

Can Blockchain Technology Facilitate the Unbundling of Higher Education

Ira Sood¹^a, Henri Pirkkalainen¹^b and Anthony F. Camilleri²^c

¹Unit of Information and Knowledge Management, Tampere University, PO Box 541, 33101 Tampere, Finland

²Knowledge Innovation Centre, 119, Triq il-Qasam, Swieqi SWQ3027, Malta

Keywords: Higher Education, Unbundling, Blockchain Technology.

Abstract: Higher education is in dire need of reform in order keep up with the rapidly advancing technology and student needs surrounding it. Unbundling of higher education has been discussed as one of the potential directions of reform. Prior research has suggested that blockchain technology has the potential to play an essential role in facilitating such change in higher education. However, the ways in which blockchain can facilitate unbundling remains missing in literature. We specifically address this gap. This study reports on a qualitative study with 17 respondents in the field of higher education as well as blockchain technology. Our findings indicate three specific areas of unbundling that can be facilitated with blockchain technology, namely new governance model, modular student experience and enhanced faculty roles. We explain how four key characteristics of blockchain (i.e., decentralization, immutability, pseudonymity and self-sovereignty) facilitate those three areas of unbundling in specific. The findings of this study can aid both the universities and the blockchain community in understanding how the concept of blockchain can be embedded effectively in the unbundling of higher education.

1 INTRODUCTION

Higher education institutions (HEIs) are facing increasing pressure to change for the benefit of the students. For example, the diploma supplements commonly used today do not clearly convey the competences developed by a student over the course of his/her education. Due to this lack of transparency, major companies have made active efforts to remove the requirement of degree certificates from their hiring policy (Glassdoor, 2018). Moreover, the ‘one size fits all’ model of learning does not correspond with the needs of lifelong personalized learning (Bass & Eynon, 2017). However, HEIs have attempted to transform their traditional models by unbundling (Israel, 2015). Many institutions have made efforts to unbundle, for example, by extending their curricula by collaborating with MOOC providers (Davis et al., 2014; EADTU, 2018).

Blockchain has been touted as a potential technology for transforming higher education

(Camilleri & Grech, 2017). Some of the major efforts in the area have come in the form of storing and issuing of blockchain based credentials by higher education institutions such as MIT, UK Open University, University of Malta and University of Nicosia among others (Camilleri & Grech, 2017; Nascimento et. al, 2019). This stream of literature suggests that the decentralized and immutable nature of blockchain offers possibilities to unbundle the traditional structure of higher education. Despite the potential, the current theoretical and empirical understanding of the use for blockchain for education is limited. To our best knowledge, there is no research that specifically links the use of blockchain technology to unbundling of higher education. This paper is an attempt to bridge this research gap.

The main research question that this study attempts to answer is: *How does blockchain technology facilitate unbundling of higher education?* We adopted a qualitative study with 17 semi structured interviews with experts in the field of

^a <https://orcid.org/0000-0001-6172-6428>

^b <https://orcid.org/0000-0002-5389-7363>

^c <https://orcid.org/0000-0003-0235-1499>

higher education and blockchain technology. The qualitative study aimed at examining specific characteristics of blockchain and linking them to areas of unbundling where these characteristics could be utilized to facilitate change.

2 THEORETICAL BACKGROUND

2.1 Unbundling of Higher Education

Unbundling can be simply defined as the process of breaking something into smaller and modular fragments (McCowan, 2017). A modular education splits the different aspects of a traditional degree into separate modules so that it can best serve the interests of the consumer that they were designed for in the first place: students. In higher education, the incoming of modularization has been much slower as compared to other industries, largely driven by the for-profit sector (Robertson & Komljenovic, 2016; McCowan, 2017). Universities have more or less continued to exist within the traditionally established models and it is hard to measure the economic impact of their services on society and industry in general (McCowan, 2017; Bok, 2003).

Unbundling in higher education has been driven by change drivers some of which are technological in nature while others can be linked to the changes occurring in the socio-political and cultural environment and the opportunities arising from that. First, the digital content space has been revolutionized, hence, the number of non-traditional knowledge providers (Udacity, Coursera, edX and others) has increased enormously¹, moving students towards personalized study pathways (Horn, 2014). Second, the student demographics and faculty roles have rapidly evolved over the years with increased emphasis on lifelong learning. The demographical composition of students today is much different and as such the 'one size fits all' model fails to provide for every sub section of learners (Mintz, 2015). Third, universities constantly struggle between trying to control costs while maintaining high quality among all of its different elements, which is not a sustainable business model (Christensen et al., 2011).

Many private entities are increasingly involved in planning curriculum alongside universities in order to create offerings that focus on general cognitive ability

and soft skills instead of grades and seat time (Friedman, 2014). Lastly, due to a clear lack of trust and consensus among most international institutions, recognition of prior learning is still a complex and difficult process in spite of tools such as European Credit Transfer and Accumulation System (ECTS) (Karran, 2004).

2.2 Blockchain Technology

Blockchain technology is based on the concept of a shared, decentralized and distributed ledger that can be used to record any form of transactions across several computers (also called a peer-to-peer network). The information related to transactions on a blockchain is stored in blocks where each proceeding block contains a reference to the hash (identifier) of the previous block, thus connecting them in a chain (Lansiti & Lakhani, 2017; Gupta, 2017). Each entry made on a blockchain is permanent, transparent and searchable and can be used to record anything including contracts, assets, identities or any other information that can be represented digitally (Camilleri & Grech, 2017).

The characteristics of blockchain overlap with each other to a certain extent. In conventional databases, all the information is kept and controlled by a centralized system that is usually owned by third parties (e.g. Facebook, Google, NASDAQ, Universities). Blockchain enables *decentralization*, which refers to the creation of a decentralized management where data and information are in a peer to peer network containing multiple nodes (Hence, multiple points of failure) (Turkanovic et al., 2017; Chen et al., 2018). *Immutability* refers to the property of being unchanged over time. Immutability of blockchain offers increased transparency, data consistency and integrity meanwhile preventing data forgery and theft (Boucher et al., 2017). Blockchain attempts to ensure anonymity by employing a public-private key mechanism (Nakamoto, 2008). Most researchers have maintained that blockchain offers *Pseudonymity* instead of complete anonymity (Lansiti & Lakhani, 2017; Boucher et al., 2017; English et al., 2016, Reid & Harrigan, 2013). In other words, all transactions are visible but it is not easy to link the information to individual identities. Blockchain inherently promotes data owners' right to own their data without the need to go through an intermediary (Camilleri & Grech, 2017). *Self-*

¹ A review by Class Central states that by 2017 there were 81 million registered users studying online courses with at least 800 universities participating.

sovereignty enables the creation of self-sovereign identities that would allow learners to take ownership of their data and control how, when and who accesses their data (Lilic, 2015).

3 METHOD AND RESULTS

3.1 Methods

The data was collected using semi-structured interviews. Semi structured interviews were chosen as they offer a way to identify areas of interest and viewpoints to which literature does not point to (Berg, 2007). We interviewed 17 respondents who were in a position to answer questions that are both related to unbundling and blockchain. The respondents were from Europe and represented a diversity of roles in higher education (E.g. Executives from universities, consultancies and non-profits). Semi structured in depth interviews were conducted either in person or via online conferencing, using tools such as Skype for Business. The length of the interviews was between 35 minutes to 70 minutes. The interviews were recorded, manually transcribed and iteratively analysed to find commonalities.

3.2 Unbundling of Higher Education

Our findings revealed three key aspects that drive the need for unbundling, namely, *new governance models*, *modular student experience* and *enhanced faculty roles*. Next, each of these are examined individually.

3.2.1 New Governance Models

Respondents pointed out the need for universities to abandon outdated business models and focus on their core competence. One respondent raised a legitimate concern regarding the incentive models as well as evaluation models that drive the universities in general.

“From a higher education management perspective, depending on the country, a university in public sector might get incentives based on something like the number of students they enrol” - Director (Consultancy)

The need for governance models to evolve in the interests of students and educators was pointed out as an important move in developing new models.

“There is a huge case to make when arguing about the indicators for teaching excellence. If you are an excellent teacher but an average researcher you will not progress in an institution even if you are the top rated teacher that there is, at least in most places in Europe. This is a good system for producing researchers but it is also a holdover from the time when universities' higher level of academia meant you were going to become a researcher. In today's era of degree inflation, where master's degree is nearly table stakes to an entry level job, these types of indicators start to seem a little outdated”- Director (Consultancy)

Furthermore, the respondents stated that there is a need to re-recognize student as the customer when it comes to higher education. The limitations imposed on universities when it comes to their ability to innovate also arises from the fact that they are usually evaluated and funded based on the number of graduates produced by organizations such as ministries who are less in touch with the ground reality as opposed to the universities themselves.

“In the current system the customer is not the student but it is the ministry of education because they have the money and hence, have control. The laws from ministry of education forbid some changes that universities would themselves like to implement.”- Vice dean for education (Technical University)

Some respondents highlighted the need for universities to be enabled to trust other universities through a network of secure and trustworthy credentials.

“We have produced a barrage of tools: ECTS, diploma supplement, qualification frameworks, 3 cycle systems, multi lingual translation databases etc. to build equivalence among universities. But all of that is still based around the idea that ‘we will trust your institution but not completely’. Everybody wants to keep autonomy over their institution, where institutions collaborate with other institutions but do not fully trust them”-Director (Consultancy)

3.2.2 Modular Student Experience

The need to provide for lifelong learning has been one of the key driving factors for unbundling. One respondent shed some light on the need to acknowledge learning that happens outside the context of a traditional classroom.

“A basic university degree is not enough for your life time. We see more need for lifelong learning and

different kinds of solutions to provide for that. Mainly because learning does not just happen in a classroom, it keeps happening everywhere, but what we don't have right now is a system that gives us credit for the learning we do everywhere”- Continuing Education Specialist (Technical University)

Other respondents similarly echoed their views on the importance of flexible learning models that are personalized in nature and offer recognition mechanisms for students meanwhile, keeping in mind the different learning pathways that might be suited to specific learners. These mechanisms would then make student mobility easy by default.

“It is important to understand that people learn in different ways. Some people are going to take a huge leap while some will learn gradually. Another thing is to understand the motivation behind learning and in some cases the personality of the learner itself. We need to cater to these needs. The popularity of something like badges and MOOCs is a clear indication that students need means of learning that are well suited and personalized to their needs” -eLearning Specialist (University of Applied Sciences)

One respondent pointed out the far-reaching socio-political aspects involving higher education and how a modular educational offer could advantage those who need it the most.

“We usually talk about a European middle class background, where you graduate high school, go to university and get a job. But majority of students in the world do not fit into that bracket. For them the idea of pursuing a full time educational degree might just be impossible. So the idea of breaking down a qualification into modules, some of which might even be free is very useful for them. Imagine the opportunity”- Pro vice chancellor (Distance Education University)

The massive disconnect between university learning and the needs of the labour market has also been identified as one of the aspects facilitating the move towards unbundling. One of the respondents summed it up as follows

“The emphasis should be towards quick responses for industrial demands and hence fulfil the lack of competent workers. There is the question that to what extent can we fulfil that with our traditional degree programmes due to a lack of flexible learning

pathways and slow speed of response”- Vice dean (Technical University)

One of the respondents identified the same disconnect using a highly relevant example of an event similar to Brexit.

“If you live in a society where one day something like Brexit happens, that will change your life a lot in the coming 5 years. The knowledge being developed at universities does not teach students to deal with uncertainties of such kind with which we are very surrounded right now”- Vice President (HEI association)

3.2.3 Enhanced Faculty Roles

Some of the respondents have pointed out that unbundling certain aspects of HE for instance, the curriculum could reduce the workload of the educators. They could then focus on their own personal development needs and move towards mentorship roles for students.

“In the current model teachers have a lot of burden on them. For e.g. they have to do a lot of research in order to get more funding for the university and themselves. Besides that, they have to divide time with teaching activities and other personnel work. There is hardly any time for personal development”- Researcher (Consultancy)

Some respondents hinted towards the emergence of new roles such as that of a ‘co-curator’ whose purpose would be to direct students in finding the pathways that fit their needs and interests in a balanced way. That would be made possible in an unbundled scenario where teachers have the resources to devote for guiding students.

“There will be a need for replicating this function from the world of art, which we call ‘co-curation’. The function of a curator will be very important and will be needed to orient and guide students in their efforts of studying in a modularized ecosystem so that they can bring these modules together in larger sense-making experience. This guided experience is very necessary”- President (HEI association)

3.3 Role of Blockchain Technology in Unbundling Higher Education

3.3.1 Blockchain Facilitating New Governance Models

Our findings point out that when the question of trust between universities arises, blockchain technology holds some answers. Blockchain could provide a system of governance that is based on decentralized trust. In the paper-based credential world, we are currently working in a very decentralized ecosystem already. There is no central educational network that makes decisions on defining and storing credentials, research or content. Almost everything is agreed upon by consensus among the educational community. The way that consensus is achieved is interesting to note, because usually it is based on personal relationships.

“The whole concept of academic freedom is predicated on the idea that there should be no single central source of truth for these things. Blockchain is a technology that is built with these principles inside the technology itself. So instead of saying we have a fully decentralized human network but we are going to need a centralized computer network, we can actually have a computer network that can reflect the reality of how our education system actually works”- Director (Consultancy)

The same views were supported by other respondents who pointed out the need for a blockchain based credential system using non fungible tokens which are in alignment with the non-fungible nature of credentials themselves.

“If you have a house you usually cannot split it into half, similarly, in our physical wallet, we have money which is fungible and then other things such as our credit cards, driver license etc. that are non-fungible. With non-fungible tokens we are just upgrading the system to something we know already occurs in the real world”- CEO (Blockchain startup)

The characteristics of blockchain make way for a possibility to build a digital credential storage and verification system that universities can trust unanimously.

“Once a trust network is created it will be technically possible for learners to use their credentials as a valid currency anywhere in the world by making it possible for universities to verify their authenticity. The universities may still not place the same kind of

value on credentials obtained from outside their own university but they would nevertheless, be able to verify them securely over the blockchain network that they are a part of”- COO (Open Education Non-profit)

3.3.2 Blockchain Facilitates Modular Student Experience

The respondents stated that the issue of linking the digital credentials to their rightful owner has remained largely unacknowledged. A digital identity wallet owned by a student which is encrypted via the public key infrastructure possible in a blockchain could serve as an immutable record of a learner’s academic credentials across multiple institutions as well as those earned outside an institution. Thus, enabling learners to build a portfolio of traditional and stackable credentials. Easily verifiable credentials could also reduce cost burden and create a seamless verification process not just for the universities but also for students and their future employers.

“In education blockchain could play the role, firstly of verification, so verifying that learning has really happened, all claims by learners and workers are real (and verifiable). Secondly, blockchain could also help on any management and reputational support related to student identity. Thus, allowing students to keep their data personal while releasing various elements for verification” –Director (Open University R&D Lab)

Some respondents stated that verifiable educational wallets or even digital CVs could help enhance student mobility both within the educational and employment context. This would also contribute to providing increased flexibility when it comes to learners.

“Blockchain technology can potentially solve the problem of identity and mobility by giving students individual wallets to use when they move from one context to another in terms of location or setting” - Pro vice chancellor (Distance Education University)

“If we have a blockchain network validating and approving the trustworthiness of credentials, then on top of that we can have multiple layers such as content offering. Its a perfect platform to understand and respond to the learners needs of mobility, flexibility and verifiability.”-COO (Open Education Non-profit)

Other respondents pointed out the enormous reduction of costs and time consumed that an automatic credential verification system could bring about

“Blockchain could cause dramatic lowering of process costs for things like issuing certificates, verifying certificates. It is a very resource and time intensive process. I have heard employers complain that they waited so long for someone’s credentials to be verified that they actually hired the person before the process ended”- Director (Open University R&D Lab

3.3.3 Blockchain Facilitates Enhanced Faculty Roles

If students are able to obtain content resulting in credentials in a trust based ecosystem from different sources, faculty can move their focus from classroom lectures to creation of high quality online content which is up to date and shift to the para academic roles.

“In today’s age where everyone is online and has access to unlimited amount of educational content, a blockchain enabled network could be instrumental in efficient sharing of this content. This would not only save money and administrative effort but will also give educators time to reflect on their personal development and other aspects such as student mentorship”- Researcher (Consultancy)

At the same time, self-executing smart contracts could take over most of the administrative work from a university and bring down the overhead costs.

“You can build automated algorithms in the blockchain via smart contracts. This will remove a massive amount of administrative overhead from universities. Smart contracts can also give researchers notarise ownership of their self produced content”- Researcher (Technical University)

4 DISCUSSION

Our findings indicated 1) three aspects how unbundling can happen in higher education institutions and 2) a way how blockchain can facilitate each aspect of unbundling. Figure 1 sums up the key relationships between the findings. It should be noted that blockchain is an essential driver for each of the three aspects of unbundling. Although the technology itself can be broken down to several characteristics, our findings indicate that these characteristics collectively aid in only the three identified aspects of unbundling. For example, in terms of new governance models, blockchain offers the possibility to build a digital credential storage and verification system that universities can trust unanimously. In terms of modular experience, the key benefits come from the way that blockchain enables

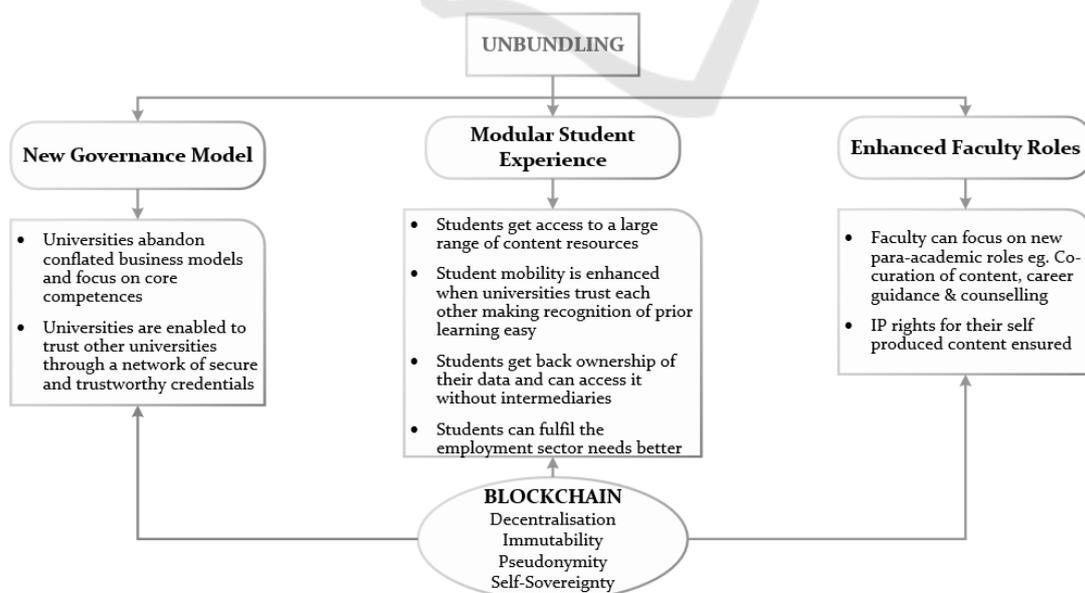


Figure 1: Research model on blockchain facilitating the unbundling of education.

ownership of data and automatic recognition mechanisms, facilitating mobility and sovereign identities for students. In terms of enhanced faculty roles, blockchain can potentially provide an ecosystem where students can go beyond their localised faculty to access resources, thus, creating scope for faculty to focus on para-academic roles.

4.1 Contributions

The theoretical contribution of this article is the linking of blockchain and unbundling of education. We identified an important opportunity for research because the linkage of blockchain and its key characteristics has not been addressed in prior literature. Our approach breaks down an unbundled higher education into distinct units for better understanding and analyses each unit with respect to the ability of blockchain technology to tackle it based on its theoretical strengths. Our study indicated four key characteristics that are essential to blockchain in general, decentralization, immutability, pseudonymity and self-sovereignty. Further, according to Acheampong (2018) & Camilleri & Grech (2017), advancements in blockchain technology have not yet been employed when it comes to higher education. Although many interesting pilots seem to be ongoing, there have not yet been any concrete results in education to the same extent as in other industries. We believe our findings are an important step forward in the literature in order to steer the ongoing adoption of blockchain in higher education.

This study aids universities that are exploring their options when it comes to modularizing their offer by providing an understanding of its numerous implications. Unbundling might suit the needs of some universities better than others, thus, it is essential for universities to understand their own needs first. The blockchain industry is rather new and still developing, therefore, this study may contribute in creating an understanding for businesses interested in developing higher education sector regarding the needs of a university when it comes to adopting any blockchain based solution. The technical characteristics of blockchain suit the needs of an unbundled university, however, that cannot be put into practice without an insight into the different elements that make up a university structure. Thus, this research might aid that understanding.

4.2 Research Limitations and Future Research

There are some observable limitations which need to be paid attention to in this research. Most of them are linked to the scarcity of knowledge resources related to a technology still in its infancy and those related to the methodology used. Blockchain as a technology is fairly new and developing continuously. As such the literature resources available are rather limited. The resources shrink further when blockchain technology is studied in reference to the education sector. There are very few blockchain experts available and people are still trying to figure out the ins and outs of the technology. There is also a lack of existing use cases of blockchain technology in public sector, which makes the process of understanding and analysing it in a pragmatic sense difficult.

The research methodology used in this study was qualitative semi-structured interviews which has its own advantages and disadvantages. Qualitative interviews can lead to reduced reliability because of the unstructured nature of the data collected (Bryman & Bell, 2015). Therefore, the reliability of the results of this thesis might be affected by similar factors. During the interviews, it was challenging for the author to guide the conversation in the desired direction, many times questions were left unasked. This might lead to incomplete results. Another challenge was to find people with common expertise in the field of higher education as well as blockchain technology. While there are quite a few of such interviews included in the thesis, there were some where the focus area was only one of those subjects. Based on the results obtained in such interviews, conclusions were drawn from the needs and issues identified by interviewees in their own experience. Qualitative interviews are also open to interpretation and personal biases and opinions often tend to seep in. Another major limitation of this research was the focus on only one aspect of unbundling (curricula) in the conducted interviews. This reduced the scope of the study in some ways.

In the short term, more academics need to venture into research areas tackling the immense possibilities that arise from unbundling certain aspects of education. Something like blockchain technology also needs to be explored from an academic point of view for the vast potential it offers when it comes to benefits such as educational equality and student centric education models. It would not be realistic to expect something as radical as blockchain technology to be put into practical use without the support of policymakers. Therefore, the policy regulations

needed to be put in place both for blockchain technology in general as well as those specific to the education sector must be researched. In the long term, some blockchain related pilots should be tested in live environment to understand the implications it can possibly cause to the current landscape.

REFERENCES

- Bass, R. & Eynon, B. (2017). From Unbundling to Rebundling: Design Principles for Transforming Institutions in the New Digital Ecosystem, *Change: The Magazine of Higher Learning*, 49:2, 8-17, DOI:10.1080/00091383.2017.1286211
- Berg, B. L. (2007). *Qualitative research methods for the social sciences*. London: Pearson.
- Bok, D. (2003). *Universities in the marketplace: The commercialization of higher education*. Princeton, NJ: Princeton University Press.
- Boucher, P., Nascimento, S. & Kritikos, M. (2017). How blockchain technology could change our lives. European Parliamentary Research Service. Scientific Foresight Unit.
- Camilleri, A. & Grech, A. (2017). *Blockchain in Education*. JRC Science for Policy Report. European Commission.
- Chen, G., Xu, B., Lu, M., & Chen, N.S. (2018). Exploring blockchain technology and its potential applications for education. *Smart Learning Environments*, 5(1), 1.
- Christensen, C., Horn, M., Soares, L. & Caldera, L. (2011). *Disrupting College: How Disruptive Innovation Can Deliver Quality and Affordability to Postsecondary Education*. 1st ed. Innosight Institute.
- Craig, R. & Williams, A. (2015). Data, Technology, and the Great Unbundling of Higher Education. *50(5) Educause Review* 11.
- Davis, H. C., Dickens, K., Leon U., Manuel, S. V., Maria D.M. & White, S. (2014). MOOCs for Universities and Learners an analysis of motivating factors. At 6th International Conference on Computer Supported Education 6th International Conference on Computer Supported Education.
- English, M., Domingue, J., Dimon, J., & Auer, S. (2016). *Block Chain Technologies & The Semantic Web: A Framework for Symbiotic Development*. Computer Science Conference for University of Bonn Students 47-61
- Friedman, T.L. (2014). How to Get a Job at Google. Retrieved from New York Times: http://www.nytimes.com/2014/02/23/opinion/sunday/friedman-how-to-get-a-job-at-google.html?_r=0
- Glassdoor. (2018). 15 More Companies That No Longer Require a Degree. Retrieved from <https://www.glassdoor.com/blog/no-degree-required/>
- Gupta, V. (2017). A Brief History of Blockchain. *Harvard Business Review*. Retrieved 11 October 2018, from <https://hbr.org/2017/02/a-brief-history-of-blockchain>
- Horn, M. (2014). *Unbundling and re-bundling in higher education*. Clayton Christensen Institute [online] 10 June. Available from: <http://www.christenseninstitute.org/unbundling-and-re-bundling-in-higher-education/>
- Horn, M. (2017). Will Alternative Credentials Replace College Degrees? *Forbes* Retrieved 22 March 2018, from <https://www.forbes.com/sites/michaelhorn/2017/01/20/will-alternative-credentials-replace-college-degrees/#74743eb61b0e>
- Israel, M.J. (2015). Effectiveness of Integrating MOOCs in Traditional Classrooms for Undergraduate Students. *International Review of Research in Open and Distributed Learning*, v16 n5 p102-118.
- Jacobs, J. (2014). *Beyond the Factory Model*. Educationnext.org. Retrieved from https://www.educationnext.org/files/ednext_XIV_4_jacobs.pdf
- Karran T. (2004). Achieving Bologna Convergence: Is ECTS Failing to Make the Grade? *Higher Education in Europe* 29(3):411-421
- Lansiti, M. & Lakhani K. (2017). The truth about Blockchain. *Harvard Business Review*
- Lilic, J. (2015). uPort; A Glimpse into a Next Generation Self Sovereign Identity System. Available at: <https://www.linkedin.com/pulse/uport-glimpse-next-generation-self-sovereign-identity-john-lilic>
- McCowan T. (2017). Higher education, unbundling, and the end of the university as we know it, *Oxford Review of Education*
- Mintz, S. (2015). Who Are Our Students? Inside Higher Ed. Available from: <https://www.insidehighered.com/blogs/higher-ed-beta/who-are-our-students>
- Nakamoto, S. (2008). *Bitcoin: A Peer-to-Peer Electronic Cash System*. <https://bitcoin.org/bitcoin.pdf>
- Nascimento S. (ed), Pólvara A. (ed), Anderberg A., Andonova E., Bellia M., Calès L., Inamorato dos Santos A., Kounelis I., Nai Fovino I., Petracco Giudici M., Papanagiotou E., Sobolewski M., Rossetti F., Spirito L. (2019). *Blockchain Now And Tomorrow: Assessing Multidimensional Impacts of Distributed Ledger Technologies*, EUR 29813 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-08977-3, doi:10.2760/901029, JRC117255
- Reid, F. & Harrigan, M. (2013). An analysis of anonymity in the bitcoin system. *Security and privacy in social networks*. Springer New York, pp. 197-223.
- Robertson, S. L., & Komljenovic, J. (2016). Unbundling the university and making higher education markets. In A. Verger, C. Lubienski, & G. Steiner-Kamsi (Eds.), *World yearbook in education (Global edu)*. London: Routledge
- Turkanovic, M., Hölbl, M., Kopic, K., Hericko, M., & Kamisalic, A. (2018). EduCTX: A blockchain-based higher education credit platform. *IEEE Access*, 6, 5112-5127.