# Analyzing a Blockchain-Based Educational Application from the Software Ecosystems View

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***Abstract.*** *Many educational institutions face the challenge of dealing with different data types, available in different systems. These systems have data related to the issuance of student certificates. A Software Ecosystem (SECO) could be a set of software products with some degree of symbiotic relationship, consisting of a set of actors acting as a unit that interacts with a distributed market between software and services, along with the relationships between these entities. Blockchain technology promotes transparency, immutability, and trust, being an attractive solution for educational systems. This research presents an educational domain application named Educ-Dapp, from the viewpoint of SECO that uses blockchain resources to treat the students' certificates from higher education institutions. The results of this work were a SECO model of an educational application that uses blockchain, and a set of research opportunities related to SECO, blockchain and collaborative systems for the educational domain.*

## 1. Introduction

Nowadays, several educational institutions have the challenge of dealing with multiple data types, coming in diverse formats, produced and made available in different systems. These data are generated and used by several functionalities and employees at the most varied levels (e.g., management of academic activities, student evaluations, registrations (professors, students, technical support), performance, finance, accounting). Another challenge is how educational institutions deal with the task of generating and distributing student certificates [Abreu et al. 2020]. Student certificates are demanded to declare that a person has completed a level of study during a job selection in private and public companies. Hence, certificates are considered valuable documents authenticated by educational institutions. However, this document may be fraudulent and misused by persons with malicious intent resulting in misuse.

A Software Ecosystem (SECO) refers to a collection of software products with some degree of symbiotic relationship [Messerschmitt and Szyperski 2003], consisting of a set of actors acting as a unit that interacts with a distributed market between software and services, along with the relationships between these entities [Jansen et al. 2009]. Such relationships are often supported by a technological platform or a common market and carried out by exchanging information, resources, and artifacts.

Blockchain is a sequence of blocks that contains a complete record of transactions as a public ledger, indicating the order in which transactions occurred [Bhaskar and Chuen 2015]. Currently, blockchain technology is integrating into different domains (e.g., logistics, energy, agriculture, and health). Blockchain can also be applied in the education domain. This study focuses specifically on higher education. In this scenario, the principles of document authentication, transparency, immutability, and trust are the key features that make this an attractive solution [Grech and Camilleri 2017].

Generally, Higher Education Institutions (HEIs) have a specialized system to maintain student records of completed courses, where data is structured to be accessed only by institution employees or students on specific applications, having little or no interoperability. These systems' databases are hosted in a data center within HEIs, with restricted access to their professionals [Turkanović et al. 2018]. In HEI, the issuance and availability of the certificates are critical roles as it is strong evidence that the student has completed the course [Al Harthy et al. 2019]. Thus, it is essential to prevent degree transcription fraud and a place to check the data issued accuracy by the institution. In this context, blockchain emerges as an alternative solution.

In a blockchain, transactions between trusted parties (HEIs, students, government) are required for validation, storage, availability, and data security from certificates. This technology can adequately address these aspects, as the solutions created through blockchain allow high trust, disintermediation, and verified transactions [Taufiq et al. 2019].

In Brazil, the certificate registration process involves documents from students and HEIs. These documents are essential to ensure safety and validity of the legal acts to be produced by this process, and certificate registration must be registered in a specific book, stored in a physical or electronic environment, at the responsibility of each institution [Abreu et al. 2020]. Following the administrative act of ordinance number 1.095 by the Ministry of Education of Brazil (MEC), after registration, it is necessary to publish an extract of the certificate registration in the Official Gazette (DOU), paying a monetary amount for the used space, and the responsibility for publishing the information in DOU rests with each issuing HEI. The purpose of this new law is to give more credibility and security to the information of students' degrees [MEC 2018]. Educ-Dapp emerged as a web application that uses blockchain to handle student certificates registration.

In this context, this work proposes a discussion of Educ-Dapp, an application in the educational domain, from the viewpoint of SECO. For this, the methodology applied to this work consisted of the following steps: (i) description of the Educ-Dapp (e.g., features, architecture); (ii) description of SECO Educ-Dapp; (iii) SSN modeling; and (iv) identification of research opportunities. The article is divided in the following sections: Section 2 presents the background; Section 3 outlines the Educ-Dapp application; Section 4 describes aspects from Educ-Dapp SECO; Section 5 discusses some research opportunities; and Section 6 presents conclusions and future work.

## 2. Background

This section presents the theoretical framework used in this research. The concepts of the education and blockchain areas that will be used to achieve the objectives of this work are briefly described.

## 2.1. Software Ecosystems (SECO)

In literature, there are many definitions for SECO. Manikas and Hansen [Manikas and Hansen 2013] defined SECO as an interaction of a set of actors on a common technological platform that results in software solutions or services. Each actor is motivated by a set of interests or business models, and they are connected to others and SECO as a whole through symbiotic relationships. The technological platform is structured to allow the involvement and contribution of different actors. The ecosystem metaphor highlights external or unknown actors who are contributing to evolving a common technological platform by shifting the traditional organization-centric value chain to a software delivery network, where multiple components developed on different platforms coexist and affect business from the buyer [Boucharas et al. 2009]. Finally, Manikas [Manikas 2016] updated the definition of SECO as: "the software and actor interaction concerning a common technological infrastructure, that results in a set of contributions and influences directly or indirectly the ecosystem".

Hanssen described three key role types for SECO [Hanssen 2012]: (i) keystone: an organization or a small group acting as the keystone organization, and it is in some way leading the development of the central software technology; (ii) end-users: central technology end-users who need it to carry out their business, whatever that might be; and (iii) third-party organizations: actors who use the central technology as a platform for producing related solutions or services. Considering the three dimensions of SECO proposed by Campbell and Ahmed [Campbell and Ahmed 2010]: (i) Business Dimension: driven through the three factors of vision, innovation, and strategic planning, which are integrated as a business vision which drives innovation which structures strategic plans; (ii) Architectural Dimension: multiple product development, achieved by sharing a typical organizational platform architecture, and through involving third parties; and (iii) Social Dimension: the need for organizations to become more open, allowing third parties to develop applications for a specific platform. Regarding SECO modeling, Boucharas et al. [Boucharas et al. 2009] tried to formalize SECO modeling with the Software Supply Network (SSN) strategy. SSN is a series of linked software, hardware, and service organizations cooperating to attend to market demands [Costa et al. 2013]. Figure 1 presents a summary of the SSN's key elements.

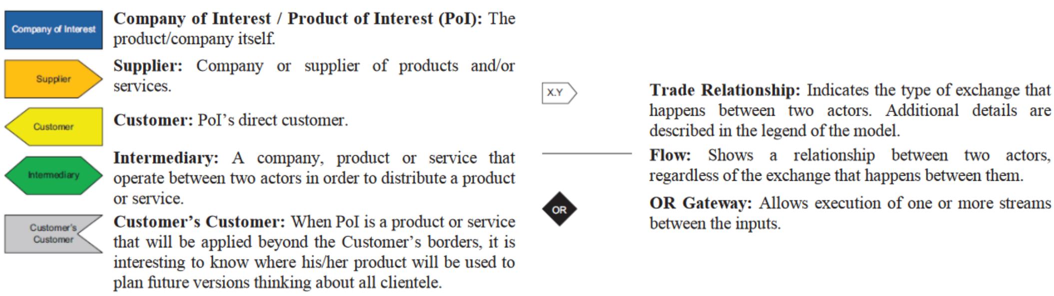


**Figura 1. SSN elements [Boucharas et al. 2009]**

## 2.2. Blockchain

Blockchain is a block sequence containing a complete transaction log as a public book, maintained by multiple nodes in a network [Bhaskar and Chuen 2015]. Each node contains an identical copy of this ledger, each block being a logical sequence of transactions, which are permanent, transparent, and unchanging records [Thakkar et al. 2018]. Each block contains a timestamp, the hash value of the previous block (parent), and a nonce, which is a random number to verify the hash. This concept guarantees the integrity of the entire blockchain to the first block (genesis block). Hash values are unique and can effectively prevent fraud since changes to a block in the chain would immediately change its value [Beck et al. 2017].

Blockchain technology can record transactions between two parties efficiently, verifiably, and permanently, eliminating the need for third parties. Besides, the availability of all completed transactions for all nodes makes a blockchain-based system more transparent than centralized solutions. Transactions are validated by member nodes using a consensus protocol, which ensures that all nodes have an identical copy. A new block is considered verified only after most member nodes vote as true and reliable using the consensus protocol [Bosu et al. 2019]. An essential parameter for analyzing blockchain is the block itself, by its size, time required for mining, and cost. Mining is the process of validating a block in the blockchain, and it can affect all system performance [Rifi et al. 2017].

### 2.3. Collaborative Systems and Blockchain

Building collaborative systems involves technical and multidisciplinary challenges [Gerosa and Steinmacher 2012]. Components can reduce these challenges by facilitating prototyping and experimentation, and encapsulating technical and multidisciplinary complexities. The technical complexity of developing collaborative systems often becomes the focus of the development team. Blockchain development often involves web or mobile applications, as in more traditional development, and aspects of developing smart contracts and blockchain network infrastructure.

A distributed system is made up of software and hardware components located on autonomous computers that communicate by exchanging messages over a network [Gomes et al. 2012]. Most collaborative systems are distributed systems in which users interact in a shared workspace through networked computers, which may or may not be centralized. An example of a decentralized architecture is P2P (Peer-to-Peer), in which resources are shared directly between clients, which is the basis for the blockchain. In this sense, a blockchain meets some requirements to be considered a collaborative system.

### 2.4. Degree Registration and Access in Higher Education

More than 1 million higher education students graduate throughout Brazil each year, and in 2018 about 1.2 million graduate students [MEC 2019]. Certificates that students receive upon completion of a course prove their education, performance and they are essential as a reference for entry into public and private companies [Cheng et al. 2018].

With technological advancement in recent years, the need for student and institution data protection has grown. Graduates prove accuracy through certificates for use in selection processes. However, they often lose the printed certificates and must request a copy from the organization issuing this document, which may take a long time because of the administrative processes for validating the certificate's data. On the other hand, ordering an electronic copy can save paper and time. However, because of this convenience, the attempts of falsification of certificates likelihood is high, then educational institutions and companies can not quickly validate the received documents [Cheng et al. 2018].

There are vital points regarding systems responsible for controlling educational data (e.g., data standardization, storage location, security) and how to filter, analyze, protect, and share this data. Because of these problems, higher education institutions keep track of complete student data indefinitely for legal reasons, depending on a country's policy [Turkanović et al. 2018]. In Brazil, the administrative act of Ordinance No. 1.095 was recently issued by MEC, stating that public and private HEIs that have the prerogative to register the diplomas issued by them should publish an extract information about the registration in the Federal Official Gazette (DOU: means of communication by which the National Press has to make public all matters about the federal scope). They shall also maintain a database of diplomas registration information to be made available on the HEIs website after proper registration in DOU [MEC 2018]. With these new rules, the Brazilian government intends to improve the institutions' internal processes, giving information agility and security to deliver a better student experience.

## 3. Educ-Dapp

Educ-Dapp is a web application for consulting student certificates. The data is stored on a blockchain.

### 3.1. Features

The context for Educ-Dapp is a private higher education institution, where the participating key users are from the institution's degree issuing sector. The educational data entered by HEI in the blockchain is based on the administrative act of Ordinance No. 1.095 by MEC. It considers the following data for the degree registration in the application: (i) name of the institution; (ii) number of the institution; (iii) name of graduate student; (iv) ID of the graduate student; (v) name and MEC code of the college; (vi) date of entry into the course; and (vii) course completion date. All the data used in the validation scenario, the flow of operations, and the interaction between actors are fictitious.

The function (login) that makes institutions registration is created in the contract time and passed on to the government. The government registers educational institutions that can use the application. Institutions make a registration to be enabled to register the diplomas, where the application makes a validation verifying if it has the registration informed by the government. The system confirms the registration made by the institution and avoids anyone from registering with the application. The other entities only have permission to query the certificate data, searching by the student's ID. Figure 2 shows some Educ-Dapp screens.

To use Educ-Dapp, it was necessary to install the Metamask plugin in the Chrome browser, as it created a cryptocurrency wallet to interact with the application, and any transaction that inserts data into the blockchain has to be approved by Metamask. After successful registration, users can login to start the degree registration process (include, revoke and consult).

### 3.2. Architecture

Educ-Dapp architecture has three layers (Figure 3A): (i) Application layer: layer for interacting with entities outside the system; (ii) API layer: composed of the technologies required to create blockchain access; and (iii) Blockchain layer: where the educational data and smart contracts reside. For the prototype, we used Ethereum blockchain.

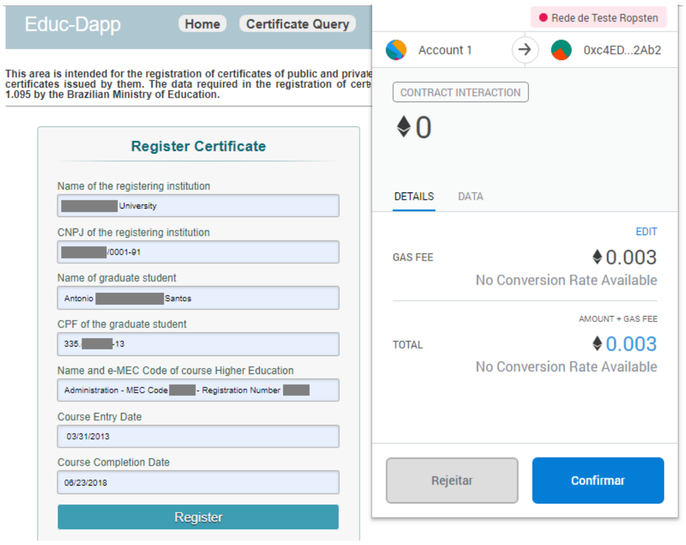


**Figura 2. Degree registration by HEI [Abreu et al. 2020]**

The Ethereum platform-related technologies used for prototype development were: **IDE Remix:** Online IDE for smart contract development; **Solidity:** Ethereum's language for smart contract development; **Web3 API:** web3 documentation JavaScript Dapp API used for decentralized application development Educ-Dapp; **Metamask:** Browser plugin to access Ethereum platform, where it works as an ether wallet and also browses the Ethereum network without having to have a copy of the blockchain installed in the local environment; **Ropsten:** Ethereum's public testing network to validate the prototype; **Infura:** website to interact with smart contracts because we need to be connected with a node, which is the gateway to the Ethereum network; and **Etherscan:** a tool for exploiting a blockchain, allowing you to analyze transactions on the Ethereum platform as a way to aid validation during application development. Metamask plugin was used for smart contract implementation. It acts as an intermediary to perform transactions on

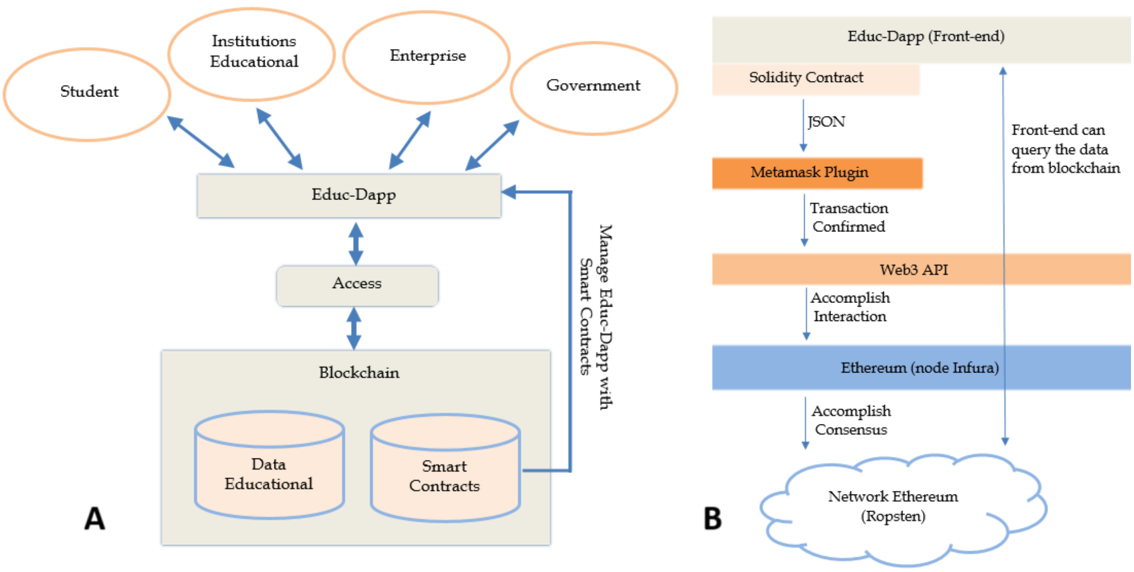


**Figura 3. Educ-Dapp architecture and technologies flow [Abreu et al. 2020]**

the blockchain network. In this prototype, we used Ropsten public network which use fictitious ethers to perform operations and could try different features before publishing contracts on the mainnet. Through an account created in this plugin, the user authorizes or not the transactions on the blockchain, managing all transactions through this account. After implementing the smart contract, the front-end application (Educ-Dapp) integration with the blockchain layer was developed.

Figure 3B displays the technologies execution flow used during transaction executions on the prototype. In the application, entities can use blockchain to send and retrieve data. The front-end provides an interface for the user to interact with the smart contract. The front-end is also informed of the contract code in JSON format, and from the transaction confirmation through the Metamask plugin, the Web3 API recognizes the Solidity code and initiates communication with Ethereum's testnet Ropsten network through the node created on the Infura website. To query the data in the blockchain is not necessary to use the plugin Metamask because after the data is entered into the blockchain, any entity can consult without the need to perform some registration or installation.

## 4. Educ-Dapp SECO

Figure 4 shows a socio-technical network for Educ-Dapp. Around the central platform, several elements collaborate for development, usage, and evolution. Four groups stand out: (i) application development technologies, (ii) blockchain technologies, (iii) application execution, and (iv) user community. We can identify some integration points with third-party products and suppliers through the network.

Application development technologies may vary depending on the addition of new features, portability to other development platforms or programming languages. At Educ-Dapp, the blockchain technology used was Ethereum, and many tools to support its development were used. To run the application, a browser is necessary, being a common tool and independent of operating systems. Metamask is an essential integration point in this solution, as the browser must have it installed and configured to be a cryptocurrency wallet. Finally, user profiles are specific to the educational domain and can expand to other institutions that work with certificates.

### 4.1. Educ-Dapp SECO Considerations

Educ-Dapp SECO promotes the integration between many types of technology providers (e.g. infrastructure, database and frameworks) for the central platform use, which is the web application by users, focusing on the student certificates treatment.

Analyzing the three key role types described by Hassen [Hanssen 2012], we have keystone, end-users, and third-party organizations. In our context, Educ-Dapp is the keystone, given that it is the educational application that integrates technologies, features, and roles. As end-users, several user profiles benefit from Educ-Dapp (e.g., students, government officials, employees of educational institutions, and companies). Related to the third-party organizations, companies, or institutions can add Educ-Dapp to existing educational solutions, generating new business and promoting systems integration.

Considering the three dimensions of SECO proposed by Campbell and Ahmed [Campbell and Ahmed 2010]: business, architectural, and social, we have the following

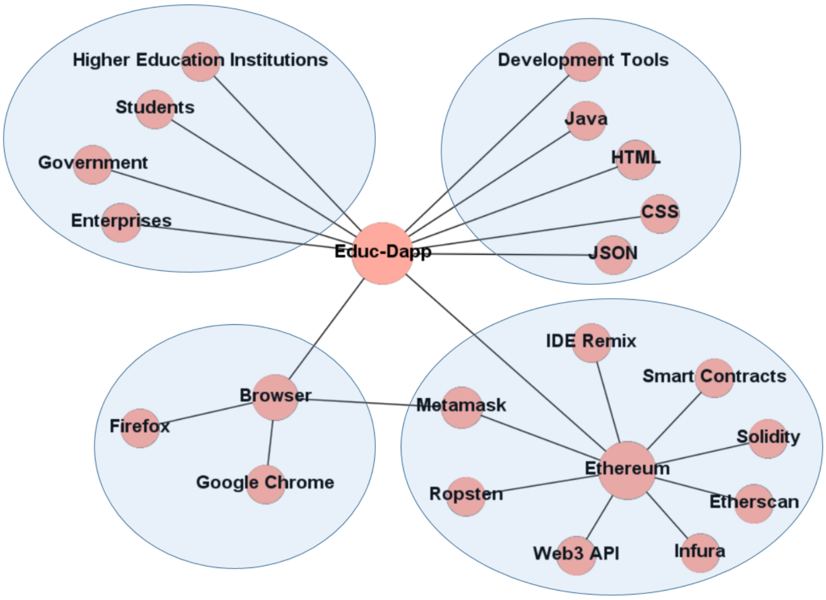


**Figura 4. Educ-Dapp socio-technical network**

observations in Educ-Dapp. Concerning the business dimension, the possibility of expanding the application, and its adoption as an integrated solution or not with other systems, is quite favorable. As there are many higher education institutions in Brazil, customizing each reality would promote several business opportunities. To architectural dimension, the very nature of blockchain integration with web or mobile applications is already a reason for research and development, given its character of interoperability and different technologies. Finally, in social dimension already serves a target audience of actors in the educational field, such as higher education institutions and students. However, the possibility of expanding to several other profiles related to the educational scope is enormous, providing communication between different components and hierarchical levels in the community.

### 4.2. Educ-Dapp SSN Modeling

Figure 5 illustrates SECO Educ-Dapp. A model designed in SSN was developed in ECOS Modeling tool [Pinheiro et al. 2022, Pinheiro et al. 2025]. As a company of interest, there is the Educ-Dapp central platform, the application where the other elements relate and depend on it. Suppliers are of various types and may undergo modifications throughout the life cycle of the central platform, varying from application server, programming languages, APIs, IDEs, infrastructure, and utilities. Clients are grouped into students, higher education institutions, companies, and government intermediaries. Metamask plugin and browsers are used to access data and applications by users. The relationships between the elements are grouped into services (e.g. API, network, and infrastructure services and facilities for accessing Educ-Dapp), products (e.g. source and executable code and the blockchain database), and finance (e.g. cryptocurrency consumed in blockchain operations). In the case of the application's cryptocurrency, which used the Ethereum blockchain, the cryptocurrency is ether.

An SSN component that did not enter the model because there is no possibility of expanding the model was the customer's customer. This point is a possible model

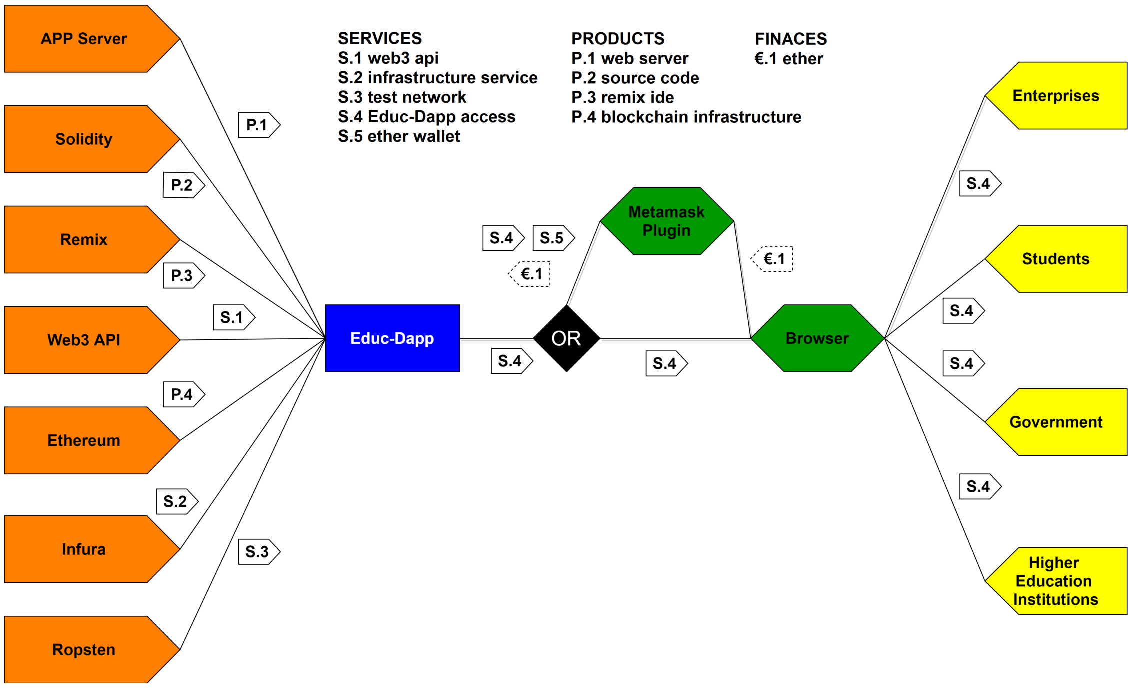


**Figura 5. SSN model of Educ-Dapp application**

extension, considering that the developer community has access to the source code of Educ-Dapp on GitHub and can develop new solutions, new features or customizations for its customers. Another example is if a client decides to develop services, software or otherwise, for another client, ensuring the use of the central platform or some component directly related to their products.

### 4.3. Collaboration in Educ-Dapp SECO

Collaboration in a SECO is something natural, due to the characteristic of a SECO having several actors acting in different ways with different types of relationships. The entry and exit of actors and the dynamics of relationships can cause the evolution of SECO. In the Educ-Dapp SECO there is a clear dependence on Ethereum, since its implementation used only this blockchain. When changing or porting to other blockchains, there is a need to carefully evaluate the impact, since some relationships may have to be reviewed or even lost. And in this context, new intermediaries may emerge, such as mobile application stores, professionals who mediate the use of the application with institutions and possible improvements.

Specifically for blockchain, which is one of the technical components of Educ-Dapp SECO, its smart contracts are tools for managing contracts that could initially be physical, such as those operated in notary offices, which require the involvement of several interested parties, physical signatures, proofs and paper documents. This simplification through the disintermediation of interested parties promotes lower costs, greater agility and the security of the blockchain, which is interesting for certificate management. From a collaboration perspective, there are a web application, blockchain, smart contracts and database coexisting in a transparent manner for the end user. From an architectural viewpoint, there is a set of distributed systems, focusing on both software and infrastructure architectures.

There is no mobile application for the Educ-Dapp, and this would be a possible expansion of Educ-Dapp application and SECO. In this case, new suppliers would enter, such as Android and iOS, in addition to all the necessary utilities, frameworks and development platforms. Developers with new profiles would also have to enter SECO.

New users may emerge, such as institutions outside the educational sector that wish to consult diplomas for some validation. In this scenario, care must be taken so that the business scope of SECO does not lose focus quickly, abruptly or without a way to maintain itself, since the focus is the educational domain. This can be a form of collaboration, but it can also be a way to monetize the SECO.

In terms of the blockchain technology sustainability, there are discussions related to the use of computing resources. For example, the energy consumption of infrastructure and cooling, which are aspects directly related to financial costs. For an institution, there is the option of having the infrastructure or outsourcing it, as in Cloud Computing. Both situations have associated costs, requiring a cost-benefit analysis. For possible scalability of the system, there is also a variation in maintenance costs, which can especially impact public institutions with limited resources. In the case of Educ-Dapp SECO, for full use of the application, there is a need for a larger study, acquisition of equipment or hiring of resource providers. This study was not conducted, but it is extremely important for the maintenance of SECO. In addition, there are changes in suppliers and technologies, impacting the relationships that occur between the actors.

Finally, it is worth highlighting that there is a great deal of collaboration from the viewpoint of computing platforms. Web applications, databases and blockchain are examples of technologies that coexist in an environment of computer networks and distributed systems, each with its own peculiarities.

## 5. Research Opportunities

This section presents some research opportunities that Educ-Dapp SECO can explore.

### 5.1. Collaborative Systems

The Educ-Dapp SECO contains several elements of collaborative systems, whether from the viewpoint of infrastructure and networks, or from the perspective of collaboration between humans and institutions. Suitable with these two visions, blockchain comes as a means to adapt business needs to both hardware and software. Exploring business needs with blockchain is a challenge because the technology varies, new suppliers enter and leave the SECO, new programming language and computational infrastructures. Considering the entry and exit of collaborators in SECO, there is a need to analyze the impact of these movements. There are both financial and social impacts, and this may imply the use of new collaboration models.

### 5.2. Integration between Different Platforms and Applications

In a SECO, the central platform is often offered in different platforms, such as web and mobile. It implies different versions of applications with diverse technologies and suppliers. Blockchain has several technologies for development and production, such as Ethereum and Hyperledger. How these different versions of applications communicate with the blockchain can vary due to data format, types of requests, and volume of data and access. Besides, these environments communicate with other applications, which support or complement the central platform, such as the several systems that make up the educational domain. There is a strong characteristic of data integration and sharing, which must be considered for the full functioning of the application. The blockchain allows data integration from different parts instead of storage on individual systems, enabling data sharing and saving time and cost of information retrieval [Wu et al. 2019]. In the presented scenario, as the HEI data have different origins, the storage environment may become heterogeneous concerning the information contained in the network. Due to the fragmentation and lack of consistent standardization of blockchain technologies and platforms [Lima 2018], the chain is built with variable data causing the reduction of interoperability and incompatible records between systems.

### 5.3. Modeling Systems with Different Technologies

As all systems modeling, SECO modeling must define the levels of abstraction and evaluate the cost-benefit of more or fewer details. A challenge already identified in the literature is the fact that SECO modeling is still very free, varying the level of abstraction, even with the SSN notation. Static and dynamic aspects of blockchain modeling have already been studied in the literature.For the educational domain, with a strong data integration characteristic, the use of blockchain requires careful modeling, as there are many technologies involved, each with particular characteristics that must be considered in the application design. In this sense, modeling the architecture of educational applications that commonly integrate with several other applications (e.g., financial, academic management, issuing certificates, assessment) can benefit from a SECO model, as the global and relationship view can minimize architectural problems and dependencies.

### 5.4. Maintenance and Evolution of the Central Platform

Due to technological changes, many maintenance and evolutions can occur on a central platform. Changes in functionality, such as new user profiles that have unique needs or simply changes in scope, impact the central platform. SECO enables the vision of customers, users, and suppliers, which impacts the evolution and maintenance of the central platform. For the educational domain, each institution can have its certificate access application, which accesses a blockchain base. This application can have web and mobile versions and customized features for different educational institutions, which must be considered when maintaining the systems. Blockchain may not impact as much from the functionality perspective. However, it can have a high impact if the structure stored in the blocks varies, which directly affects the database and the applications.

### 5.5. Social Aspects

A blockchain application involves different stakeholders and can impact the users' lives on different levels. Understanding how a blockchain system can impact users is a way to assess service improvements and the level of digital transformation. Educ-Dapp impacts students who need access to their certification, also the HEIs involve public staff to interact with the system and provide the correct information for end-users. Another social aspect involved by blockchain technology is how companies (public or private) use it, what are the advantages and disadvantages that come from that context and impacts their users, how we as researchers can develop blockchain systems to maximize the benefits and improve users work environment to make easier to perform their tasks. From a development perspective, there is a need for blockchain training to provide integrated solutions. This enables the creation of courses, inclusion in curricula and the creation of an effective blockchain development base.

### 5.6. Economic Aspects

One challenge is the cost-benefit analysis of migrating production applications that work to new blockchain infrastructure. Many educational institutions have their infrastructures, and when using blockchain, either build new infrastructure or use a third party base. Data access must also be designed to be free or paid. This depends on the business model to be used and impacts end-users. The learning curve for developing blockchain applications should also be analyzed, as it has a cost. Developers must prepare for this new technology and integration aspects between systems. Furthermore, the change of actors and relationships in SECO can also have an economic impact, for example a component that was open source and is no longer open source, or a service that was free and changes its pricing plan.

## 6. Final Remarks

This research presented the Educ-Dapp educational application, which uses blockchain to treat the students' certificates from higher education institutions. Despite the application is a prototype, it is understood that blockchain provides suitable solutions for integration, data traceability, and security, attractive features for educational domain. The main contributions of this work are: (i) SSN model of an educational application that uses blockchain resources; (ii) dissemination of blockchain technology in educational domain; and (iii) a set of research opportunities related to SECO and blockchain for educational domain.

Some research limitations can be listed. The prototype was evaluated by experts in the educational field, but not from the SECO viewpoint, only from the application. In addition, the SECO concepts was not presented to the participants, since the evaluation was only of the application. There was also no validation of the SSN diagram by experts or stakeholders of the Educ-Dapp SECO. Some technical challenges occurred in the application evaluation, as some users did not want to install some technologies, which denotes the dependence on specific technologies such as Metamask or Ethereum. As future work, we intend to deepen each presented challenge to collaborate with the blockchain community, specifically in the educational field.

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