From Learning to Assessment. Utilizing Blockchain Technologies in Gaming Environments to Secure Learning Outcomes and Test Results


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Abstract: This study, pursues the following three goals, namely the introduction and discussion regarding Blockchain technologies in education in general and serious games in particular; a definition and proposal of a category system for digital games with the aim not only to teach but also to assess; and a description of the serious game Gallery Defender, one of the very first games which maps grades/certificates for the player/learner as well as further information for the teacher on Blockchain. This game is currently in the middle of an iterative design process and the authors describe the used Blockchain approach of the first iteration of the game to inspire further developments in this direction, especially for the Maltese audience, as Malta is perceived as the leading EU country in the field of Blockchain regulation.

Keywords: Education, Game-based Assessment, Game-based Learning, Blockchain

Introduction

For many decades, computerized media have continued to change our world through their main characteristics of interactivity, digitalization, and virtualization (Kraemer 1998): being interactive, they have allowed us to engage with complex social, political, and economic processes in a meaningful way; being digital, they have made a wide range of properties, actions, and processes measurable and comparable and being virtual; they
have opened up alternatives to the restrictions of the material world, creating spaces in which properties, actions, and processes can be produced and reproduced at will and in which the limitation of resources does not apply.

This third characteristic of virtuality becomes vividly apparent in the seemingly limitless possibilities of computer-game worlds. When players of a computer game have fulfilled the requirements to be awarded a specific kind of resource, this resource can instantly be ‘produced’ by the game system, without risking depletion of supplies. The volume of resources can be increased at any time if more players enter the game (Pfeiffer 2018). In a similar manner, space is not limited in a virtual world: regardless of whether one player or a million players enter a room within a game, each one of them can have one’s own version (a so-called instance) of the room available, without the increasing number of rooms taking up increasing space. And, as these game spaces are virtual, they can be accessed from anywhere in the material world, making it possible for players from all over the world to ‘meet’ and interact within the same virtual space.

All these features of virtuality have contributed greatly to the success of digital learning environments (and particularly game-based or gamified learning environments). In these virtual spaces, learners can receive instant feedback for their learning efforts, regardless of whether their teacher is currently engaged with another student, or even the place where the learner is located. They can immediately access the resources which best support their individual learning progress, without having to wait for another student to finish using them. Virtual classrooms will never be crowded, and learners can enter the learning environment from any place in the world, if they have access to the Internet. However, while virtual environments leave behind certain limitations of the material world, this can create problems of a different kind. Such problems are especially prevalent when the uniqueness of items or matters of ownership are of importance, the possibility to reproduce items, actions, or processes infinitely and without any loss of quality can have unwanted effects like data piracy, copyright infringements, identity theft, and other kinds of online fraud (Rüdiger and Pfeiffer 2015).

In the educational sector, similar problems arise as soon as value is placed on the assessment of learning performance and the grading of learning achievements. Even when the assessment of learning success is not deemed important, the individual experience of achievement, and therefore the learner's motivation, depends on the trustworthiness of learning achievements; it might not seem worthwhile to make an effort if the same effect can be achieved more easily by cheating or if the idea prevails that others are awarded a good grade without the same effort. The need to create trust, reliability, and, in some cases, a sense of achievement has therefore made it necessary to re-introduce certain limitations artificially to serve as safeguards against fraudulent behaviour. Most importantly, these safeguards limit by whom and under what conditions data can be changed. Just as a person cannot simply edit the amount of money on his banking account, and not just anybody can make a transfer from his account, certain data stored in virtual learning environments cannot be changed at will. Learning achievements will be tied to his learning efforts which are again tied to his personal, password-protected account; and grades can only be changed either by the system or by a teacher, whose account will again be password protected to prevent unauthorized persons from tampering with the grades.

But even these safeguards are only as safe as the systems that provide them and, if these systems are controlled by one centralized authority, they are far from manipulation-proof. While these measures can in many cases prevent manipulations within the system,
it will still be possible to manipulate the system itself. Even if the learner trusts teachers to grade learning efforts fairly, the data can still be manipulated by the system’s creators and administrators or by people ‘hacking’ into the system and changing data without permission.

A recent answer to these challenges presents itself in the form of Blockchain-based technologies. As decentralized systems, Blockchains should offer by design little opportunity for tampering attempts, and especially in the case of sufficiently established, public, and permission-less Blockchain systems, manipulation becomes virtually impossible.

When information is stored on the Blockchain, it cannot be altered retroactively (Atzei 2018). In addition to giving users full control over how their data is used and providing unambiguous information about the provenance of this data, it is this immutability that makes Blockchain systems the perfect technology to secure critical information like personal data and finances, but also learning achievements and educational credentials. Once learning achievements and credentials are stored in a Blockchain-based system, neither teachers nor learners, and not even system administrators or the designers of the system can change entries, remove success criteria, or add additional milestones. And as this system is de-centralized, there is nobody who can be approached and ‘convinced’ to change data entries retroactively.

Game-based learning

Far beyond their obvious success as entertainment media, digital games have increasingly gained attention as a facilitator of learning processes and education. The potential benefits of digital game-based learning (GBL) applications and strategies have been explored thoroughly (Gee 2007; Klopfer et al. 2009; Annetta 2010; Bers 2010; Squire 2011; Klopfer et al. 2018; Thomas 2018; Thompson et al., 2019) as have their limitations (Wagner 2009; Linderoth 2010; Wernbacher 2013). However, Zusho (2014) proposes to extend the impact of game-based learning in terms of motivation and transfer aspects to models other than flow (Csíkszentmihályi 1990) and/or self-determination theory (Ryan 2000), because new approaches are needed to actually prove the impact of game-based learning.

Various initiatives are promoting educational gaming as a suitable tool to face the educational challenges of the digital age such as Quest2Learn, which transforms a whole school into a game environment (Salen 2011), and ‘Learning with Computer Games’, a curated collection of didactically useful games (Pivec and Pivec 2012). The Centre for Applied Game Studies at Danube-University in Krems researched the applications of gamification, games, and serious games at schools for nearly a decade, leading to the creation of the online resource www.toolkit-gbl.com (Koenig 2014) and the project ‘Create Digital Games for Education (CDG4E), a tool for creating decision-based games. Both projects were funded by the European Union. The LIVE Lab (Learning interactive visualization experience) is a research facility at Texas A&M University College Station that has developed interactive learning experiences since 2014 and works closely with publishers and policy-makers in the educational sector. The MIT Scheller Teacher Education Program and The Education Arcade focus on creating playful and powerful learning experiences using the affordances of new educational technologies. All of these approaches show that the pedagogical value of digital games is becoming increasingly acknowledged within the educational community and beyond and that the application of this potential in educational practice is a declared goal.
According to Prensky (2001, 2012), today's students are ‘digital natives’, people who have lived with access to computers and digital media since early childhood. Dingli and Seychell (2015) go one step further and call the generation that already grew up with tablet-PCs and Smartphones 'the new digital natives' or 'generation glass', as growing up with those devices differs from the 'Computer & Mouse generation', due to the gesture control only using the fingertips. The impact of digital games on cognitive, motivational, behavioural, social, and affective outcomes has been examined in various studies (Green and Bavelier 2007; Gee 2007; Rosser 2007; Tüzün et al. 2009, Dingli et al. 2013; Camilleri et al. 2017, Dingli and Montaldo 2019). In addition to these individual but important studies, there is also a limited number of meta-analyses on the impact of serious games and gamification in education. A study by Wouters et al. (2013) summarizes the effects of studies on more than 12,000 participants and states that serious games are a superior alternative to conventional educational practices. Significant positive effects on motivation, skill acquisition, and retention were reported in most of the studies (p<.05; d=.29-.45). A literature review by Hamari et al. (2014) showed that gamification has positive effects on psychological variables like motivation or enjoyment and behavioural outcomes, like user participation or learning outcomes.

**Classification of game-based approaches to assessment in the context of education**

In addition to the concern of enabling effective learning experiences, the assessment of learning processes through gamified and game-based means has also become a trend in recent years (Bezzina 2015; DiCerbo 2015; Kato and de Klerk 2017; Nikolaou 2019). This can be achieved by either playing games or gamified approaches only with the sole purpose of simulating and/or assessing or by using the same game/gamified approach that was used for educating through a playful experience before the assessment. Irrespective of the structure, game-based and gamified approaches (Deterding 2011; Pfeiffer 2018) to learning assessment can take various forms:

First, game-based approaches to learning assessment can either rely on the gamification of conventional testing situations or on the creation of actual testing game environments. Second, game-based assessment approaches can either serve the sole purpose of testing, or they can be part of a broader game-based learning approach in which game-based tools are used for enabling as well as evaluating learning experiences. And finally, the difference between game-based learning and game-based assessment can either be explicit or done in a way that is hardly noticeable by learners. The authors therefore suggest the following classification of game-based approaches to assessment in the context of education:

**Gamified Learning Assessment (GLA)**

Gamified assessment concepts rely on existing psychometric science, including gamification characteristics, such as points and challenges. They should be implemented well thought-out and are most of the time cheaper to develop than serious games as assessment tools, as they are only a second layer on the existing real-world environment. Just as in any ‘regular’ E-learning assessments, it is crucial that such assessment tools can ensure that the user taking the test is who he pretends to be and that the result (if not the test itself) is not prone to manipulations, especially those which are (a) easy to conduct and/or (b) hard to detect.
Game-Based Assessment (GBA)

Game-Based Assessments consist of testing environments that take the form of an actual game. Apart from being also based on psychological methodology, the main challenge here is to create a game that stays true to the curriculum by incorporating the testable skills and knowledge in a meaningful way, while at the same time being designed in a way that is also entertaining, engaging and accessible. In addition to gamified learning assessments, developers and educational designers have to avoid glitches within the game environment, as these glitches might distort the testing results.

Combined Game-Based Learning and Assessment (GBL&A)

Due to the success of game-based learning, it makes sense to design game-based assessment and game-based learning tools as complementary to each other. In combined Game-Based Learning and Assessment environments, a learning experience might take place in one level of a game, while another level serves as a testing stage for the evaluation of learning progress. While the demands regarding safeguards against identity fraud, cheating, and result-distorting glitches are the same as in regular game-based assessment, an additional challenge lies in the fact that the assessment segments must not only reflect the curriculum but must also be synchronized with the learning segments.

Integrated Game-Based Learning/Assessment (GBL/A)

The most promising, but also the most challenging, form of game-based assessment is the actual integration of learning assessments as interlaced parts of game-based learning experiences. Contrary to Game-Based Learning & Assessment, there is no noticeable switch between learning and testing, as the system tracks and maps learning progress as it happens, and learners do not have to step out of their learning experiences for the purpose of testing. While all forms of game-based assessment call for measures that ensure security and establish trust, GBL/A approaches are especially demanding not only regarding data volumes, but also regarding the criteria under which a constant assessment of even the smallest actions and decisions can occur. Integrated Game-Based Learning/Assessment raises the questions of where the game stops and where the exam begins, and whether this form should only be used for self-directed learning, without any effect on a school, university, or company-related examination of performance.

However, in all these cases the examiners as well as the examinees should have faith regarding the validity of the test outcome and fairness of the testing tool. Furthermore, it should be impossible to manipulate the results, e.g. altering the txt, .csv or .json file storing the data (which may include personal identifiers, time and date, results, steps to results, etc.). In this sense, non-Blockchain-based approaches can hardly ensure the required level of trust and immutability. This raises the question whether Blockchain-based approaches are better suited to do so, and if they are, in which ways?

Currently, most digital learning environments and assessment tools safeguard their data using safety systems (e.g. password protection) that are not Blockchain-based but controlled by a centralized authority. While these centralized systems provide a certain level of security against unauthorized access from outside the system, the possibility of manipulation from within the system cannot be dismissed. Users with high enough access rights (teachers, administrators, system managers) can still add, change, or delete
entries. This becomes an even greater problem when learning achievements are to be reflected in fair and transparent credit systems and especially when these educational credits are to be valid across different institutions or even countries, or if the assessment outcome is an important factor in the admissions for a college or university. As a result, there could be cases in which the administrative staff is bribed to change the learning results to the positive (referring to the Felicity Huffman case). These and other reasons speak for the use of Blockchain technologies in the education sector.

**Discussing Blockchain technologies in the educational sector**

Immutability to changes made retroactively make Blockchain systems the perfect technology to secure learning achievements and educational credentials. Keeping data trustworthy, secure, and manipulation-proof has become an increasing issue in education due to the rise of digital learning environments which often combine learning experiences, testing procedures, and educational credential management. Due to their ability to store data in a de-centralized, transparent, and manipulation-proof way, Blockchain-based technologies can provide solutions to this problem. However, it is necessary to first gain a sound overview of the different ways in which these technologies can be used in the educational sector and to assess the expected merits and drawbacks of these respective strategies.

In the early 1980s, Lamport et al. (1980, 1982) described the Byzantine generals’ problem and outlined possible solutions in their papers ‘Reaching Agreement in the Presence of Faults’ and ‘The Byzantine Generals Problem’. The name refers to the attack on Constantinople in 1453, during which the city had to be attacked simultaneously from several sides due to its strong fortifications. The generals who were to coordinate the attack communicated with each other by messenger, as they could not be in the same place at the same time. However, some of these generals were prone to send false and contradictory messages to other generals on purpose, as they wanted to gain a personal advantage by discrediting their fellow combatants in the eyes of the sultan. In effect, while there was a constant flow of messages in all directions, the receivers could never be sure whether they could trust the message and the person who had it delivered to them.

Just like the Byzantine generals more than 500 years ago, today’s digital society, too, is struggling with severe trust issues. We have to trust the retailer when shopping as private individuals on craigslist.org, eBay, sellinmalta.com, willhaben.at or even from large corporations such as Amazon. Apart from the transfer of monetary-values, we need to build trust in e-mails and other electronic correspondence – e.g. via Internet forums – or the belief that the sender is in fact who it is supposed to be. And when it comes to game-based-assessment in classroom, the teacher also needs to trust that, for example the set of information that is delivered from the game engin/gamified e-learning system has not been altered. This is where Blockchain technology comes in:

> "From a social perspective, Blockchain technology offers significant possibilities beyond those currently available. In particular, moving records to the Blockchain can allow for:

1. **Self-sovereignty**, i.e. for users to identify themselves while at the same time maintaining control over the storage and management of their personal data;
2. **Trust**, i.e. for a technical infrastructure that gives people enough confidence in its operations to carry through with transactions such as payments or the issue of certificates;"
3. Transparency & provenance, i.e. for users to conduct transactions in knowledge that each party has the capacity to enter into that transaction;
4. Immutability, i.e. for records to be written and stored permanently, without the possibility of modification;
5. Disintermediation, i.e. the removal of the need for a central controlling authority to manage transactions or keep records;
6. Collaboration, i.e. the ability of parties to transact directly with each other without the need for mediating third parties.’ (Grech and Camilleri 2017)

These features of Blockchain as technology also have great value for the field of education. Especially in combination with digital identity management, Blockchain technology unfolds its full power. Even if Blockcerts (an open standard for Blockchain credentials, developed by the MIT Media Lab) is intended to be a technical standard to work across any Blockchain (currently working on Bitcoin and Ethereum), when MIT Media Lab developed Blockcerts, they decided on building it upon the Bitcoin Blockchain for the following reason:

‘The easy answer is that, when we started out, Ethereum was a mere whiff of an idea (no pun intended). The other part of the answer is that Bitcoin has been the most tested and reliable Blockchain to date; in addition, the relatively robust self-interest of miners, and the financial investment made into Bitcoin (and Bitcoin-related companies) make it likely that it will be around for a good while longer. Our solution is not locked to one particular Blockchain – it would be easy to also start publishing our credentials to other Blockchains, but for most of what we want to do, the functionality of the Bitcoin Blockchain continues to be sufficient. That is not to say that we are not curious about the potential of smart contracts, and we are discussing the potential of Ethereum-based side-chains to reduce transaction cost and expand functionality.’ (Juliana Nazaré on Medium.com)

The afore-mentioned blog posting was made in June 2016. Three years later, the Blockchain ‘Ethereum’ had a market cap of 20 billion USD (9 September 2019), which is nearly double the market cap of all Blockchain systems, including Bitcoin, had when Juliana Nazaré from the MIT Media Lab wrote her article. Apart from Ethereum, many different Blockchain systems have entered the market. Some of them (Ardor, Etc, Eos, Nem, Nxt, Tron, or Waves, just to mention a small selection) allow to create Tokens/Assets and Cryptocurrencies upon them (like the ERC20 Tokens on Ethereum). All these new systems and applications built on them lead to a number of new problems:

(I) In the near future, there might be a number of different educational credit systems similar to blockcerts built upon a large variety of different Blockchain systems, and different institutions (universities, colleges, schools, ...) might also use different credit systems. A possible solution to this problem would be an independent mediator who can collect and validate the credentials issued on the various systems. Such a mediating system could serve as a ‘collection point’, compiling and validating the results of the various credential systems and connecting them to the users digital ID (e.g. the ‘A-Trust ID Card’ issued by the Austrian government), or (within the EU) other digital identity procedures within the EIDAS (Electronic iDentification, Authentication and Trust Services) regulation), making it possible for users to access their own data and share it as proof of achievement (e.g. as a link in their CV).

Another reason why such an independent mediating system might be useful or even necessary is the possible dependency on the provider of a Blockchain-based application. This is mainly due to these credential systems not being based on open-source, public,
permission-less Blockchains, but on centralized, controlled Blockchains, owned by private companies, who intend to sell their systems to governments and universities (for instance, Sony corporation has recently developed such a system, based on a patent the company holds, and is currently marketing it to schools and universities). While this company might successfully sell its system to an educational institution and might even provide an excellent service in handling this institution’s processes regarding test results, credentials, admissions, etc., it is still possible that, for whatever reasons, the company decides to shut down its centralized permissioned Blockchain at a later point. Without an independent mediating system, the data would almost certainly be lost, defeating the purpose of using a Blockchain-system altogether. If, on the other hand, the data was compiled at a universal ‘collection point’, together with the data from all the other credential systems, a verified copy of the results would still exist on a public permission-less Blockchain and could be stored on this (de-centralized) Blockchain potentially forever. Such a system would provide the security of a decentralized Blockchain even for centralized Blockchain applications, enabling anyone to run a full node at low costs that acts as a public ledger and ensuring that the Blockchain and its entries will exist unless everyone in the world including yourself is shutting down the node.

(ii) Other potentially challenging issues (technologically as well as financially) are the number of transactions that can be handled within a certain period, the transaction costs, and who is responsible in payment terms (because on a public Blockchain transactions usually cost a certain amount of money, commonly paid in the native token of the specific Blockchain).

A university using blockcerts might only have to issue the learning credentials twice a year to each student. In this case, the number of transactions is still easily manageable, and the transaction fees (amounting to two times the number of students, multiplied by the fees payable to the network), will be in the affordable range. While Blockchain technologies even for basic E-Learning and E-Assessment applications already lead to a much higher number of transactions, since not only the final grades would be entered in the Blockchain but also the results from each single test and maybe even the answers to specific questions.

The greatest number of transactions, however, occur when game-based assessments (and especially Integrated Game-Based Learning/Assessment solutions) make use of Blockchain-systems. In this case, any single-step learners take might be stored, in addition to milestones they reach and badges that signify a specific competence gained, even before all this data leads to a test result which, again, is reflected in a final grade. This enormous number of transactions is necessary to reach the goal of immutable and continuous learning environments and the possibility of learning credentials that do not only show the results at the end of the semester, but also record all steps in-between that lead to the final grades. Due to this enormous number of transactions, game-based learning assessment calls for especially robust Blockchain systems and, as these transactions will need to be nearly instant as well as cost-effective, strategies that enable more efficient transaction management (utilizing, for instance, mechanics like bundling, pruning, proof-of-existence-secure timestamps using merkle-trees) will be in high demand. Future research projects in this direction are of utmost importance. In all mentioned cases it should also be possible to make Blockchain-enabled learning and assessment environments without the player/learner having to hold tokens of the Blockchain-system used by himself and the system has to offer an interface which can easily be used by third parties (e.g. educational software providers) while still being immutable at the same time.
A Blockchain-based system must therefore be extremely robust in order to handle the enormous number of transactions that occur using game-based assessments (and especially GBL/A) approach. Any system that is strong enough to handle this volume of transactions will easily handle more simple demands like E-Learning assessments or storing the final grading results at the end of each semester. Hence, focusing on Blockchain solutions for GBL/A as a long-term goal makes sense, as this will ensure that its findings will also be applicable for less demanding applications, making them highly relevant not only for the educational sector as a whole, but also for Blockchain-developers who are interested in stable and sustainable strategies Blockchain-applications.

(III) Yet another issue that differs, but cannot be dealt separately from technological problems, is the human factor, or more specifically, the question what role humans play in the process of creating, storing, and managing data on the Blockchain. While safe-keeping data on a Blockchain is primarily a technical process, the data itself (at least some of the educational data, like grades) is often produced by human agents. Regarding the human factor, the following issues must at least be kept in mind when developing future Blockchain-in-education scenarios:

- Humans as a source of error. Especially in the educational sector, even the most sophisticated digital environments will not make human interaction obsolete, as learning and education are inherently social processes. This also means that any application that involves learning and assessment must deal with problems caused by human error. Some of these problems can effectively be countered or excluded by Blockchain-based technologies. Especially in the case of retroactive manipulation of data, non-Blockchain systems are prone to manipulation, as even the most advanced safeguards cannot prohibit users with high enough access rights to manipulate existing data entries (this may be a mere annoyance when a well-meaning teacher edits a favourite student's attendance times, but it can quickly become a large-scale problem when the recognition of diplomas is tampered with on an institutional level). As data stored on the Blockchain cannot be altered retroactively, the problem of tampering with existing data could easily be ruled out.

However, even when a Blockchain-system secures the storage and management of data, there are still humans involved in the process. Especially when Blockchain is used only for the final storage of grades, there is still plenty of room for error. When a professor takes an exam, tells his assistant to note the grade, which is then dropped off at a secretary's desk, who emails the grade to the Blockcert-department for secure entry in the Blockchain, this process offers many opportunities for human error, ranging from unfair grading by the professor, to the assistant mixing up US and European grading scales, to the secretary mistyping when copying the grade, to the Blockcert-clerk assigning the grade to the wrong student.

This problem can be reduced when a whole (basic, gamified combined, or even integrated game-based) E-learning and Assessment system is based on the Blockchain, as this allows the immediate storage of test results and ensures that grades are calculated based on a grading fixed key and in real time. While the initial creation of the test (including how answers and actions are evaluated, and the determination of the grading key) is still subject to human error, it is the system that provides transparent testing conditions for every student, saves the (intermediate and final) results immediately and securely, and safeguards this data from retroactive manipulation.

- Dealing with faulty entries: While Blockchain-based systems can ensure the immutability of data, this also creates problems when it turns out that this data has been created based
on faulty premises. The more obvious reason for faulty data entries has already been described on the example of systems which only use Blockchain technologies to store final grades, as there is a great number of reasons that can lead to a wrong grade being entered in the Blockchain. Even when a sophisticated E-learning and assessment system ensures that grades are always correctly calculated in accordance with the grading key, mistakes in determining the grading key or in setting the correct and incorrect answers in a test cannot be ruled out.

If it turns out that the wrong grades have been saved, or if the learner has improved his grade on a new attempt of the test (or if it has stayed the same or even worse, but definitely with a new timestamp), they still cannot be changed. Instead, additional entries must be made that contain not only the correct grade but also the information that the previous grade has been entered incorrectly into the system, because corrections cannot made as edits, but only as additions to existing entries. In this sense, Blockchain-based systems might require a radical re-thinking of educational credentials, as these systems no longer highlight the learner's successes but instead serve as a comprehensive learning biography, in which successes, stagnation, and failures are equally reflected.

In order to further investigate the previously discussed approaches, the authors decided to go for an applied approach and develop a serious game (named Gallery Defender) including an assessment mode that uses Blockchain technology to store and transfer the grading and other information related. The approach is described in detail below, starting with the Blockchain system selected for the serious game.

**The Ardor Blockchain**

After intensive research, the authors chose the Blockchain system Ardor. The Blockchain implementation takes place in the testnet of Ardor, on the Ignis childchain. The decision for this Blockchain system was taken based upon the following thoughts:

1. Ardor is based on a Proof of Stake (PoS) Consensus Algorithm which is considered extremely environmentally friendly. The (testnet) node the LIVE Lab of Texas A&M University uses is based on a Raspberry Pi3 B+, with even the possibility to use the strong Texan sun to power the computer nearly independently from conventional power sources.

2. As the tokens storing grades should be pure-utility tokens, the player/learner is unable to send the token peer2peer to someone else (without the issuing institution approving the transfer first). The asset management on the Ignis childchain and the possibility to enable phasing meets the functional criteria of the game prototype. Phasing is a feature that allows certain phasing-safe transactions to be created with conditional deferred execution based on the result of a vote, on a list of linked transactions or on the revelation of a secret; or simply with unconditional deferred execution.

3. The possibility to set up ‘Bundling-Accounts’ means that accounts can pay transaction fees for the player/learner. There is therefore no need at all that all player/learner or other users have to purchase cryptocurrencies, in this case the ‘Ignis token’. This seems to be a key feature to build Blockchain-based systems beyond the cryptocurrency and Blockchain community.

4. While sending a token, the designers of the system can decide if the information attached to the token is stored forever or only for a certain amount of time. This enables the possibility that the grading results and points are stored forever at the user account (and the issuing institution can of course retrieve the information
from there), while the information on the token sent to the teacher is considered as 'prunable data', meaning that the information is only stored for a predefined time, e.g. 90 days by default.

5. The Ignis asset exchange on the Ardor platform already supports most of the ERC20 and ERC 721 operations out of the box without the need to issue a smart contract. That means that using the Ignis childchain is not closing doors to other widely used Blockchain-systems, but opening them.

6. With the possibility of the asset-control functions, KYC (know your customer) or in this case KYL (know your learner), KYT (know your teacher) and KYI (know your institution) can be implemented in future versions of the Gallery-Defender prototype. This aspect is of utmost importance regarding fraud-prevention and recognition of the results beyond the issuing institution. The idea behind this is that the school verifies the Ardor Blockchain Address of teachers and students, a process that can obviously be conducted on Blockchain, again possibly using the Ardor Blockchain.

Porting from the testnet to the mainnet, the time the game is ready to be published, is easily possible. Following is an overview of different Blockchain systems which were considered for this project:

<table>
<thead>
<tr>
<th>Language</th>
<th>ARDOR</th>
<th>CARDANO</th>
<th>ETHEREUM</th>
<th>EOS</th>
<th>NEO</th>
<th>NXT</th>
<th>WAVES</th>
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<td>PoS</td>
<td>PoW</td>
<td>DPOS</td>
<td>dbFT</td>
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<tr>
<td>Privacy Features</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Token creation</td>
<td>Yes</td>
<td>Planned/only a concept</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Figure 1: Blockchain comparison table**
From Learning to Assessment. Utilizing Blockchain Technologies in Gaming Environments to Secure Learning Outcomes and Test Results

Gallery Defender

The game Gallery Defender helps to understand the requirements for art history of the K-12 Curriculum Framework:

The learning goal, which equals the game goal (following Wagner 2008), is defined as ‘All students=all players will understand, analyse, and describe artstyles in their historical, social, and cultural contexts.’ The serious game likes to introduce and later assess the following art concepts to the player/learner, categorized by art movements:

- Cubism
- Surrealism
- Impressionism
- High Renaissance
- Realism

The player/learner slips into the role of a gallery owner. Using his profound knowledge of art history he must defend the pictures of the gallery against a master thief.

![Game Screen Gallery Defender](Figure 2)

The game is a turn-based card game, split into multiple levels. Within each level, the player/learner has a deck of cards with images of historical paintings on them. A small subset of the deck is dealt into his hand at the start of each turn. Each card in hand corresponds to an action, which is denoted by a small icon; such actions include ‘racecar,’ ‘headphones,’ ‘helmet,’ and ‘building.’ These actions were chosen from existing icon assets that the authors already owned; the icons themselves are not related to learning outcomes.

The player/learner faces off against a simple AI who declares an action at the start of each turn. There is exactly one painting in hand that corresponds to the AI’s declared action at any time, which must be correctly matched to the art movement that it belongs to by dragging the card into one of several labelled buckets near the bottom of the screen. After successfully matching some number of artworks (varies by level), the player/learner can move on to the next level. Incorrectly matching too many artworks to art movements will result in failure of the level. Not all levels contain the same number or types of art
movements. Additionally, certain levels may allow the player/learner to click on various buttons to gain more information about artworks, art movements, and their previous moves. The Simulation and Assessment Levels are based on the highest difficulty settings possible.

**Gallery Defender’s combined game-based learning and assessment approach**

Following their own classification, the authors are following the Combined Game-Based Learning and Assessment (GBL&A) approach. For this serious game, which is functioning as an early prototype regarding the impact of Blockchain technologies for the future development of serious games, a clear distinction between learning and assessment had to be made. Gallery Defender consists of three different levels the player/learner can choose from: playing/learning/exploring; simulation/self-test/practice, and assessment/evaluation/testing. The thoughts behind this split are the following:

1. **Learning/exploring while playing** gives the user all information needed to learn and apply new concepts self-reliantly.
2. **Simulation/self-test** gives the user the opportunity to self-test in an assessment-like situation, but without storing the results in a manner that would allow third-party access, eliminating performance-related consequences for the user while still providing detailed feedback related to right/wrong actions and helping the user find the right resources to improve. Teacher guidance of the player/learner is recommended in this stage. Information from this stage should not be stored on Blockchain.
3. **The assessment/evaluation approach** changes the game into an assessment-tool. This change must be communicated clearly to the user, as it changes the typical role of a gamified or game-based approach for learning into the same level of consequence as a classic test would do. This information is stored on Blockchain. However, as an assessment has an impact on the user’s life outside of the game due to the grading/evaluation component (and therefore removes, to a large extent, the ‘playfulness’ of the serious game), following Caillois (1961) this disqualifies it from being called a game per se, since a game should not affect the life of the player outside of the game. Gallery Defender follows this clear structure starting at the main menu screen:

![Figure 3: Tutorial, practice, simulation and assessment (Screenshot Gallery Defender)](image-url)
The table below shows the difference between the three options in detail. An important aspect is when and how Blockchain technology is useful enough to be considered:

<table>
<thead>
<tr>
<th></th>
<th>LEARNING</th>
<th>SIMULATION</th>
<th>ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Playing/Exploring</td>
<td>Self-test/Practice</td>
<td>Evaluation/Testing/Grading</td>
</tr>
<tr>
<td>All needed information on the topic provided anytime</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Feedback on the topic after completing the game</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Feedback on the topic while playing the game</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
<tr>
<td>Repeatable</td>
<td>YES</td>
<td>YES</td>
<td>NO (or max. to X times)</td>
</tr>
<tr>
<td>Play the game and enjoy</td>
<td>YES</td>
<td>It can be enjoyed but the player should simulate the test situation.</td>
<td>The player can still play a test but should be aware of the consequences of failure.</td>
</tr>
<tr>
<td>Get feedback in the form of a grade</td>
<td>YES (for the player)</td>
<td>YES (for the player)</td>
<td>YES (the player, the teacher)</td>
</tr>
<tr>
<td>Receive a certificate on Blockchain</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Information for the teacher pruning</td>
<td>NO</td>
<td>YES (not on Blockchain)</td>
<td>YES (on Blockchain, using</td>
</tr>
</tbody>
</table>

**Figure 4**: Learning, simulation, assessment

**Implementation and use cases of Blockchain technologies within the serious game Gallery Defender**

As mentioned earlier, Blockchain-based systems might require a radical re-thinking of educational credentials, as these systems no longer highlight the learner’s successes but serve as a comprehensive learning biography, in which successes, stagnation, and failures are equally reflected.

While Blockchain does not play a role for the ‘Learning’ and ‘Simulation’ part of the game Gallery Defender, Blockchain Technology has a core function for the ‘Assessment’ section. Gallery Defender utilizes Blockchain technology in three different ways.

1. A player/learner receives a digital token at the end of the assessment which contains the grade, the points, and the time the assessment was finished as a message. This token and the attached message are stored forever and unchangeably on the Blockchain in the player’s/learner’s Ardor Blockchain Wallet (which is a unique public Blockchain address, with a unique private key per user). The certificate is encrypted and can only be decrypted, for privacy purposes, by the sender and the original recipient. However, using a shared key should (in future versions of the game) enable the player/learner to share the results with third parties, such as their future boss, his family, or another school/university.
2. A player/learner with particularly good results receives an additional token with which the authors of the paper want to show gamification principles on Blockchain. This token can be exchanged for digital rewards, e.g. a game poster. In future versions, the whole ecosystem for rewards can be built on Blockchain.

3. Teachers can receive a token with further information about the respective test result. After a (definable) time, the message is deleted, and only the proof that the token has been sent remains (and thus an assessment has been carried out). For the first iteration of the prototype the teacher token is sent to a pre-defined Ardor address used to showcase the function. For the final version of the game the teacher's address can be pre-defined by the teacher when setting up the player/learner accounts for the class at the administrative dashboard which has not yet been developed.

The tokens used in the game Gallery Defender are defined as utility tokens. It is of utmost importance that the tokens cannot be traded/sent outside of the learning/assessment environment. This is, on one hand, obviously needed, so that the certificates cannot be changed between accounts, besides the very rare cases when the issuing-entities allows this exchange; on the other hand, it is important so that, within 'a typical government regulatory framework', it can be 100 per cent ensured that the tokens are not perceived as securities or cryptocurrencies.

As described above, the authors use the functionality of phasing. A token called ‘veduc’, standing for ‘virtual education confirmation’, with the token asset ID (the unique identification number on the Blockchain) B8383323259086863643, is held by the account (ARDOR-365M-XM4Z-RZ48-23XNQ – Ardor Testnet) issuing the certificates. The token itself is a ‘Singleton Token’, meaning that there is only one unique token in existence. It is also defined that the token can only be hold by the dedicated issuer's account. This token is needed to enable ‘phasing by voting’ which means that, whenever a certificate of completion to the player/learner is being sent, the transaction needs to be verified by the main account. This prevents the possibility that tokens can be sent peer2peer without the permission of the issuing account, as mentioned above. The token used for the certificates of completion is called veduut, which stands for ‘virtual education user token’, with the asset ID 13489968754320443895 on the Ardor Testnet Blockchain. 10,000,000 tokens have been created, meaning that this number of certificates can be issued by the game. However, the developers have the option to reissue a new set of tokens, should more than 10,000,000 assessments be done using Gallery Defender.

To enable this process automatically, the authors, as developers of the game, have to run at least one Ardor Full Node (in the form of a Raspberry PI3) that acts as a ‘contract runner’ for the smart contract. On the Ardor network, in contrast to other Blockchain systems like Ethereum, not every node runs and verifies every smart contract. The authors suggest that every project needs to run a couple of nodes (at different places) to ensure a 100 per cent uptime. In the future, schools, universities, and developers of software used for assessment can set up a stable system that reruns and verifies those Blockchain transactions used for assessment purposes.

The third token in the ecosystem of Gallery Defender is named vedutt (virtual education teacher token), with the asset id 11478600775360421069 on the Ardor Testnet Blockchain. This token contains information useful for the teacher, relating to an assessment taken. The information in the message of the token is also encrypted for privacy purposes. The difference for this token, however, is that the message for the teacher is only stored for a predefined timeframe (counted in blocks created on the Blockchain). After this...
time period, the information is no longer stored on the Blockchain; only the proof of the
transfer itself is left on Blockchain. The authors use a function called ‘pruning’ to
demonstrate that, although on Blockchain, you can distinguish between information
that needs to be stored forever and information stored only for a limited amount of
time on the Blockchain. In both cases there is no possibility that the information can be
manipulated or altered retroactively.

The fourth and final token in the Gallery Defender Blockchain ecosystem is called vedugt
(virtual education gift token) with the asset id 15596172380431790053 on the Ardor
Testnet Blockchain. This token tests how gamification can be implemented as additional
layer and reward system. A player/learner who passes the assessment with an ‘A’ or ‘B’
grade receives a vedugt token which can be redeemed, in the case of Gallery Defender,
for a digital gift. In this case the token can be sent to a dedicated Ardor Blockchain
account. The player/learner needs to include his e-mail address in the transaction to
receive the gift.

Critics could argue at this point that a token has now been included which has a certain
monetary value (depending on the possible value of the prize) and therefore the token is
not just a simple utility token. The authors counter this argument with the fact that the
token can only be sent to a predefined address and cannot be sent peer2peer between
other Ardor addresses. A possible payment, for example between the publishers of a
game and the institution awarding the prizes, can still occur in FIAT currency to fit into
a possible ‘typical regulatory framework’. However, a smart contract can trigger this
payment and thus maximize trust between the partners of an ecosystem. To give an
example: At the end of the period a prize can be redeemed; the institution sending the
prizes to the player sends the received tokens to the publisher’s Ardor address which
then triggers an automatic payment from one bank account to another.

At this point, the concept of transaction fees must be described and who pays for them.
Who must have Cryptocurrencies of the used Blockchain system, in order to operate
the ecosystem? Transaction fees are fees that have to be paid to the network to verify
the transactions and include them into the next block of the Blockchain. In the case of
Gallery Defender, the main account of the game has to hold a particular amount of Ignis,
the cryptocurrency of the childchain that our tokens were created with. Each transaction
that occurs after a player/learner has completed an assessment triggers the sending
of a token, which holds further information, from the main account to the account of
the player/learner. Consequently, this triggers a transaction fee to the network. For this
simple transaction the account needs to hold cryptocurrencies but the authors would not
need to run their own node to conduct such a transaction.

This changes in the case of the gamification approach because here the users send the
token from their account to another address. Since it is extremely important that the
users themselves have no costs and do not need any further technical knowledge, apart
from the simple creation of an Ardor address for themselves, the bundling accounts
approach comes into play here. This means that on the node, run by the authors, a
‘bundling account’ is in place. All transactions that take place within the Gallery Defender
ecosystem to the Ardor network are being paid for by the game-creators. The authors
believe that Blockchain-based applications, at least in the near future, can only work if
the users do not handle Blockchain processes themselves, and therefore must purchase
cryptocurrencies and store them on their Ardor address.
Although storing learning credentials on Blockchain, or at least the possibility to verify an original document using a 1-way hash, is already being conducted (e.g. blockcerts), the topic of Blockchain-based credential management, its broad usage, and its understanding from politicians and other policy-makers is still at a very early stage. Real-life use cases can be counted on a single hand. Integrating Blockchain technologies into e-learning applications or even into serious games is therefore comparable to a new-born child. In order to generate progress over the next few years, holistic processes must be mapped, created, and researched, and the results shared between the parties involved. It is important to look beyond one’s own immediate interests and to consider this topic from many different points of view. In summary, the authors would like to point out following aspects as necessary to consider regarding the usage of Blockchain technology to store learning credentials, especially for serious games:

- A Know Your Customer (KYC) approach needs to be established. Knowing all parties participating in the Ecosystem is most important to prevent fraudulent behaviour and enable an instant verification of credentials, not only as proof of origin of a document but also of the actual private information, like grades, which are stored on Blockchain directly.
- This KYC approach should involve government-issued digital IDs, wherever possible.
- Encryption on the one hand, but also the possibility of sharing the information, for a certain amount of time, with trusted third parties needs to be established.
- The institutions issuing credentials, the companies creating learning environments, and of utmost importance the users/learners need to run a full node themselves and therefore have a copy of the Blockchain including their very own credentials always in their own hands.
- A consortium of involved parties should cooperate to rerun each other’s smart contracts, if one uses a Blockchain system like Ardor that does not run all Smart
Contracts on all nodes. This will ensure uptime and security, while keeping the Blockchain system fast and scalable. Regarding the Ardor Network, a Child Chain operated by a consortium of schools and universities, could be a possibility to get issuing, storage, and acceptance of educational credits to a new level.

- Payment and regulation of transaction fees necessitate a clearly defined solution for assigning responsibilities to involved parties.
- Blockchain-based credential solutions should follow an open-source approach.
- Not all information needs to be stored on Blockchain or, at least, not all information (attached messages to transactions) needs to be on Blockchain forever. Designers need to be trained the best way possible to identify and create a feasible solution.
- Think green. Opt-in for solutions that are safe but environmentally friendly. Especially for use cases like this, that do not store monetary records.

On https://alexpfeiffer.mit.edu readers can find the link to the game, to surveys related to the topic, and progress of the studies. Please do not hesitate and contact the authors to start a discussion and collaboration.

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