Erasmus+ [13], are dedicated to support individual applicants and organizations such as universities, training centers and companies to take part in education and training in Europe, apply for grants and facilitate the complete mobility process. The actors interacting in this use case are the students and the HEIs. What is worth noticing for Fig. 2 which presents the high-level steps for this scenario, is that the HEI that issued the diploma as a DC and digitally signed it - named university A - in the previous scenario takes no part in this information exchange and DC verification. That happens because BC eliminates the need for verifying DCs by a third-party other than the ones that are involved in this specific transaction [14]. Additionally, in this use case instead of a university acting as

an actor for auto-verifying the integrity of the diploma, could be a LLL training center with the only condition to have registered for an account and participate in the BCA network.

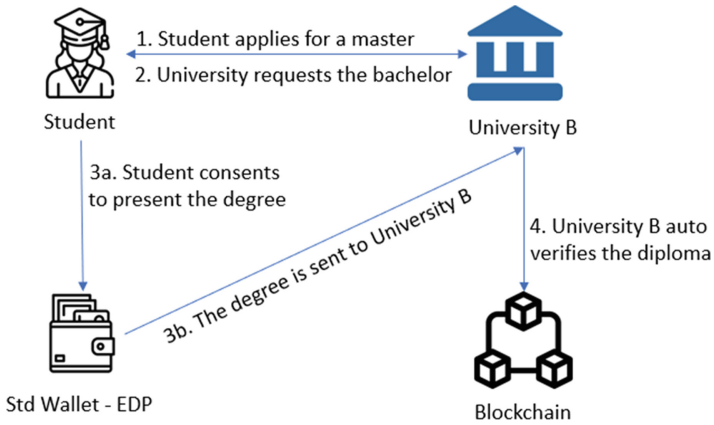

Fig. 2. Applying for a master course

The third scenario BCA covers is the need of companies searching for job candidates in order to find the appropriate ones based on their training and skills. Moreover, it allows companies to publish job vacancies so students fulfilling the requirements can apply for a them. After a company registers and creates their profile, it is assigned an account which serves as an identity for accessing the BCA network. After that, they are able to issue queries with specific criteria to receive results from a pool of students and alumni holding diplomas, certificates and skills and who have consent to be included in this list. That use case will facilitate the need for connecting the education institutions students and alumni and the labor market, easing the process called school-to-work transition [15,16]. Figure 3, demonstrates the high-level steps when a student or alumni applies for a job vacancy and the auto-verification of the DCs that are needed and presented for this position. As explained before, the verification of the DCs presented does not require the involvement of the issuer as argued before, disengaging the necessity for third-party verifiers, speeding up the whole process. In this particular scenario, the forming of a subset of DCs on the fly from the EDP - rather than sending just one DC for proving the candidate fulfills the specific skills and education - inserts a level of flexibility per use case and is a paradigm of how an EDP can serve as a life-long secure education passport in different circumstances and occasions.

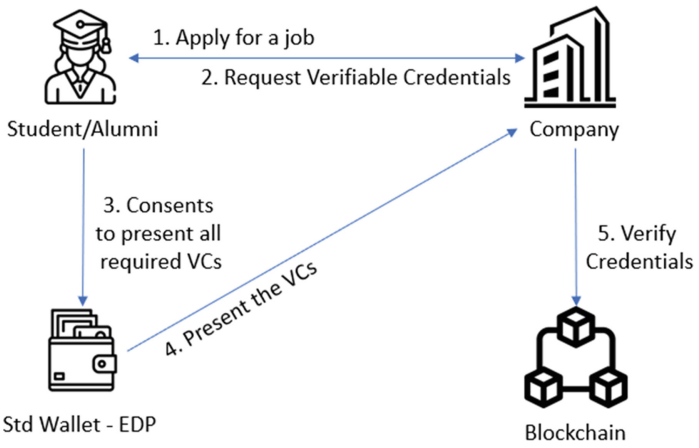

Fig. 3. Applying for a job

2.2 Innovation and Objectives

The project is innovative to its grounds due to the fact that it uses BC decentralized technology for security, confidentiality and combines it with learning analytics, as follows:

- It ensures the authenticity and makes impossible to falsify the learning outcomes, as well as the acquired knowledge, abilities and skills through the registration of the tokens and the relevant diplomas/certificates on the ledger. This is achieved by distributing copies of data to all BC nodes hosted by the participating organizations and institutions. The distribution of data enhances also the speed and the consensus (agreement) and avoids the single point failure in the education network.
- It ensures access to the system only to authorized users and allows the definition of classified rights. For example, only certified instructors/training providers are able to record students' results, while students/trainees are in control of sharing with third parties, such as companies, only the data they choose to share.
- It automates the process of certification of learning outcomes. For this purpose, SCs have been developed, which are code (software) that is executed automatically as long as certain predefined conditions are met.
- It enhances the participation of students/learners in the process of consent and verification of learning activities. Suitable decentralized blockchain-based mobile decentralized applications (DApp) has been developed for this purpose.
- It ensures interoperability with the support of international standards and their implementation on the BCA platform to lay the foundations for integration with other systems of similar educational applications in either the national or international educational environment.

– It assesses the learning activities with additional metrics other than learning outcomes. Such metrics aim at assessing the skills necessary for the student to enroll for a particular course or general skills such as communication, collaboration, understanding, taking initiatives, problem solving. Those metrics are usually collected through calibrated psychometric tests and in BCA through user actions like contributing to collaborative activities.
– It increases usability and end user friendliness through the adoption of gamification techniques, interfacing with existing digital training platforms and connecting to social media, mainly professional as Linkedin, and academic as ResearchGate and academia.eu (Fig. 4).

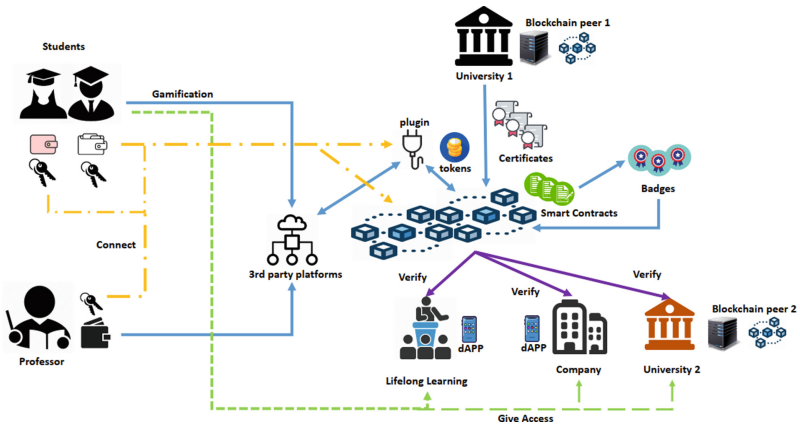

Fig. 4. BlockAdemiC overview

BCA successful implementation is divided in four separate and equally important objectives as described below:

– **Objective 1:** To create a complete system of distributed security with open source technologies, which will extend and ensure the certification and verification of educational activities, skills and qualifications in HE and LLL. BCA will provide an individual, tamper-proof and therefore inviolable educational passport, based on BC technology. In this EDP, both the diplomas and the relevant educational records will be stored in the form of convertible digital educational credits (tokens), adopting appropriate mechanisms of learning analytics. The tokens will be linked to the formal education system (in the case of HEI), and the labor market through the adoption of corresponding interoperability mechanisms that will allow the recognition of educational 'parchments' at a pan-European and global level. In this way it is expected to facilitate the mobility of students, but also professionals, by opening new prospects for professional and academic development, including personalized learning.

- **Objective 2:** To design and develop the appropriate framework and mechanisms of learning analytics in order to automatically link learning metrics with the assessment of (technical) knowledge (hard skills) and horizontal skills (soft skills) of learners. The proposed framework of learning analytics will directly link the individual learning activities of the trainees with the relevant knowledge and horizontal skills through a credit system compatible (where possible) with ECTS. At the same time, this framework will allow learners - in collaboration with trainers - to choose their learning path (personalized training), adapted to their learning goals, knowledge and skills ensuring the interoperability of learning tools. The learning analytics mechanisms that have been developed are integrated into a gamification framework in order to make the overall solution more attractive to the learners and to give them additional incentives to adopt it.
- **Objective 3:** To develop a technological platform of distributed digital security for the registration of educational activities, degrees and certifications on a BC ledger forming an EDP. The platform supports storing, presentation and verification of diplomas and other kinds of tokens as well as the ability to share student VCs with stakeholders and companies. BC solutions improve verification processes and eliminate false training credits claims that were never obtained or that have undergone forgery. At the same time, they enable transactions such as the transfer and convertibility of educational units, and the recognition of learning activities.
- **Objective 4:** To pilot and validate the operation of the proposed technological solution in real conditions. The integrated system, as well as its individual functions will be piloted in 2 broader scenarios: in a postgraduate program of AUTh and in at least 3 more collaborating educational institutions in Greece and abroad, the network of the partner Web2Learn. The results of the pilot application will be evaluated for the purpose of (a) the performance of the proposed system in relation to the requirements analysis and project objectives, (b) the recording and implementing of individual improvements in the system, and (c) the evaluation of possibilities for exploiting the results beyond the framework of the project.

2.3 BlockAdemiC Technological Background

As argued before, BCA is a project that utilizes open source BC technology in order to create a secure, decentralized and tamper-proof EDP for storing DCs. The reason behind using the BC technology for the system is mainly to prevent forgery of diplomas in HE and LLL domains and to create a LLL EDP. BC can increase transparency and credibility with its immutable storage, the ledger. Additionally, the immutable transactions that are being added on the ledger create permanent records, with an associated permanent link, called anchor. This anchor, along with the digital signature for each transaction makes autoverification of the records possible. In more detail, when a transaction such as a diploma is stored on the ledger for a graduate student, the digital signature of the institution issuing this diploma is stored along with the transaction. Digital

signatures have the characteristic of being self-verified, because they contain the public key of the signer, in this case the HEI's or the LLLI's [17].

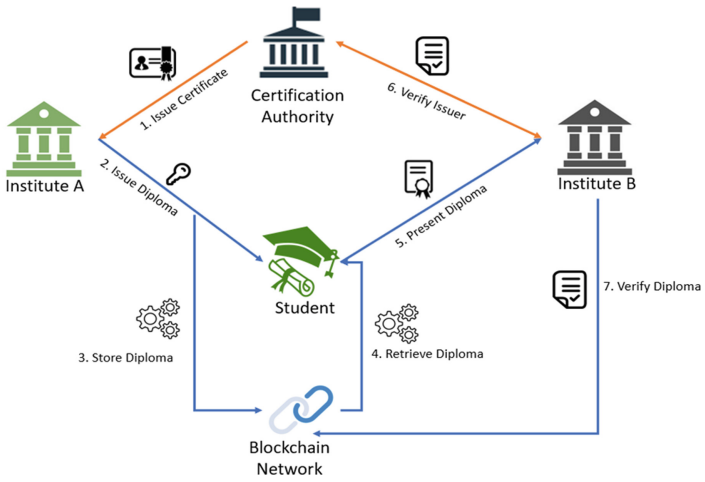

Fig. 5. Auto-verification of a diploma's validity

The verification of the diploma based on the HEI's digital signature that is stored along with the diploma, follows certain steps that are implied by the Public Key Infrastructure specification framework, utilizing the X.509 HEI's digital certificate issued by a trusted Certification Authority (CA) [18]. First, institute A is issued a certificate by a trusted CA and holds a private and a public key. Then, institution A issues a diploma as a DC for a student and digitally signs it with its private key. The DC contains, apart from the related information and the holder of the diploma, the digital signature and the public key of the issuer, in this case institution A. When the holder of the diploma presents it to institution B to apply for a master course for example, institution B receives the DC that contains information about the issuer and retrieves the issuer's public key. With this information alone, institution B is able to verify the validity of institution's A certificate and the integrity of the information regarding the diploma record on the BC which institution A signed before. The high-steps of this process are displayed in Fig. 5.

What is worth noting regarding the BCA implementation is that institution A and institution B have no direct interaction or information exchanged between them. Instead, the PKI infrastructure and the BC network supporting the solution allows the auto-verification of the diploma's origins and integrity directly from the BC solution. The only difference in BCA regarding a traditional PKI implementation, is that the CA is running on the BC network as a service and it's not a third-party trusted authority. When more than one CA is running on the BC we can achieve a decentralized CA along with the decentralized storage for the BCA platform. Currently only one CA is running on the network,

but more than one is possible to cooperate in real life scenarios, where a trusted chain can be formed between the various CAs, for example at an institution level (one per HEI). The actual implementation differs from the above general one and is displayed in Fig. 6, where the trusted CA runs on one of the BC nodes, participating on the network.

To achieve the automation of assigning DCs to trainees and students but also enforce the rules that frames the allowed and prohibited interactions between BCA's participating actors, BC smart contracts (SC) are running on the background. A SC is a software program that runs on the BC network and contains conditions that must be met in order for specific actions to happen, such as storing a diploma in a student's EDP or controlling the process when the student consents upon to an institutions request to present their diploma to apply for a master course. SCs are functions that run on the background as services and they can be called directly or indirectly. For example, if a HEI other than the one that issued the diploma attempts to access a student's diploma without their consent, a SC is activated without a human interaction to prevent this from happening. In another situation, where the student wants to present their diploma to apply for a master course or for a job application, a human interaction is needed to trigger the appropriate SC. This happens through a software application, which is called DAPP. The DAPP makes possible for the BCA users to interact with the SCs and consequently the BC network through a user-friendly environment, hiding the complexity of the background technologies. The system is powered by the Hyperledger Indy BC solution (Linux Foundation), which is an open source framework, providing tools, libraries and reusable components for providing decentralized digital identities with focus on interoperability among the various connected applications and platforms [19]. It contains mechanisms for storing students' and alumni's verifiable DCs in the EDP and associate them with specific digital decentralized IDs called DIDs [20], keeping them secured, immutable and private.

2.4 Expected Impact

The piloting of the platform is expected to have strategic positive effect in the following areas:

- The trust between the training institutions as well as the companies (future employers of the trainees) regarding the knowledge and skills of the trainees. The security and availability of the data that is registered and exchanged will improve.
- The competitiveness of the educational institution based on the innovations that the project brings to the educational practice. The transparency of the whole process supported by BC technology will enhance the credibility of the institutions and the degrees they award. It aspires also to provide the framework for personalized education in HEIs and LLLIs, and enhance student mobility between educational institutions, as well as business confidence in

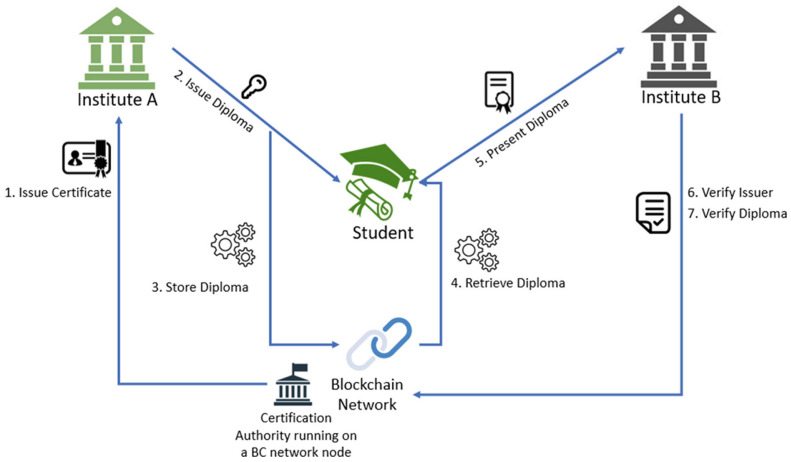

Fig. 6. Auto-verification of a diploma in BlockAdemiC project

the quality of education and the breadth of their knowledge and skills. Students and alumni will be better evaluated by the companies as prospective employees.

- In the educational part, to help in better quality learning and teaching practices, improved curricula, better guidance services for students in terms of their courses and studies either in the same institution or in other educational institutions. Teachers will have a more complete picture of their students' progress, so they will be able to intervene more sportively and effectively, but also in a more general context. Teachers and therefore the educational institution, will be in position to guide and support students during and after completion of courses, and faster (in terms of selecting subsequent courses or study programs at other institutions). Due to the transparency of the information, that information and the monitoring will be more effective for the student
- In the financial part to exploit economic benefits deriving from the BCA application adoption and usage by the stakeholders.
- In the social part to provide better educational services and opportunities in society and enhance the credibility of institutions to students and businesses. The project will also help build institutional trust, using the functions of BC immutability and timestamping. The service will provide employers and recruiters with reliable information about their degree and other skills they may have acquired during their careers.

3 Conclusions and Further Research

The academic and employment processes are being transformed due to the technological evolution. Along with this, students and job seekers need to prove

their skills and special training in the digital world and educational institutions are called to provide these proofs, while maintain the integrity of this information. BC open source technologies support the integrity of information stored and exchanged, ensures the validity of the stored microcredentials and diplomas and protects against forgery of these digital credentials. That creates a secure, trusted and transparent environment where all of the education stakeholders take advantage form the automation of verification of diplomas, certificates, skills and microcredentials in general. With BCA, the decentralization of the information provides an additional layer of data redundancy eliminating the problems of service outages, single point of failure and data loss. Furthermore, by utilizing an EDP, a secure and organization independent personal storage for tokens is created which can accompany the holder throughout their education and working careers.

We acknowledge the limited testing of the system in a lab environment, and we anticipate to use it in production to confirm the expected outcomes presented in this paper. In order to explore the system's usefulness for the education ecosystem's end users a research questionnaire has been formed and distributed to selective HEIs at principals and students. Its results are encouraging and substantiates our expected results and they will be presented after piloting the system. Additionally, in the future, we intend to connect the identity management system we developed based on Hyperledger Indy with well established and legacy systems of HEIs and LLLIs in order to examine the compatibility and interoperability with these systems on site. In our next paper we will also present metrics regarding the efficiency of the system. Another research area that concerns us for BCA is the scalability of the solution and we will examine it in relation to the actual piloted environment. As mentioned before, the questionnaire provided us preliminary information for the necessity of a platform like BCA which provides an holistic solution from the educational process to the actual employment market and we are sure that our system will be well established among the different stakeholders.

Acknowledgements. This work was funded from the PA (Partnership Agreement for the Development Framework) 2014–2020 under project No. T2EDK-04180, project BlockAdemiC.

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