Teaching Applications and Implications of Blockchain via Project-Based Learning: A Case Study

Kevin Mentzer
kmentzer@bryant.edu
Information Systems and Analytics Department
Bryant University
Smithfield, RI 02917, USA

Mark Frydenberg
mfrydenberg@bentley.edu

David J. Yates
dyates@bentley.edu

Computer Information Systems Department
Bentley University
Waltham, MA 02452, USA

Abstract

This paper presents student projects analyzing or using blockchain technologies, created by students enrolled in courses dedicated to teaching blockchain, at two different universities during the 2018-2019 academic year. Students explored perceptions related to storing private healthcare information on a blockchain, managing the security of Internet of Things devices, maintaining public governmental records, and creating smart contracts. The course designs, which were centered around project-based learning, include self-regulated learning and peer feedback as ways to improve student learning. Students either wrote a research paper or worked in teams on a programming project to build and deploy a blockchain-based application using Solidity, a programming language for writing smart contracts on various blockchain platforms. For select student papers, this case study describes research methods and outcomes and how students worked together or made use of peer feedback to improve upon drafts of research questions and abstracts. For a development project in Solidity, this study presents the issues at hand along with interview results that guided the implementation. Teams shared lessons learned with other teams through a weekly status report to the whole class. While available support for the Solidity teams was not ideal, students learned to use available online resources for creating and testing smart contracts. Our findings suggest that a project-based learning approach is an effective way for students to expand and develop their knowledge of emerging technologies, like blockchain, and apply it in a variety of industries.

Keywords: blockchain, distributed ledger, emerging technologies, project-based learning, self-regulated learning, peer learning

1. INTRODUCTION

Project-based learning (PjBL) is a pedagogical approach in which students take primary responsibility for their learning through focused inquiry (Barron et al., 1998; Gordon & Brayshaw, 2008; Thomas, 2000). One area where this approach has been successful is learning and applying an emerging technology in the context of a project that students define and develop (Bell, 2010; Gibson, O'Reilly & Hughes, 2002; Yue, Chandrasekar & Gullapall, 2019).

Blockchain is an important and timely example of an emerging technology. It also has the potential to be disruptive in many different industries (Bambara & Allen et al., 2018). Such potentially disruptive technologies are of are interest to students since they present opportunities to consider and study applications that are new, different, and exciting. Blockchain's first use cases were to mediate payments, which led to blockchain's early adoption in financial services (Hileman & Rauchs, 2017). More recently blockchain has been proposed for a much more diverse range of applications (Bashir, 2018).

As summarized in Figure 1, a well-designed project-based learning experience is one in which the student has ownership of the project. Furthermore, student learning outcomes are improved if the project demands both creativity and critical thinking (Rice & Shannon, 2016; Weimer, 2013). Finally, in many learner-centered environments, different forms of collaboration, e.g., peer learning and peer teaching, often improve the quality of course projects (Aditomo & Goodyear et al., 2013; Jackson & Bruegmann, 2009; Stefanou & Stolk et al., 2013).

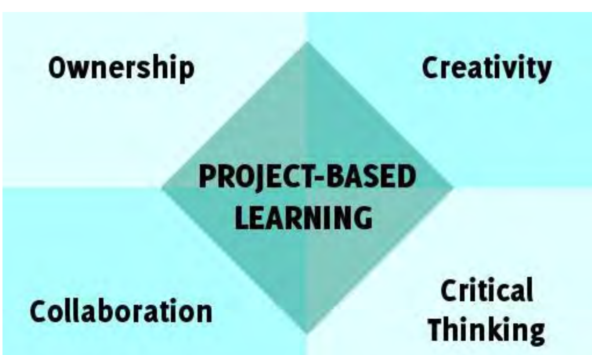

Figure 1. Key aspects of project-based learning [Adapted from (Stefanou & Stolk et al., 2013)]

A central goal of this study is to understand how students learned and applied the fundamentals of blockchain technology via PjBL. The remainder of this paper is organized as follows: Section 2 provides a brief overview of blockchain technology. Section 3 describes how the learning goals of blockchain courses at Bryant University and Bentley University were supported by PjBL. Section 4 presents and analyzes four student projects, and finally we conclude with some reflections and lessons learned after delivering these courses.

2. BLOCKCHAIN OVERVIEW

A blockchain is a continuously growing ledger of transactions that are grouped into blocks. Each block is linked to the prior block and secured using cryptography. By design, a blockchain is immutable, meaning that it is highly resistant to modification of the data that has been recorded on the chain. The ledger is distributed amongst all nodes in the network. Each node has a copy of the entire transaction history. When a new transaction is generated, all nodes in the network verify the transaction; this is known as consensus.

A blockchain can be either permissioned or permissionless. Permissionless blockchains, like Bitcoin and Ethereum, mean that anyone can participate by generating transactions while in a permissioned chain only those with permissions can generate transactions. In addition, blockchains can be either public or private. This indicates who can see the transaction history. Anyone can see the history in a public blockchain while only certain entities can see the transactions in a private blockchain (Norman, 2017).

The initial concept behind blockchain technology was produced in a white paper by the anonymous author Satoshi Nakamoto (2008) and was used as the foundation on which the Bitcoin cryptocurrency was launched. Since its launch, Bitcoin has grown to a market cap of $151B (as of October 1, 2019).

However, the Bitcoin blockchain is limited in functionality to a single application, that being the cryptocurrency Bitcoin. Others recognized that the underlying blockchain technology could have much wider application with some key changes. In 2014 Anatoli Buterin published a whitepaper that introduced the concept of *smart contracts*, or code that could be embedded and executed on the blockchain (Buterin, 2014). This became the foundation for the Ethereum blockchain. While the Ethereum blockchain has a cryptocurrency like Bitcoin, it also supports a myriad of other applications.

While both Bitcoin and Ethereum are public blockchains, meaning that anyone can see any and all transactions that occur on the blockchain, businesses often need additional flexibility to manage who can participate in and view transactions. As a result, in late 2015 the Linux Foundation launched Hyperledger which has emerged as a leading blockchain for developing enterprise applications (Sharma, 2019) and is often used by businesses in areas, such as supply chain, where transactions may be visible based on permissions (Wüst & Gervais, 2018).

Looking at a recent Gartner Emerging Technologies Hype Cycle (Gartner, 2018) shown in Appendix A, Figure 5, one can see that blockchain is moving away from the peak of inflated expectations and towards the trough of disillusionment. As a result, one could surmise that the interest in blockchain will wain overall. However, as Pisa (2018) argues, the early excitement of blockchain was based on the public, permissionless blockchains like Bitcoin and Ethereum and a second wave of interest may be emerging around permissioned ledgers such as Hyperledger.

While blockchain emerged as a platform by which a cryptocurrency could be maintained, its applications are far-reaching and well beyond financial uses. Blockchain has application in areas such as digital supply chains (Korpela, Hallikas, & Dahlberg, 2017; Tian, 2016), digital government, including land records and voting (Jun, 2018; Ølnes, Ubacht, & Janssen, 2017), and gaming (Gainsbury & Blaszczynski, 2017; Piasecki, 2016), just to name a few.

3. PROJECT-BASED LEARNING AND LEARNING GOALS

According to Blumenfeld et al. (1991), the essence of project-based learning is that a question or problem serves to organize and drive student activities. Although the central features and benefits of PjBL are well understood (e.g., see Figure 1), specific implementations of this instructional approach vary widely (Aditomo & Goodyear et al., 2013; Zimmerman, 1990). For example, Thomas (2000) and Helle et al. (2006) agree that projects should have students "encounter (and struggle with) the central concepts and principles of a discipline" (Thomas, 2000, p. 3). Furthermore, in a post-secondary setting, projects should engage students in a significant constructivist activity resulting in a thesis, report, model, design plan, computer program, composition, or performance (Helle, Tynjälä & Olkinuora, 2006). Because of the focus on business education at both universities involved in this study, Bryant and Bentley feature PjBL as central to our curricula, as it would be in other disciplines, e.g., engineering (Hadim & Esche, 2002). This means that the students in our classes, who were mostly juniors and seniors, had experience working on both team and individual projects before taking our courses.

Many of the outcomes due to PjBL in the context of the courses offered at Bryant and Bentley were consistent. The most successful projects were the ones in which students took the greatest initiative (Weimer, 2013), were most resourceful (Bell, 2010), and worked the hardest (Freire, 1993).

In spite of the common connection to blockchain technology, however, some differences in the educational activities enabled and even catalyzed student projects. The *Introduction to Blockchain* course at Bryant (see Appendix B) was designed for more technically-oriented students with some programming background. Hence students were required to learn Solidity, a programming language for writing smart contracts, and implement a simple smart contract in an Ethereum development environment during the first half of the course. This exercise supported two of the five learning goals of the Bryant course: to enable students to evaluate and develop smart contracts using the Solidity language, and to enable students to recognize the unique challenges of implementing blockchain including the inability to easily change smart contracts and the inability to reverse transactions. (See Appendix B.)

In contrast, the *Blockchain: Applications, Policy and Implications* course at Bentley (see Appendix C) was designed for more managerially-oriented honors students from diverse academic backgrounds. Specifically, the seven students in this class hailed from five different majors. Their initial activities required that they complete selected readings – taken from (Bashir, 2018; De Filippi & Wright, 2018; Hevner & Chatterjee, 2010; Norman, 2017) – and engage in discussions and design exercises in class. Taken together these activities supported the second and third learning goals for this course. (See Appendix C.) Unfortunately, because these honors students were engaging in these instructional activities while also refreshing their skills related to research methods (Saunders, Lewis & Thornhill, 2016), the students often felt overwhelmed by their capstone experience.

Even though the student audiences at Bentley and Bryant were different, the connections between the foundational educational activities and learning goals for each course were similar. For example, in the Bentley course, the critical literature review due in week six helped assure that each student was on a trajectory to conduct original research by having them situate their research project within the current literature. This activity directly supported the fourth and fifth learning goals for the Bentley course. For students on the research track in the Bryant course, the industry-focused midterm paper due in week seven helped assure the rigor and relevance of the final projects and also supported the fifth learning goal for the Bryant course.

As a final note, although self-regulated learning is common in project-focused courses (Saks & Leijen, 2014; Stefanou & Stolk et al., 2013), it played out very differently in our two courses. Discussion of this finding is deferred to Appendix B and Appendix C, after a discussion of student projects in the next section and lessons learned in Section 5.

4. BLOCKCHAIN STUDENT PROJECTS

To successfully complete their coursework students either wrote a research paper, in phases, during the semester or worked in teams on a Solidity programming project. To provide an interesting cross-section of the student projects, we describe four of the sixteen projects in the next four subsections.

Bryant Student Project by **Cayla D'Amico**: Healthcare Privacy

The first student project explores the security concerns related to storing private individual healthcare-related information on the blockchain. This work explores one of the key factors driving blockchain adoption in healthcare, the privacy and security of private health information as well as key factors inhibiting growth, the challenge of an immature infrastructure, and the risks associated with patient-controlled health data (Rabah, 2017). While others (Peterson, Deeduvanu, Kanjamala, & Boles, 2016) have focused on creating blockchain-based solutions for the healthcare industry, they fail to distinguish between the varying types of health data and whether some data is more appropriate for the blockchain than other data. This work intended to extract patient concerns related to different types of health information, which could lead to suggestions on which data might be better received given the challenges of this immature technology.

D'Amico used a survey to elicit responses from 100 individuals ranging in age from 19 to 73. She used her personal network, which included several relatives who work in healthcare, to distribute the survey.

Recognizing that the general public lacks knowledge about blockchain, the survey instead focused on the underlying features that could be enabled using blockchain technology. She found that 75% of the respondents felt confident that their personal data was kept safe and secure. Younger respondents were more likely to trust that their data was secure over older respondents, as shown in Figure 2.

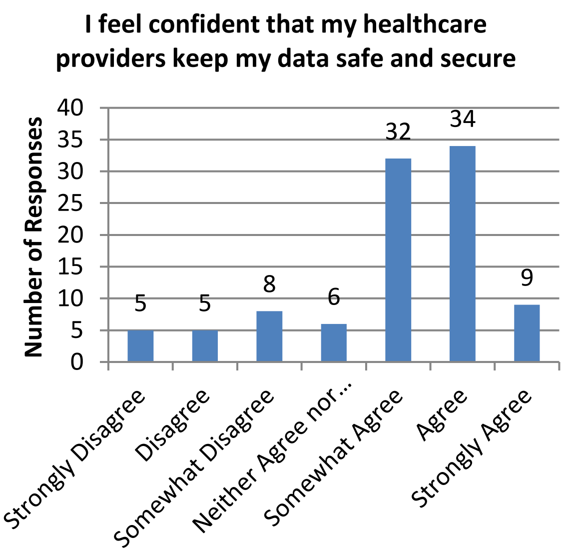

Figure 2. Confidence in security of healthcare data

When asked about specific security concerns (HIPPA, hackers, and poor system controls), the majority were concerned most with hackers, followed by the leaking of the data as a result of poor controls, and finally HIPPA violations, as shown in Figure 3.

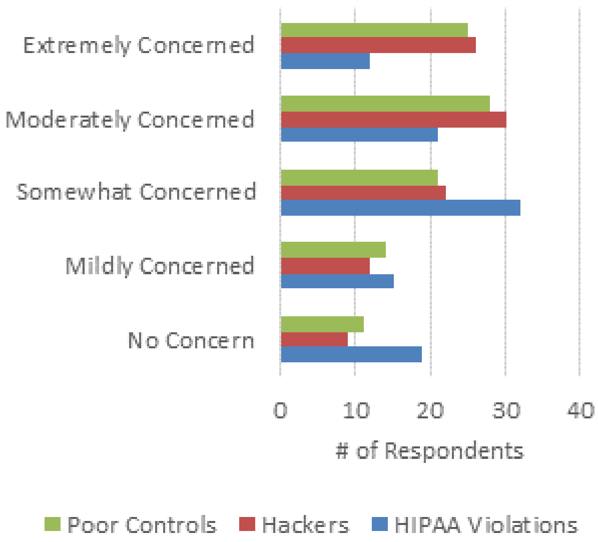

Figure 3. Security concerns related to healthcare data

She then tried to uncover what types of information are less sensitive than others. Her rationale was that pilot studies could potentially focus on data that is of less concern until public confidence in the new technology has been obtained. This was measured by how much money a person would have to be paid to share this information. As shown in Appendix F, Figure 8, respondents were more likely to sell data such as eye and dental history, while respondents were either unwilling to sell, or only would sell for higher amounts, data such as DNA and disease history.

Discussion

Through the weekly status reports, D'Amico was able to discuss and pilot her survey instrument which went through several iterations. Feedback from others helped her add questions that would allow for the accounting of whether someone felt they had personally embarrassing information or not. She was able to explain the constructs she was trying to measure and get feedback on better ways to word questions or ways to ask additional questions to get better responses.

D'Amico's challenge was how to measure the appetite for an emerging technology, knowing that those she would be asking about that technology would have little to no understanding of the technology. In order to do this, D'Amico had to understand the risks and opportunities of the new technology so that she could ask questions related to those risks and opportunities.

Bentley Student Project by Yishan Wang: IoT Security

The second student project explores the benefits of using blockchain to improve the security of Internet of Things (IoT) devices (Sicari, Rizzardi, Grieco, & Coen-Porisini, 2015). Wang used a design science research approach to this problem (Hevner, 2007; Peffers, Tuunanen, Rothenberger, & Chatterjee, 2007; Vaishnavi, Kuechler, & Petter, 2019) targeting a *knowledge contribution* that represented a substantive improvement over existing designs (Gregor & Hevner, 2013). Figure 4 summarizes how Wang's project achieved this goal: IoT security was considered part of an application domain – information security – that is quite mature, since early work in the area dates back to the 1970's (Saltzer & Schroeder, 1975). This placed Wang's study in the *improvement* or *routine design* quadrants in Figure 4. This study was a knowledge contribution that was an *improvement* over prior research since it addressed novel and significant research objectives, which in aggregate represented a research opportunity, placing it in the top left quadrant of this figure.

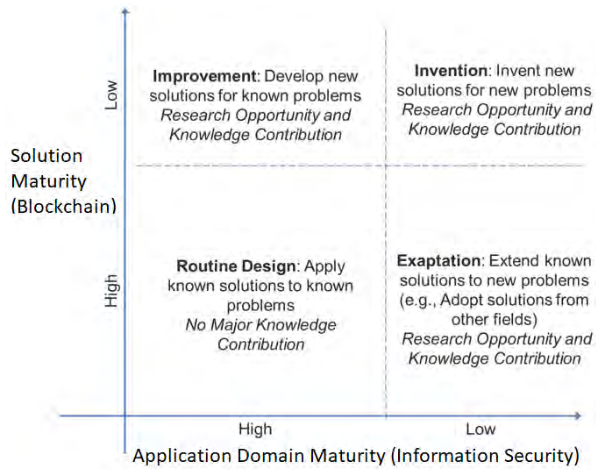

Figure 4. Knowledge contributions of Gregor & Hevner (2013) showing the research potential of blockchain-based solutions to address information security problems

This project had four research objectives:

1. To understand ways that blockchain could improve the confidentiality, integrity, and availability of the data processed and stored in IoT devices.
2. To understand how blockchain can reduce or eliminate single points of failure in IoT device deployments.
3. To assess the role of edge or fog computing and how they can help secure IoT devices.

4. To explore and assess the feasibility of design proposals through analyzing specific applications and use cases.

Perhaps the most important insight of this project was that since almost all design is domain dependent (Suh, 1998), there is no one size fits all solution that solves the "IoT security problem." For example, the security policies and mechanisms used to secure the IoT network in a hospital likely would be different from those used to secure IoT devices in a smart home. Because of this insight, Wang proposed a framework for securing IoT devices with respect to their computation, communication, and storage (McCumber, 1991) by pairing each IoT device (or a set of devices) with a block on a permissioned blockchain. Thus, by leveraging edge computing principles, each "IoT security block" acts as a gateway for three secured services:

A. Access control for invoking underlying services provided by the IoT devices;
B. Information flow management for consuming data elements or data streams produced by the IoT devices; and
C. Monitoring and alert information services about the overall health of the IoT devices, including their security health.

By requiring (and enforcing) that applications only configure, access, and use IoT devices via their associated IoT security block, the IoT devices inherit the security properties of their security block. If the IoT devices can serve as both data sources and data sinks, information flow must be managed and secured in both directions.

Designing for security is never perfect, however, the blockchain-based IoT security framework proposed in this second project, with the appropriate assurance (Bishop, 2018), would provide robust protection for four out of the Top 10 IoT security vulnerabilities (Paul, 2019):

- Insecure network services;
- Insecure ecosystem interfaces;
- Insufficient privacy protection; and
- Insecure data transfer and storage.

Furthermore, services A, B, and C above could provide some protection against some vulnerabilities in the IoT devices:

- Insecure default settings (e.g., by overriding unsafe default configurations and settings);
- Weak, guessable, or hardcoded passwords (e.g., by blocking access to or securing these insecure interfaces); and
- Lack of device management (e.g., by implementing minimal control and status functions in the security block).

The most interesting use case analysis in this project demonstrated that securing the seven above vulnerabilities would have been sufficient to stop the Mirai botnet attack on the Domain Name System in October 2016 (Kolias, Kambourakis, Stavrou, & Voas, 2017; Tan, 2018).

Unfortunately, within Wang's framework, there are three vulnerabilities that cannot be protected by a permissioned blockchain designed to secure IoT devices:

- Lack of secure update mechanism;
- Use of insecure or outdated components; and
- Lack of physical hardening.

This is because such vulnerabilities typically are present in (or absent from) the design or deployment of the IoT devices themselves.

Peer Assessment and Discussion

Wang's peer, LGZ, provided important comments about Wang's project. LGZ highlighted that Wang's original research question was too vague, and LGZ guided him to narrow it down. He helped Wang expand upon his two broad research objectives ("to understand ways that blockchain can improve the security of IoT from a theoretical perspective" and "to assess the feasibility of this theory based on real-life cases") by providing suggestions to select a more focused course of study. LGZ helped Wang reflect on a path forward: "You need to be clearer on which of the multiple aspects of improvement you will focus on. Perhaps ask yourself which will have the greatest impact on the future of IoT? Will it be on trust – if people trust a system, are they more likely to use it? Or data availability – if information is more readily available, how will that increase your user adoption?"

In his final paper, Wang acted on these suggestions. His research question is much more pointed: "If we combine IoT with blockchain, which has built-in securities such as inalterability, will this significantly improve the confidentiality, integrity, and availability of IoT user data by introducing a unique and tailored architecture?"

Wang clearly benefited from the assessment provided by his peer review. He followed his partner's advice, narrowing a broad topic to one that was focused and manageable, and thus targeted specific aspects of blockchain that he felt were most impactful.

Bentley Student Project by Matthew Burns: Public Records Management

The third student project explored the potential benefits of using blockchain to improve the management of public records (Cumming & Findlay, 2010) in the context of property record-keeping and conveyance in the United States. Burns conducted this research using the case method from an interpretivist perspective (Walsham, 1995). Specifically, Burns performed an in-depth analysis of two cases to understand similarities and differences in how blockchain technology was utilized in each case.

In the first case, deeds were recorded in South Burlington, Vermont (De, 2018) in the traditional way (on paper) with the following added to the deed: The disclosure that "This conveyance has been recorded in smart contract 0x… of the public Ethereum blockchain" and a QR code referring to the deed's location on the Ethereum blockchain. Thus, the transfer of property was still recorded on paper and signed by the Chittenden County Clerk and a Notary Public [see Appendix E, Figure 7 (a), for an example].

In the second case, Cook County Illinois created and updated "digital property abstracts" for approximately 2,000 vacant properties scheduled for demolition in the Chicago area. This project required consolidating and reconciling property information that was fragmented across numerous government offices. These digital abstracts were entered on the Bitcoin blockchain. The consolidation of property information enabled the creation of a public-facing portal called *Property Health*. This portal allows potential buyers to search for land or homes and better understand the health of a property, and let them know if they should proceed with caution. A visual of the *Property Health* portal for Cook County can be found in Appendix E, Figure 7 (b). Yarbrough and Mirkovic (2017) summarized the findings and results of the Cook County Recorder of Deeds (CCRD) blockchain pilot project in four "Result" bullets as follows:

1. Participants designed a framework for the first legal blockchain conveyance in Illinois (and possibly the US).
2. CCRD successfully used components of blockchain technology (file hashing and Merkle trees) to secure government records.
3. CCRD used the concept of 'oracles' to build the most informative property information website in Cook County, with a dedicated landing page for each parcel.
4. CCRD's current land records vendor, Conduent (formerly Xerox/ACS) agreed to incorporate some of the technology used in blockchains into the new land records system currently being installed at CCRD. (Yarbrough & Mirkovic, 2017)

The most striking similarity between these two cases was the benefit provided by a collection of records that were secured, verified, and indexed by a blockchain. By deconstructing these two cases, Burns concluded that there was an opportunity for property record-keeping and conveyance in the U.S. to be managed using shared services (Fishenden & Thompson, 2012) provided at the state level. This would allow municipalities or counties to function as peers on a common blockchain, sharing both the benefits and cost of using a "blockchain-as-a-service" (Cachin, 2016). Furthermore, other types of assets, for example, automobiles, motorcycles and boats, could be registered (or recorded) and conveyed using the same service-oriented infrastructure at the state level (Reed, 2010).

Peer Assessment and Discussion

Burns' peer, JG, provided comments early on regarding his research methods (interviews) and benefits to be gained from conducting them, as well as the quality of primary and secondary sources, which "can provide … valuable information regarding connections that can be made between blockchain and governments around the world."

JG identified claims that Burns might wish to clarify moving forward, such as why "vulnerability to fraud and tampering" is a risk but "safeguarding is a benefit," justifying his concerns with his own insights. JG evaluated Burns' approach and whether he thought his research goals were reasonable given constraints of time and resources.

Burns assessed his own learning as he reflected on his interview with a city clerk involved in a blockchain pilot program. He said, "I was able to gain a better understanding regarding the success of this pilot program. I asked about any identifiable efficiencies that blockchain brought to the table throughout the pilot program, namely around time, cost, and security" (which was reflected in his modified research question, as suggested by JG) and then summarized the response.

That Burns considered the feedback and comments from JG is evident in the organization of his final paper. Burns' final paper presented overviews of blockchain technology: an introduction, public vs. private blockchains, smart contracts, and other topics prior to a case study analysis of districts using blockchain technology in governmental practices, specifically land registry and property record keeping transactions.

Bryant Student Project by Team Moscowicz: Smart Contracts

The final student project described in this paper consisted of a hands-on development exercise to build and deploy a smart contract based on the Ethereum blockchain.

Students who opted for the smart contract project were tasked with becoming familiar with the Solidity programming language through a set of free tutorials aimed at creating a CryptoZombies game (see http://www.cryptozombies.io). CryptoZombies is a free, hands-on set of tutorials for those who are new to developing in the Solidity programming language. No software is needed to install since the tutorials' development environment is a hosted solution, allowing students to code and test directly on the CryptoZombies website.

The CryptoZombies tutorials emphasize the difference between fungible and non-fungible tokens (ERC-20 versus ERC-721). With fungible tokens, each token is identical. These tokens have no characteristics that make them distinguishable from one another. With non-fungible tokens, each token has unique attributes which allow for the potential of varying values amongst the tokens (see http://www.erc721.org). Through the CryptoZombies tutorials, the students create a smart contract that can create new Zombies. These zombies have attributes that are often thought of as the DNA of the token. This allows each zombie to be unique.

After completing the tutorials, Moscowicz and his teammates initially decided to develop a smart contract for a complex gambling site. After several weeks of working on this project, they decided that they simply didn't have the skills needed, nor the time to gain the skills, to complete this ambitious effort.

Instead they opted to create a smart contract that was more in-line with what they learned in the CryptoZombies tutorials. What emerged was the Crypto Ice Cream Shop (see Appendix F, Figure 9). The intent was that each "ice cream cone" would be unique (i.e., non-fungible) with different elements of the "DNA" representing the flavor, toppings, cone choice, etc.

The students were responsible for finding and setting up their own development environments. After several attempts using different IDEs, Team Moscowicz settled in with using Remix as their IDE and MetaMask as their test wallet.

Remix allowed for the testing of the smart contract and, by utilizing the Ethereum Ropsten test network, they were able to see the execution of their currency exchange through the website http://ropsten.etherscan.io.

In the end, the team was able to deploy a basic smart contract that generated a non-fungible ice cream cone. They were able to execute the contract (see Appendix F, Figure 10) and see the transaction on the Ropsten test blockchain along with the test fees moving from their MetaMask test wallet (see Appendix F, Figure 11 and Figure 12).

Discussion

With Solidity being a new programming language, online resources to support the students were lacking. Each smart-contract team struggled with simply setting up an environment in which they could develop and test their smart contracts. Through the weekly status reports, teams were able to share lessons learned which helped other teams get past technical hurdles.

While each Solidity project had skilled coders, they were used to programming in a mature language (e.g., Python, Java, etc.) with plenty of examples readily available. In general, the smart contract-teams were frustrated with the lack of resources to help them with their development. Each team frequently evaluated the scope of the project and whether they would be able to deliver a working solution at the end of the semester. In some cases, including this ice cream shop example, projects were abandoned or dramatically changed to account for the unanticipated challenges when working with an emerging technology.

5. LESSONS LEARNED AND CONCLUSIONS

To facilitate PjBL, the courses at Bryant and Bentley were delivered in a format in which the instructor designed activities and assignments to challenge students to apply their understanding of blockchain technologies in areas that supported their projects. These activities and assignments were also designed to pull students out of their comfort zones and to provide an appropriate mix of motivation and frustration (Weimer, 2013). Motivation was needed so that every student successfully completed a significant project. Most frustration was because PjBL centered on a significant project was challenging for many students.

At Bryant, self-regulated learning provided a learner-centered process by which knowledge discovery occurred in areas related to an emerging technology. This helped students bridge their conceptual understanding of blockchain with hands-on activities building components of a decentralized application (dApp). Adaptation occurred as students struggled to translate their conceptualization of blockchain into action (Weimer, 2013).

At Bentley, peer feedback had a positive influence on students' final projects. Students worked in pairs to review each other's abstracts, research questions, goals, methods, and sources, and offered recommendations for improvement. The process of peer assessment allowed students to reflect on what they had learned, apply their knowledge, review the work of a partner, articulate their own insights, draw conclusions, and to provide constructive criticism and suggestions (Reinholz, 2016). Exchanging feedback with their partners empowered students to be teachers and learners of blockchain-focused knowledge and skills.

While PjBL, self-regulated learning, and peer learning are not new concepts, this case study highlights the benefits of each in relation to learning about an emerging technology. At both Bryant and Bentley, these teaching methods extended student understanding of blockchain to new domains, gave audience to the students' work, and enabled students to learn from each others' insights. Furthermore, reflection, and the sharing of that reflection with others, helped everyone in our classes gain a more in-depth understanding of blockchain technology and how it might be used. Emerging technologies, however, may lack clear and consistent resources. It is often left to the instructor to try to answer all of the students' questions. However, having a community of students develop the skills to answer their own questions − after some research − and solve their own problems gave most students the confidence to learn and apply the emerging technologies that lie over the horizon.

6. REFERENCES

Aditomo, A., Goodyear, P., Bliuc, A., & Ellis, R. A. (2013). Inquiry-based learning in higher education: principal forms, educational objectives, and disciplinary variations. *Studies in Higher Education, 38*(9), 1239-1258.

Bambara, J. J., Allen, P. R., Iyer, K., Madsen, R., Lederer, S., & Wuehler, M. (2018). *Blockchain: A practical guide to developing business, law, and technology solutions.* McGraw-Hill Education.

Barron, B. J. S., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., & Bransford, J. D. (1998). Doing with understanding: Lessons from research on problem- and project-based learning. *The Journal of the Learning Sciences, 7*(3/4), 271-311.

Bashir, I. (2018). *Mastering blockchain: Distributed ledger technology, decentralization, and smart contracts explained* (2nd ed.). Packt Publishing.

Bell, S. (2010). Project-based learning for the 21st century: Skills for the future. *The Clearing House, 83*(2), 39-43.

Bishop, M. (2018). *Computer security: Art and science* (2nd ed.). Addison-Wesley Professional.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3-4), 369-398.

Brookfield, S. P. (2017). *Becoming a critically reflective teacher* (2nd ed.). Jossey-Bass.

Buterin, V. (2014). *A next-generation smart contract and decentralized application platform*. Ethereum White Paper.

Cachin, C. (2016). Architecture of the hyperledger blockchain fabric. Presented at the *Workshop on Distributed Cryptocurrencies and Consensus Ledgers*.

Clough, P., & Nutbrown, C. (2012). *A student's guide to methodology* (3rd ed.). Sage.

Cumming, K., & Findlay, C. (2010). Digital recordkeeping: Are we at a tipping point? *Records Management Journal, 20*(3), 265-278.

De, N. (2018). Vermont city pilots land registry record with blockchain startup. *CoinDesk*.

De Filippi, P., & Wright, A. (2018). *Blockchain and the law: The rule of code*. Harvard University Press.

Fishenden, J., & Thompson, M. (2012). Digital government, open architecture, and innovation: Why public sector IT will never be the same again. *Journal of Public Administration Research and Theory, 23*(4), 977-1004.

Freire, P. (1993). *Pedagogy of the oppressed* (Rev. ed.). Continuum.

Gainsbury, S. M., & Blaszczynski, A. (2017). How blockchain and cryptocurrency technology could revolutionize online gambling. *Gaming Law Review, 21*(7), 482-492.

Gartner. (2018). *Gartner identifies five emerging technology trends that will blur the lines between human and machine*. https://www.gartner.com/en/newsroom/press-releases/2018-08-20-gartner-identifies-five-emerging-technology-trends-that-will-blur-the-lines-between-human-and-machine

Gibson, I. S., O'Reilly, C., & Hughes, M. (2002). Integration of ICT within a project-based learning environment. *European Journal of Engineering Education, 27*(1), 21-30.

Gordon, N. & Brayshaw, M. (2008). Inquiry based learning in computer science teaching in higher education. *Innovation in Teaching and Learning in Information and Computer Sciences, 7*(1), 22-33.

Gregor, S., & Hevner, A. R. (2013). Positioning and presenting design science research for maximum impact. *MIS Quarterly, 37*(2), 337-355.

Hadim, H. A., & Esche, S. K. (2002). Enhancing the engineering curriculum through project-based learning. In proceedings of the *ASEE/IEEE Frontiers in Education Conference*.

Helle, L., Tynjälä, P., & Olkinuora, E. (2006). Project-based learning in post-secondary education−Theory, practice and rubber sling shots. *Higher Education, 51*(2), 287-314.

Hevner, A. R. (2007). A three cycle view of design science research. *Scandinavian Journal of Information Systems, 19*(2), 87-92.

Hevner, A., & Chatterjee, S. (2010). *Design research in information systems: Theory and Practice*. Springer.

Hileman, G., & Rauchs, M. (2017). *2017 global blockchain benchmarking study*. Social Science Research Network Report, Sept. 27.

Jackson, C. K., & Bruegmann, E. (2009). Teaching students and teaching each other: The importance of peer learning for teachers. *American Economic Journal: Applied Economics, 1*(4), 85-108.

Jun, M. (2018). Blockchain government - a next form of infrastructure for the twenty-first century. *Journal of Open Innovation: Technology, Market, and Complexity, 4*(7), 1-12.

Kember, D., & Gow, L. (1994). Orientations to teaching and their effect on the quality of student learning. *The Journal of Higher Education, 65*(1), 58-74.

Kolias, C., Kambourakis, G., Stavrou, A., & Voas, J. (2017). DDoS in the IoT: Mirai and other botnets. *Computer, 50*(7), 80-84.

Korpela, K., Hallikas, J., & Dahlberg, T. (2017). Digital supply chain transformation toward blockchain integration. In proceedings of the *50th Hawaii International Conference on System Sciences*.

McCumber, J. (1991). Information systems security: A comprehensive model. In proceedings of the *14th National Computer Security Conference*.

Mehta, N., Agashe, A., & Detroja, P. (2019). *Blockchain bubble or revolution: The present* *and future of blockchain and cryptocurrencies*. Paravane Ventures.

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system.

Nicol, D. J., & Macfarlane-Dick, D. (2006). Formative assessment and self-regulated learning: A model and seven principles of good feedback practice. *Studies in Higher Education, 31*(2), 199-218.

Norman, A. T. (2017). *Blockchain technology explained: The ultimate beginner's guide about blockchain wallet, mining, Bitcoin, Ethereum, Litecoin, Zcash, Monero, Ripple, Dash, IOTA and smart contracts*. CreateSpace Independent Publishing.

Ølnes, S., Ubacht, J., & Janssen, M. (2017). Blockchain in government: Benefits and implications of distributed ledger technology for information sharing. *Government Information Quarterly, 34*(3), 355-364.

Paul, F. (2019). Top 10 IoT vulnerabilities. *Network World*, Jan 14.

Peffers, K., Tuunanen, T., Rothenberger, M. A., & Chatterjee, S. (2007). A design science research methodology for information systems research. *Journal of Management Information Systems, 24*(3), 45-77.

Peterson, K., Deeduvanu, R., Kanjamala, P., & Boles, K. (2016). *A blockchain-based approach to health information exchange networks.* In proceedings of the *NIST Workshop on Blockchain Healthcare*.

Piasecki, P. J. (2016). Gaming self-contained provably fair smart contract casinos. *Ledger, 1*, 99-110.

Pisa, M. (2018). Reassessing expectations for blockchain and development. *Innovations: Technology, Governance, Globalization, 12*(1-2), 80-88.

Rabah, K. (2017). Challenges & opportunities for blockchain powered healthcare systems: A review. *Mara Research Journal of Medicine & Health Sciences, 1*(1), 45-52.

Reed, B. (2010). Service-oriented architectures and recordkeeping. *Records Management Journal, 20*(1), 124-137.

Reinholz, D. (2016). The assessment cycle: A model for learning through peer assessment. *Assessment & Evaluation in Higher Education, 41*(2), 301-315.

Rice, M., & Shannon, L. J. Y. (2016). Developing project based learning, integrated courses from two different colleges at an institution of higher education: An overview of the processes, challenges, and lessons learned. *Information Systems Education Journal, 14*(3), 55-62.

Saks, K., & Leijen, Ä. (2014). Distinguishing self-directed and self-regulated learning and measuring them in the e-learning context. *Procedia - Social and Behavioral Sciences, 112*, 190-198.

Saltzer, J. H., & Schroeder, M. D. (1975). The protection of information in computer systems. *Proceedings of the IEEE, 63*(9), 1278-1308.

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2016). *Research methods for business students* (7th ed.). Pearson Education.

Sharma, T. K. (2019). Top 10 blockchain platforms you need to know about. Retrieved July 15, 2019, from https://www.blockchain-council.org/blockchain/top-10-blockchain-platforms-you-need-to-know-about/

Sicari, S., Rizzardi, A., Grieco, L. A., & Coen-Porisini, A. (2015). Security, privacy and trust in internet of things: The road ahead. *Computer Networks, 76*, 146-164.

Stefanou, C., Stolk, J. D., Prince, M., Chen, J. C., & Lord, S. M. (2013). Self-regulation and autonomy in problem-and project-based learning environments. *Active Learning in Higher Education, 14*(2), 109-122.

Suh, N. P. (1998). Axiomatic design theory for systems. *Research in Engineering Design, 10*(4), 189-209.

Tan, A. (2018). How blockchain can secure the IoT. *Computer Weekly*.

Thomas, J. W. 2000. A review of research on PBL. http://www.bobpearlman.org/BestPractices/PBL_Research.pdf, accessed Sept. 28, 2019

Tian, F. (2016). An agri-food supply chain traceability system for China based on RFID & blockchain technology. Presented at the *13th International Conference on Service Systems and Service Management*.

Vaishnavi, V., Kuechler, B., & Petter, S. (2019). *Design science research in information systems*. DESRIST Working Paper, June 30.

Walsham, G. (1995). Interpretive case studies in IS research: Nature and method. *European Journal of Information Systems, 4*(2), 74-81.

Weimer, M. (2013). *Learner-centered teaching: Five key changes to practice* (2nd ed.). Jossey-Bass.

Werbach, K. (2018). *The blockchain and the new architecture of trust*. MIT Press.

Wüst, K., & Gervais, A. (2018). Do you need a blockchain?. In *2018 Crypto Valley Conference on Blockchain Technology*, 45-54.

Yarbrough, J., & Mirkovic, A. (2017). *Blockchain pilot program - Final report*. Cook County Recorder of Deeds, May 30.

Yue, K. B., Chandrasekar, K., & Gullapalli, H. (2019). Storing and querying blockchain using SQL databases. *Information Systems Education Journal, 17*(4), 24-41.

Zimmerman, B. J. (1990). Self-regulated learning and academic achievement: An overview. *Educational Psychologist, 25*(1), 3-17.

Appendix A. Blockchain and the Hype Cycle for Emerging Technologies

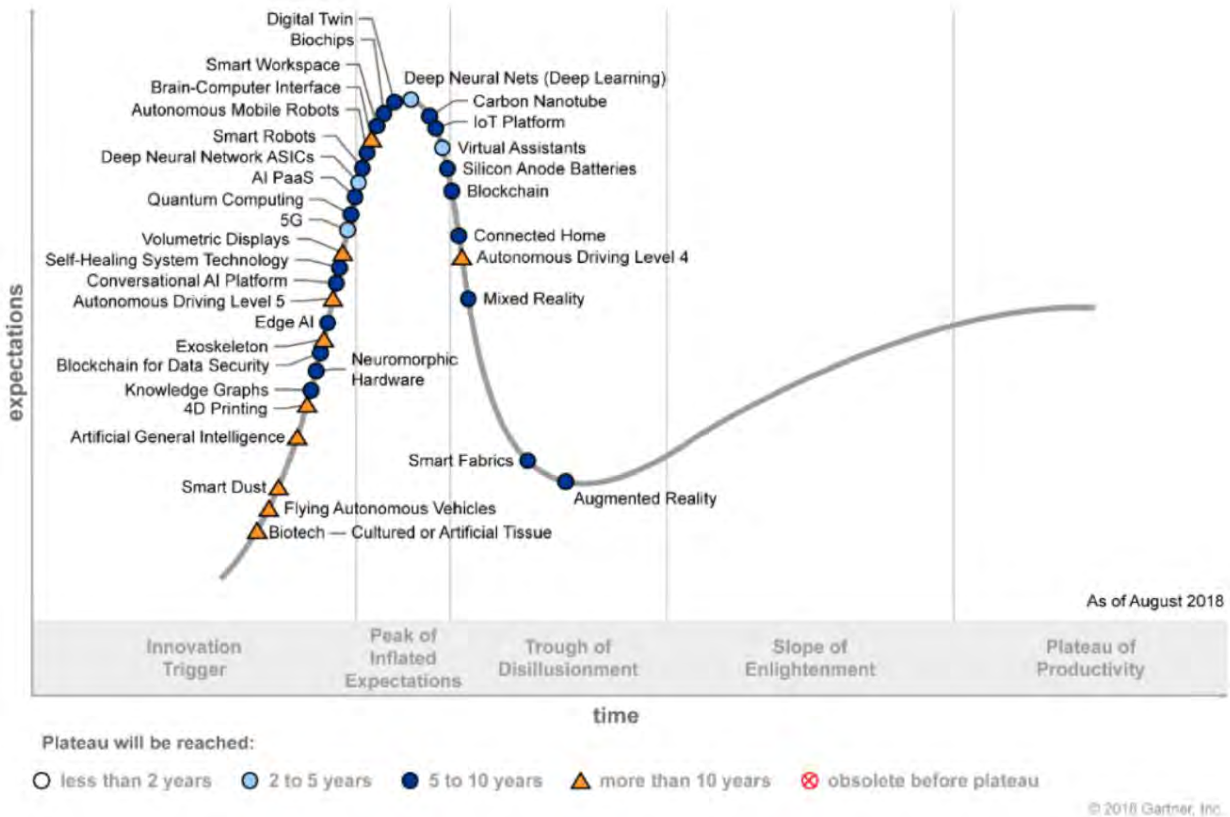

Figure 5. Blockchain is past its peak in the Gartner hype cycle for emerging technologies [Source: (Gartner, 2018)]

Appendix B. *Introduction to Blockchain* at Bryant University

Introduction to Blockchain at Bryant was a 400-level special topics course aimed at seniors in an undergraduate program taught in the spring of 2019. Most students only had a vague idea of what blockchain was when they started the class.

The first half of the semester was focused on student understanding of blockchain, its terminology, the difference between the technology and its applications, and what it means to be a "miner." During this time the students were each given a Raspberry Pi to create their own mining device, which required them to gain the skills and basic knowledge of crypto-mining and digital wallets. This was worth 10% of their grade as shown in the syllabus below.

The midterm exam (20% of the grade) was formatted in a way to mimic the format of the Blockchain Architecture exam given by the Blockchain Training Alliance (see http:///www.blockchaintrainingalliance.com). This tested the fundamentals and basic terminology of blockchain.

The students then had to demonstrate that they understood the potential applications of blockchain by writing an industry-focused midterm paper (20% of the grade) in an industry of their choice.

The course then split into two paths. Students could take a technical (i.e., development-oriented) path by designing and developing their own smart contract in Solidity, or a research path by expanding on their industry paper through a mini-research project in that domain.

Students provided status reports (included as part of the 20% class participation grade) to the class once a week for the remainder of the term. This allowed students to share their forethought and goals for the week, an assessment of how well they achieved those goals, and a self-reflection on how well the work towards these goals was executed.

While the instructor provided the initial instructions, along with expectations appropriate for self-regulated learning (Saks & Leijen, 2014; Stefanou & Stolk et al., 2013), the students relied on the process of forethought, performance, and self-assessment (Zimmerman, 1990) to accomplish this project (30% of the grade). A central component of self-regulated learning in this course was the choice that the students had during week nine – to complete the course via either the developer track or the research track. (These tracks are summarized in the *Course Description* below.) A comparison of the projects by D'Amico and Moscowicz and his teammates, in Section 4, provide illustrative examples of how important this choice was for the students. Since project-based learning typically demands that the faculty member's role is that of an advisor to the students rather than an instructor, the first author yielded control of this choice to each student, but required that their first step in either track was to submit and receive feedback on a proposal.

Course Syllabus, Spring 2019
ISA ST400 Introduction to Blockchain

TEXTBOOKS AND OTHER RESOURCES

1. Bambara, J. J. & Allen, P. R. et al. (2018). *Blockchain: A Practical Guide to Developing Business, Law, and Technology Solutions.* McGraw Hill Education (ISBN 978-1260115871) Required
2. Bennet, K., Rieger M., & Lee E. (2018). *Certified Blockchain Solution Architect: Official Exam Study Guide.* Blockchain Training Alliance (Available from www.blockchaintraining alliance.com). Optional – On Reserve in Library
3. Weisner, T. & Lee E. (2018). *Certified Blockchain Developer Ethereum: Official Exam Study Guide.* Blockchain Training Alliance (Available from www.blockchaintraining alliance.com). Optional – On Reserve in Library

RATIONALE

Blockchain is being discussed as a serious disruptor across vast industries. We have seen cryptocurrencies, built on blockchain technology, surpass the GDP of many countries, thus leading some governments to suggest replacing their own currency with a new cryptocurrency. Venezuela is one such country, having launched the cryptocurrency Petro to supplement their plummeting currency the bolivar.

With the advent of *smart contracts*, or the ability to embed logic in with the blockchain transaction, a new crop of applications (called dApps or decentralized applications) has emerged. Success has already be achieved in the areas of gaming (CryptoKitties), betting or futures prediction (Auger), identity management (uPort), and computing power sales (golem), just to name a few.

Cryptocurrencies have been of keen interest to public safety, as we have seen Bitcoin used as the currency of choice in illegal activities such as drug and arms sales. By hiding behind the anonymity afforded by the cryptocurrency, people are engaging in transactions that otherwise would have been more difficult.

These smart contracts present enormous opportunity, as well as heightened risk. We have seen poorly designed smart contracts lead to enormous financial loss. Unlike traditional software development, rolling out a smart contract with a bug can wreak havoc financially, due to the inability to easily change contracts and the inability to reverse transactions.

This course will provide students with a) a full understanding of the blockchain technology with the understanding of why companies are choosing this technology as their platform and b) the ability to develop smart contracts based on the Ethereum blockchain. The course will involve hands-on instruction, using the Solidity programming language, to implement a simple smart contract in an Ethereum training environment.

This course will prepare students to take the BTA Certified Blockchain Solution Architect (CBSA) exam for an industry recognized certification in the field of blockchain.

COURSE DESCRIPTION

This course introduces students to blockchain technology. The first half of the course will be used to gain a full understanding of the technology from a management perspective. Students will gain the knowledge needed to understand where this emerging technology is being used and explore why companies are choosing to build their business on blockchain. Students will gain an appreciation of the different types of blockchain with discussion around when each is appropriate to implement. We will explore many industries to understand the global nature of blockchain and begin to see the value in implementing blockchain in many vertical markets including supply chain, finance, gaming, and government, just to name a few.

Students will choose a path to pursue shortly after the midterm exam and once everyone has a general understanding of solidity. There are two paths – the Developer Path and the Research Path.

Developer Path: The second half of the course will be hands-on with the students developing their own smart contract. The students will learn the Solidity programming language in order to write their own smart contracts. Existing smart contracts will be used to discuss techniques and ways to organize code. Students will deliver weekly status reports, including hands-on lessons-learned to the other Developers. These status reports are intended to a) keep the project moving forward and b) share knowledge with the other teams in order to help others overcome technical hurdles. We will deploy the smart contracts in a private Ethereum environment so students understand the full development lifecycle.

Research Path: The second half of the course is devoted to developing the "industry paper" into a full-fledged research paper. Students will propose how they intend to add new knowledge to the field of blockchain beyond their industry paper. In most cases this will be through the gathering of data (survey data, social media data, interviews, etc.) and the reporting of the findings. Students will deliver three presentations to the entire class. The first presentation is to explain to the class how they intend to pursue their research. This will include research objectives and potential data sources.

The two subsequent presentations are to give updates to the class in order to a) motivate the team to keep moving forward and b) brainstorm on data gathering techniques, should hurdles be met. This would also be a good time for a team to distribute a survey to the class if survey data can be used in the research topic. The final deliverable is a research paper.

PREREQUISITES Any course with a programming component

LEARNING GOALS The learning goals and objectives of this course are as follows:

1. To enable students to develop knowledge, skills, and understanding around a range of subjects in the field of blockchain.
2. To enable students to evaluate and develop smart contracts using the Solidity language (technology or developer track).
3. To enable students to apply concepts and principles from various industries to understand blockchain opportunities.
4. To enable students to recognize the unique challenges of implementing blockchain including inability to easily change smart contracts and the inability to reverse transactions.
5. To enable students to effectively interpret and communicate their ideas through written and oral reports (emphasized on research track).

PROGRAM-RELATED LEARNING GOALS

1.2.A. Students will demonstrate effective writing for business.

1.2.B. Students will demonstrate effective oral communications in business situations.

1.2.C. Students will use multimedia to support effective presentations.

2.1.B. Students will demonstrate critical thinking skills by analyzing complex problems and recommending feasible solutions.

2.2.B. Students will use information technology to formulate, analyze, and solve business problems.

6.1.E.a. Describe the concepts, procedures and tools necessary for building a computer-based information system.

6.1.E.b. Use technology to analyze data and solve real-life business problems.

STUDENT EVALUATION The criteria used to evaluate students will be:

Cryptocurrency Mining	10%
Mid-term Exam	20%
Smart Contract Project OR Research Paper	30%
Industry Paper	20%
Class Participation / Assignments	20%
Total	100%

Grade	Point Range
A	92.5-100%
A-	90.0-92.4%
B+	87.5-89.9%
B	82.5-87.4%
B-	80.0-82.4%
C+	77.5-79.9%
C	72.5-77.4%
C-	70.0-72.4%
D+	67.5-69.9%
D	60.0-67.4%
F	0-59.9%

Class Participation Every member of the class is expected to participate in every class. Participation is one of the major keys to active learning. Each student will be judged on the quality and quantity of participation in class discussions. I expect students to be interactive in the class. Contributions that add new insights or advance the discussions, including clarifying questions, will be rewarded. An evaluation will be performed at the end of the semester.

Students are not allowed to leave class early except with permission of the instructor. If permission is not obtained, it will count as a class absence. In addition, failure to sign the attendance sheet will count as a class absence.

Assignments and Projects The student will work on multiple assignments throughout the semester including homework that will target specific blockchain understanding (industry research, blockchain inspection, smart contract analysis, etc.). Each student will have a mid-term research paper that will either be broad (analyze how blockchain is impacting a specific industry) or deep-dive (analyze a specific blockchain implementation). Students will have their choice for a final project. The student can choose between a technology track (developing a smart contract using Solidity) and a research track (writing a final paper for a specific market). All assignments are to be done individually unless otherwise stated.

Exam The exam will be based on the Blockchain Training Alliance Blockchain Solution Architect Exam for blockchain certification. Students can optionally take the exams through the Blockchain Training Alliance which will give them an industry recognized blockchain certification – Students will be responsible for the extra cost (currently $300 per exam) associated with this certification if they choose this option (see: https://blockchaintrainingalliance.com/pages/blockchain-certification). Any student who takes the BTA exam and scores a passing grade (thereby becoming "certified") will automatically receive an A on the mid-term exam.

Schedule

Week #	Topics		Assignment
1	Introduction to Blockchain		Intro to Blockchain Slides
2	Blockchain Fundamentals *Industry Application: Cryptocurrencies*		Mining Proposal
3	Deciding to Implement Blockchain *Industry Application: Finance*		Discussion Post: Finance
4	Introduction to Distributed Applications (dApps) *Industry Application: Supply Chain*		Discussion Post: Supply Chain
5	Designing dApps *Industry Application: Gaming*		Discussion Post: Gaming
6	Challenges Associated with dApps / Testing dApps *Industry Application: Government*		Discussion Post: Government
7	Project Presentations		Industry Paper Mid-term Exam
8	Ethereum Basics		
9	Introduction to Ethereum Programming		Smart Contract Proposal OR Research Proposal
	FORK – Students decide programming track or research track		
	Developer Track	Research Track	
10	Solidity Basics – Status Update #1	Proposal Due	
11	Solidity Basics	Literature Review	
12	Solidity: Advanced – Status Update #2	Proposal Presentations	
13	Solidity: Advanced	Status Report #1	
14	Contract Security and Testing – Status Update #3	Status Report #2	
15	Smart Contract Presentations	Research Paper Due	

Appendix C. *Blockchain: Applications, Policy and Implications* at Bentley University

The blockchain course offered at Bentley was an undergraduate honors capstone course taken by advanced students from a variety of business-oriented majors. This course provided students with conceptual frameworks, methodologies, and analytical tools (Saunders, Lewis & Thornhill, 2016) for the study of blockchain technology and its applications and implications. The final deliverable in this course was an individual research project in which each student made an original research contribution based on blockchain technologies.

One of the more challenging dimensions of project-based learning for many instructors is yielding control over the design of the most important learning experience, i.e., the project, to the student (Brookfield, 2017; Freire, 1993; Kember & Gow, 1994). Brookfield (2017) carries this idea further and suggests that in many situations instructors can empower and motivate students by having them specify intermediate milestones, grading percentages, due dates, etc. At the urging of the students in this HNR 440 class, such a conversation occurred during week two of class (i.e., on September 5). This conversation resulted in three important changes to the syllabus shown below: First, the students had three chances to refine their research questions (noted as Take 1, Take 2 and Take 3 below). The order of the *project proposal* and *critical literature review* was reversed. And the weight of the final paper was reduced from 45% of the course grade to 25%, spreading the remaining 20% to other intermediate milestones.

The syllabus for this course, which was finalized after week two, is shown below. The research project counted for 80% of the course grade. Breaking down this 80%, 45% of each student's grade was based on four intermediate milestones, and a final presentation and final paper counted for 35% of their grade. Together with one-on-one meetings with each student, these milestones encouraged iterative and incremental development of the projects.

Recall that a critical component of this project-based course was peer feedback, including peer assessment. Activities and assignments to challenge students to apply their understanding of blockchain technologies to their project and their peer's project accounted for the remaining 20% of the course grade.

Peer assessment is a set of activities through which individuals make judgments about the work of others – often students enrolled in the same course – to confer and provide feedback about each other's work. In the Bentley course, the most rigorous peer assessment was the third assignment, which was due during week four of the semester; on September 19 in the fall 2018 syllabus below. Appendix D presents this assignment (Assignment 3). And the discussion of two Bentley student projects in Section 4 includes an analysis of how the peer assessments provided to Wang and Burns both influenced and improved their final projects. Furthermore, much of the in-class discussion focused on challenges and opportunities that the students experienced as they worked on their research (Brookfield, 2017; Thomas, 2000). This discussion led to students relying heavily on giving feedback to and receiving feedback from each other. Furthermore, respectful peer feedback and constructive peer assessment forged a sense of community among the students (Freire, 1993) that developed quickly and remained strong throughout the semester.

Honors Capstone Course Syllabus, Fall 2018

HNR 440/445 Blockchain: Applications, Policy and Implications

Rationale: Because blockchain has the potential to be disruptive in so many different sectors, it can be studied from different perspectives, e.g., economic, political or social. Since blockchain began as one of the important technologies that underlies Bitcoin and other cyptocurrencies, its first use cases were to mediate payments, which subsequently led to blockchain's early adoption in financial services. More recently blockchain has been proposed for applications as diverse as supply chain management, health record management, land and deed registration, and voting. These very different use cases means that blockchain – and its associated applications, policy or implications – can be examined either in the context of a single discipline, e.g., accounting, finance, computer information systems, or at the intersection of several disciplines, e.g., economics, public policy, and law.

Perhaps the most exciting 'killer app' for blockchain is *smart contracts*. According to *Wikipedia*, a "smart contract is a computer protocol intended to digitally facilitate, verify, or enforce the negotiation or performance of a contract." In other words, a blockchain can be decentralized system that serves as on-line intermediary between parties, providing faster, cheaper, more secure, and more predictable contract (or transaction) execution than traditional systems. Hence the significant interest in blockchain technology within both the public and private sectors. However, because smart contracts are multi-party entities, study and research in this area often requires a multi-stakeholder approach.

Library Resources: These books are on reserve in the Bentley library –

Bashir, I. (2018). *Mastering blockchain: Distributed ledger technology, decentralization, and smart contracts explained* (2nd ed.). Packt Publishing.

De Filippi, P., & Wright, A. (2018). *Blockchain and the law: The rule of code*. Harvard University Press.

Hevner, A., & Chatterjee, S. (2010). *Design research in information systems: Theory and Practice*. Springer.

Norman, A. T. (2017). *Blockchain technology explained: The ultimate beginner's guide about blockchain wallet, mining, Bitcoin, Ethereum, Litecoin, Zcash, Monero, Ripple, Dash, IOTA and smart contracts*. CreateSpace Independent Publishing.

Saunders, M. N. K., Lewis, P., & Thornhill, A. (2016). *Research methods for business students* (7th ed.). Pearson Education.

Course Description: This capstone project course provides students with conceptual frameworks, methodologies, and analytical tools for the study of blockchain technology and its applications, policy and implications. Why is there so much hype around blockchain? Anything that you can create a record for and enter in a ledger, you can manage with a digital blockchain. Furthermore, blockchain's processing capability is near real-time, near tamper-proof and increasingly low-cost. Blockchain technology therefore has the potential to be hugely disruptive. It can be used by a wide variety of industries and services, such as financial services, real estate, healthcare, and government, for example.

The course has the same objectives as the individual honors capstone project. During the course, students will be required to read, discuss and analyze a multitude of readings (peer-reviewed articles, book chapters, practitioner articles, industry reports, etc.). The final deliverable is an individual research project in which the student will focus on a particular aspect of blockchain – applications, policy, implications, technology, etc. – and make an original research contribution. Students are encouraged to identify a topic of interest within this broad area and to develop their own research questions, consistent with their interests and academic strengths. The instructor will offer guidance regarding the appropriate research methods and theoretical perspectives for the project.

We will begin the semester with regular class meetings and then to move to independent work and one-on-one meetings with your faculty advisor (i.e., the course instructor) with periodic group meetings to share information, provide feedback on each other's work, and assist each other in overcoming any challenges. The course will address broader themes in the earlier weeks of the semester, which might help students identify research questions of interest. Later in the semester, students will focus on their research projects.

This capstone course will count as either a Business Elective (HNR 440) or A&S Elective (HNR 445), and many topics lend themselves to integrating students' business and arts & sciences education with an interest in blockchain technology and its applications, policy or implications.

Additional assigned articles and material will be available through the course's Blackboard site or Google Drive.

Prerequisites: An understanding of quantitative and qualitative research methods and good standing in the Bentley Honors Program.

Learning Goals:

1. Understand and describe common use cases and emerging applications that are based on blockchain technology.

2. Understand and analyze policy, legal, and regulatory challenges posed by blockchain (Werbach, 2018).
3. Design distributed applications based on blockchain and explain critical design decisions.
4. Learn how to formulate a tractable research question and determine how to answer it.
5. Design and execute a novel and significant research project from initiation to manifestation and public presentation.

Course Requirements:

Participation:	10%
Assignments:	10%
Project critical literature review:	12%
Project proposal:	10%
Project progress report I	8%
Project progress report II & analysis:	15%
Presentation:	10%
Research Paper:	25%

Participation: Every class session will consist of discussion of one or more of the following:

- Blockchain concepts relevant to applications, policy or implications
- Research methods
- Current events related to blockchain

All students are expected to participate in these discussions and be able to elaborate on their viewpoints.

Project Critical Literature Review: Provide a critical literature review of the previous academic research on your research topic (i.e., a literature review). What are the areas of consensus and controversy in this previous academic work? What are the substantive and methodological shortcomings? This review should end by reaffirming or refining the research question(s) and research objectives that you developed as part of your first three assignments. [Research question(s) and research objectives, Take 2.]

This literature review should be a synthesis of a number of sources organized in a thematic manner. It is not a summary of each article in turn. The sources that you use for this review typically should include at least at least 15 scholarly articles and possibly one or two scholarly books. The balance between books and articles may be different for certain subject areas, however. For most projects in a rapidly evolving area like blockchain applications, policy or implications, more than half of your sources should have been published in the previous five years. This section should be approximately 2,500 words in length including in-text citations.

Project Research Proposal: Each student will prepare an eight- to twelve-slide presentation that presents:

- Research question(s) and research objectives, Take 3
- Method
- Timescale
- Research philosophy and research approach
- Research strategy
- Research methodology

and an associated research paper proposal (1,000 words) the covers the same areas.

Project Progress Report I: Each student will hand in a 1,000-word progress report and present his or her progress with a single slide in class. The student will refer to his or her original proposal, address any new or revised research question(s) or research objects, give an update of the research process and research progress.

Project Progress Report II & Analysis: Each student will hand in a 1,500-word progress report and present his or her progress with two slides in class. The student will refer to his or her original proposal, address any new or revised research question(s) and research objectives, give an update of the research process, and introduce an overview of his or her analysis of the research topic.

Final Presentation: Students will present their paper in a formal 10 minute long Power Point (or similar presentation tool) presentation. A question & answer session will follow. Instructions for completing the presentation will be distributed during the course.

Final Research Paper: Each student will write a research paper (their 'honors' thesis) in the form of a 'publishable' journal article. Instructions for completing this paper will be distributed during the course. The paper for this course will be around 8,000 words (standard journal article length). The paper will require the use of outside resources. Students MUST cite any and all sources used. All assignments will be submitted though Blackboard. No deadline extension will be offered. Papers handed in after the specified time will have ten percent subtracted from their final score for each day they are late.

Tentative Course Schedule:

WEEK	THEME
Aug 29	Introduction to the Course, Blockchain overview
Sep 05	Abstracts on Projects due Sep 04 at 11:59 PM Discussion of projects based on abstracts
Sep 12	Project Overview Presentations due Sep 11 at 11:59 PM [Research question(s) and research objectives, Take 1.] Blockchain, Applications, Policy and Implications overview
Sep 19	Library Resources and Project Planning Peer Project Feedback due Sep 21 before 11:59 PM
Sep 26	The Role of Trust in Blockchain
Oct 03	Project Critical Literature Review due before 6:29 PM
Oct 10	One-on-one meetings
Oct 17	Blockchain Case Study: CryptoKitties and Ethereum Project Research Proposal due before 6:29 PM
Oct 24	Project consultations [mandatory]
Oct 31	Project Progress Report I due before 11:59 PM
Nov 07	One-on-one meetings
Nov 14	Project consultations [mandatory] Project Progress Report II & Analysis due Nov 19 before 11:59 PM
Nov 28	One-on-one meetings
Dec 05	Reflections on Blockchain, Applications, Policy and Implications
Dec 12	Final Presentations due before 6:29 PM
Dec 15	Final Research Paper due before 6:29 PM

Appendix D. Peer Assessment Assignment

Spend a minimum of 5 hours and a maximum of 7.5 hours on Assignment 3 to conduct a peer-assessment of your **partner's** Assignment 2 using the seven parts below, i.e., A. through G.

Based on my experience writing up feedback for KM, an alternative way to think about this assignment is to write up the most helpful approximately 2,000 words you can write to advance and improve your peer's project:

A. Is (Are) your peer's research question (questions) clear?
B. What is not clear about their research question(s)? If their research question(s) is (are) 100% clear, that's OK.
C. Does their research question pass Clough and Nutbrown's (2012) 'Goldilocks test', i.e., is it neither too big nor too small?
D. How do their research objectives align with the narrative around and content of Table 2.3 in Saunders, Lewis & Thornhill (2016) [*Examples of research questions and related research aims*]?
E. How many secondary sources did your peer find?
F. Find three additional secondary sources for their project and list them in APA format.
G. Provide written feedback to your peer with respect to two aspects of their revised abstract:

1. Is the motivation for their research project clear?
Assignment 1 revisited [see Figure 6 (b)]: Why is the topic of interest to business or consumers [or both] (for private sector projects) or to governments or citizens [or both] (for public sector projects).
2. Did they answer the 'Why blockchain?' question?
Assignment 1 revisited: Consider benefits, risks and implications of using blockchain motivated by applications or use cases that are well suited to blockchain. Consider this carefully in the context of the "distributed databases" technology hierarchy slide we covered in the slides of September 12:

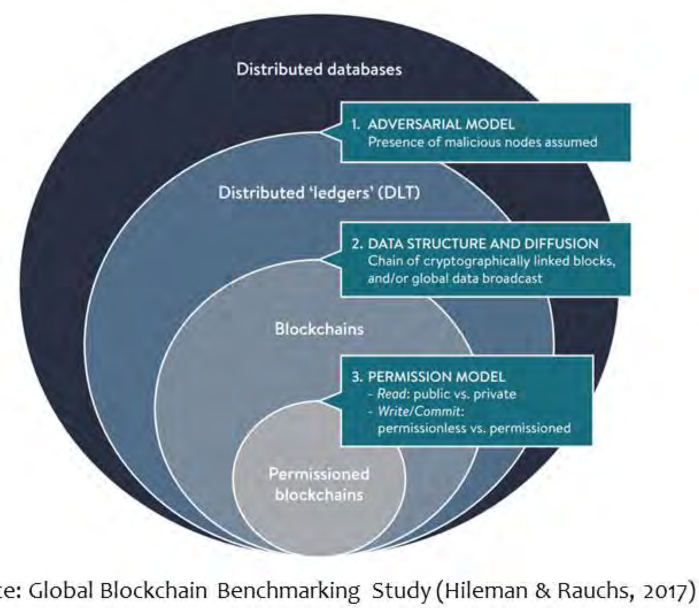

Figure 6 (a). Specification of the peer assessment Assignment 3 from Bentley University

Abstract for your Research Project, 250 words maximum

By being so concise, this is a "less is more assignment" designed to focus your time and energy on a research topic that you can start and finish by mid-December with minor, but not major, modifications along the way.

Your abstract should explicitly do three things:

1. Identify a right-sized topic area for your research project.
   (Hint: Right-sized topic areas are usually smaller than you think.)
2. State the motivation for your research project:
   Why is the topic of interest to business or consumers [or both] (for private sector projects) or to governments or citizens [or both] (for public sector projects).
3. Answer the 'Why blockchain?' question:
   Consider benefits, risks and implications of using blockchain motivated by applications or use cases that are well suited to blockchain.

If it's helpful to address the methodology or approach in the first draft of your abstract, please do so. If it's not helpful, please don't. Recall that I said in class that it is fine at this point if your abstract is methodology agnostic.

If you need some non-blockchain examples of good abstracts, I have put four research papers on our course blackboard site in Course Documents > Example Abstracts.

Finally, please submit your abstract at the Assignment 1 TurnItIn.com link below.

Figure 6 (b). Specification of Assignment 1 which was revisited as part of Assignment 3

Appendix E. Maintaining Land Records with Blockchain in Chittenden County, Vermont and Cook County, Illinois

00048316 V: 1412 PG: 199

CITY CLERK'S OFFICE
Received Feb 21,2018 11:32A
Recorded in VOL: 1412 PG: 199 -200
OF So. Burlington Land Records
Attest:
Donna Kinville
City Clerk

WARRANTY DEED

KNOW ALL PERSONS BY THESE PRESENTS that **KATHERINE M. PURCELL**, of Burlington, County of Chittenden and State of Vermont ("Grantor"), in consideration of the sum of Ten and More Dollars, paid to her full satisfaction by **KP2 LLC**, a Vermont limited liability company with a place of business in Burlington, County of Chittenden and State of Vermont ("Grantee"), by these presents, does hereby **GIVE, GRANT, SELL, CONVEY and CONFIRM** unto the said Grantee, **KP2 LLC**, and its successors and assigns forever, a certain piece of land with all improvements thereon and appurtenances thereto in the City of South Burlington, County of Chittenden and State of Vermont (the "Premises"), described as follows, viz:

> Being all and the same lands and premises conveyed to Katherine M. Purcell by Warranty Deed of Maurilio Fabiano dated March 18, 1988 and recorded in Volume 259 at Page 382 of the South Burlington Land Records, and being more particularly described therein as follows:
>
> > "Being all and the same lands and premises conveyed to the within Grantor by Warranty Deed of Stephen B. Jamison and Patricia A. Jamison dated 10/23/85 and recorded in Volume 214, Page 226 of the South Burlington Land Records and being more particularly described therein as follows:
> >
> > 'Condominium Apartment 143, Cluster 6, Twin Oaks Condominium, together with a 3.073 percent interest in the Common Areas and Facilities and Limited Common Areas and Facilities as set forth in the Declaration dated August 20, 1980, of record in Volume 162 at Page 264 of the City of South Burlington Land Records.
> >
> > Said premises are subject to the Declaration of Condominium for Cluster 6 of the Twin Oaks Condominiums, dated August 20, 1980, recorded in Volume 162, Page 264; the Bylaws of the Twin Oaks Condominium Association, Cluster 6, dated August 20, 1980, recorded in Volume 162, Page 273; and an Agreement and Declaration of Covenants, Conditions, Easements and Liens, dated January 16, 1979, recorded in Volume 143, Page 514, as amended by instruments datec February 20, 1979 and April 9, 1979, recorded in Volume 143, Page 559 and Volume 150, Page 110, respectively, and as confirmed by an instrument dated January 31, 1980, recorded in Volume 157, Page 475. The lands are further subject to Land Use Permits dated October 19, 1979 and November 27, 1979, recorded in Volume 157, Pages 184 and 272, respectively...'
> >
> > Stephen B. Jamison and Patricia A. Jamison join in the execution of this deed to convey any interest they may have in this premises as a result of a defect in the execution of their deed to the Grantor herein."
>
> The Premises are subject to: (a) taxes assessed on the Grand List not delinquent on the date of this Deed, which Grantee herein assumes and agrees to pay as part of the consideration for this Deed subject to such taxes being prorated between Grantor and Grantee on the date this Deed is delivered; (b) the provisions of municipal ordinances, public laws and special acts; and (c) all easements and rights of way of record, not meaning to reinstate any claims barred by operation of the Vermont Marketable Record Title Act, 27 V.S.A. § 601, *et seq*.
>
> Reference is hereby made to the above-mentioned instruments, the records thereof and the references therein contained in further aid of this description.

00048316 V: 1412 PG: 200

TO HAVE AND TO HOLD the said grantee Premises, with all the privileges and appurtenances thereto, to the said Grantee, **KP2 LLC**, and its successors and assigns, to their own use and behoof forever; and the said Grantor, **KATHERINE M. PURCELL**, for herself and her successors and assigns, does covenant with the said Grantee, and its successors and assigns, that until the ensealing of these presents, Grantor is the sole owner of the Premises, and has good right and title to convey the same in the manner aforesaid, that the said Premises are **FREE FROM EVERY ENCUMBRANCE**, except as aforementioned; and they hereby engage to **WARRANT and DEFEND** the same against all lawful claims whatsoever, except as aforementioned.

This conveyance has been recorded in smart contract 0xa188e5a3da203f8ebc72ec7578532926dc1d3bec of the public Ethereum blockchain.

IN WITNESS WHEREOF, the parties do hereby execute this Warranty Deed this 20th day of February, 2018.

Katherine M. Purcell

Katherine M. Purcell

STATE OF VERMONT
COUNTY OF CHITTENDEN, SS.

On this 20th day of February, 2018, personally **KATHERINE M. PURCELL**, to me known to be the person who executed the foregoing instrument, and she acknowledged this instrument, by her signed, to be her free act and deed.

Before me, ______________
Notary Public

Printed Name: Michelle N Farkas

Notary commission issued in Chittenden County
My commission expires: 2/10/19

Vermont Property Transfer Tax
32 V.S.A. Chap 231
-ACKNOWLEDGEMENT-
RETURN REC'D-TAX PAID BOARD
OF HEALTH CERT. REC'D.
VT LAND USE & DEVELOPMENT
PLANS ACT. CERT. REC'D
Return No. ______________
Donna Kinville City Clerk
Date Feb 21,2018

END OF DOCUMENT

Figure 7 (a). Copy of the paper deed registered in Chittenden County (Vermont) used in a property transfer during South Burlington's blockchain pilot

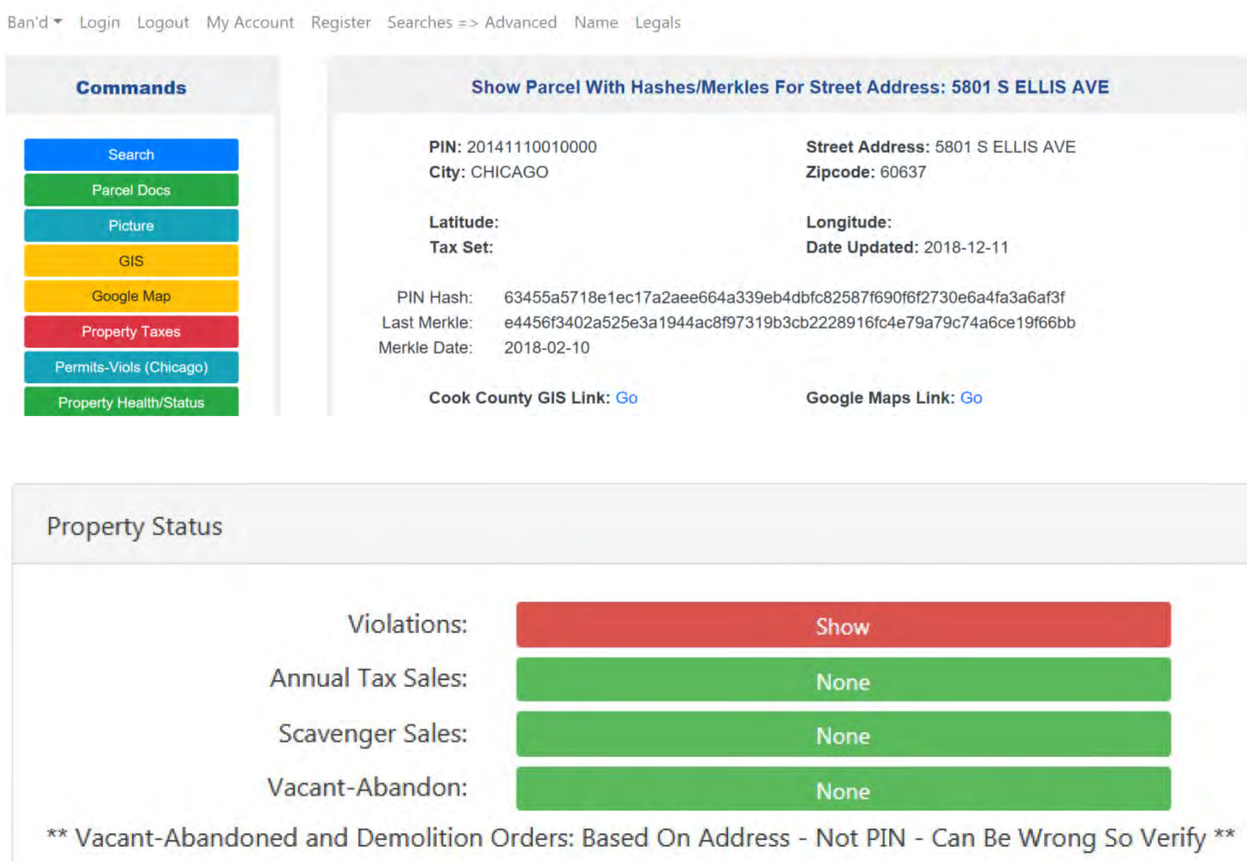

Figure 7 (b). Visual of the *Property Health* portal used in Cook County (Illinois) Recorder of Deeds blockchain pilot

Appendix F. Privacy Concerns for Healthcare Data on a Blockchain and Smart Contracts with CryptoZombies

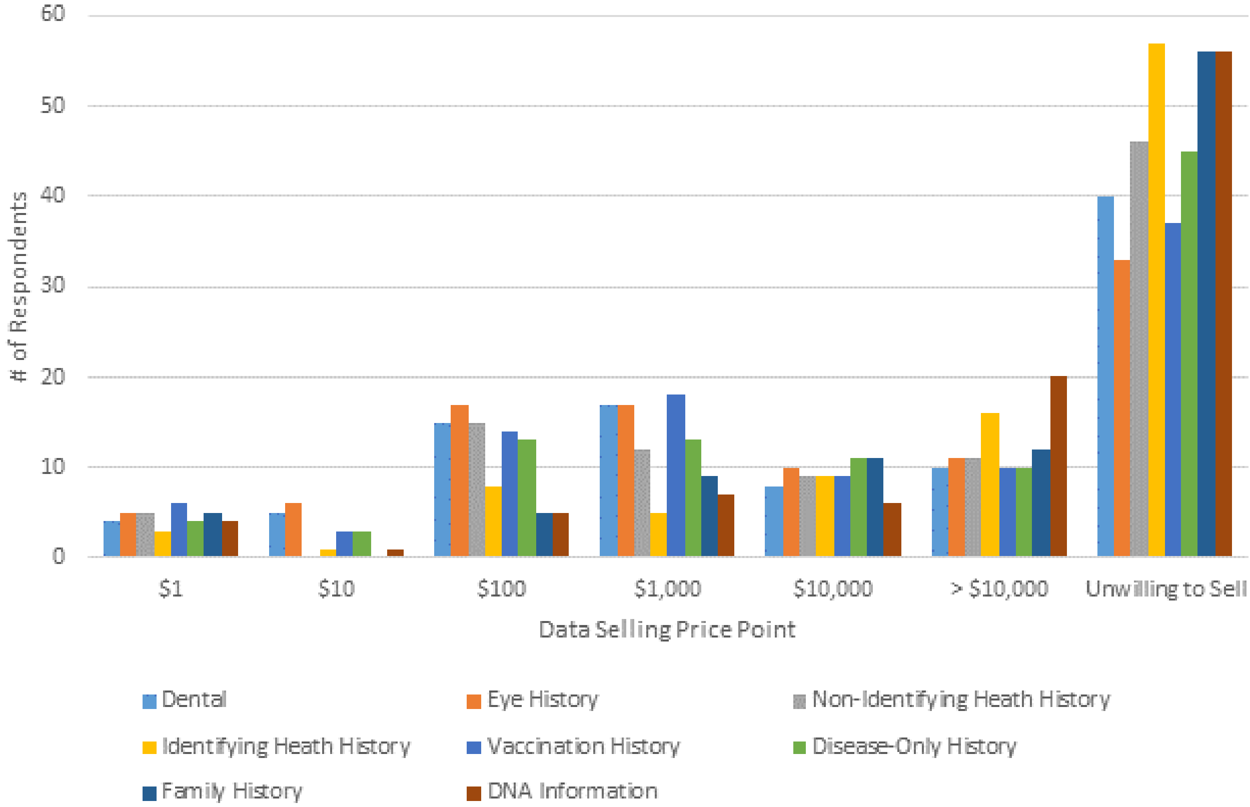

Figure 8. Data sensitivity of healthcare data

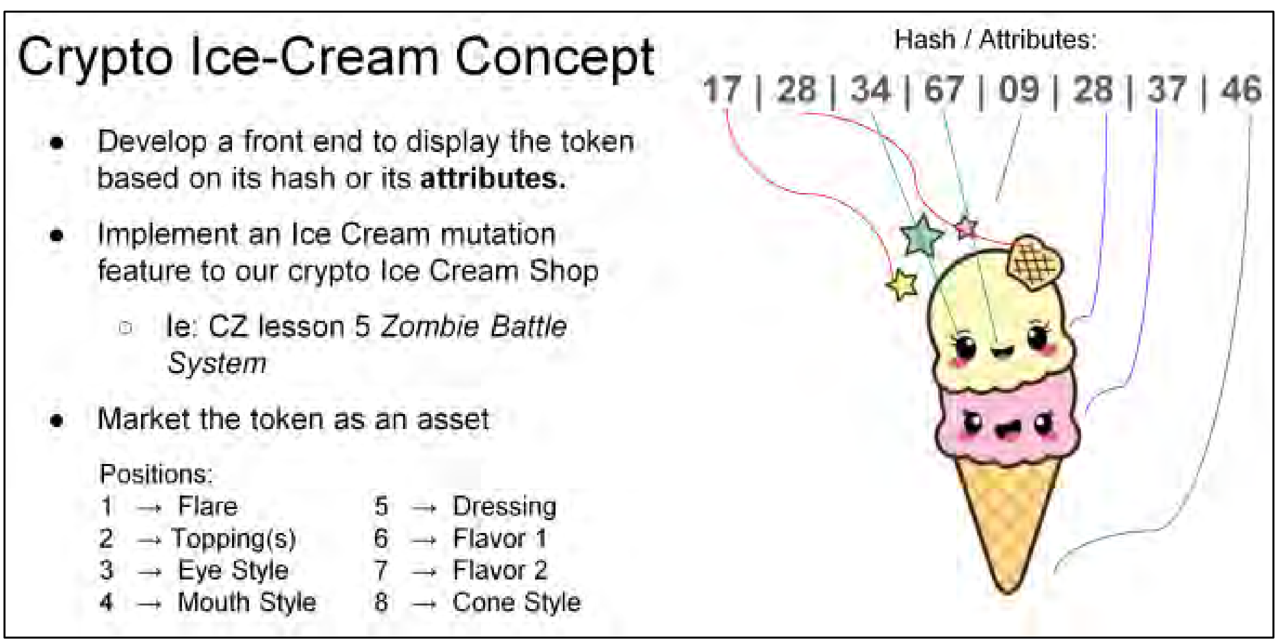

Figure 9. Conceptual design of crypto ice cream shop with example cone

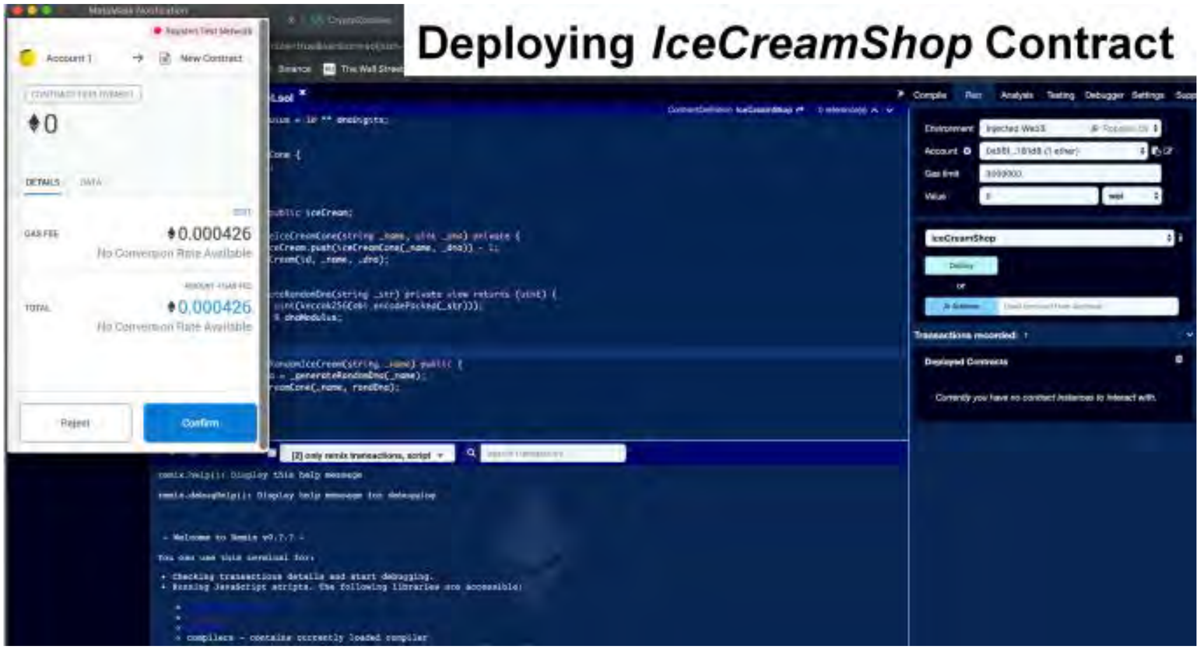

Figure 10. Smart contract deployment screen with transaction confirmation

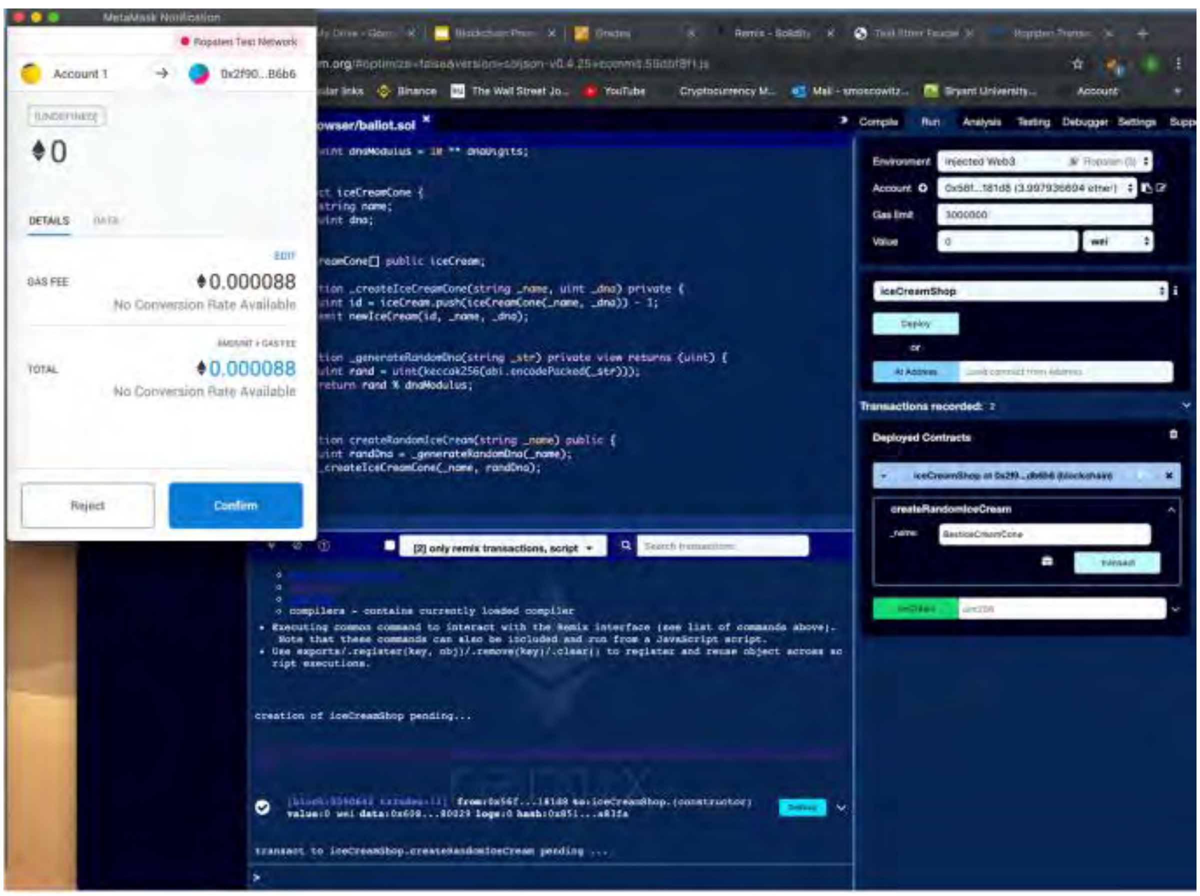

Figure 11. Evidence of smart contract deployment to test environment

[This is a Ropsten **Testnet** Transaction Only]

Transaction Hash:	0xa7eb89ae7d1686e42166e6fc6fa15923592db272f6850c623e2342bd9feb1e00
Status:	Success
Block:	5590644 1 Block Confirmation
Timestamp:	1 min ago (May-13-2019 03:53:10 PM +UTC)
From:	0x56f0efacc559525ac56f5628d3e891b07a3181d8
To:	Contract 0x2f90299b29643a8406d6a121317ee37a91cdb6b6
Value:	0 Ether ($0.00)
Transaction Fee:	0.000087527 Ether ($0.000000)

Figure 12. Transaction confirmation on Ropsten test environment