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International Journal of Game-Based Learning

Volume 7 • Issue 3 • July-September-2017 • ISSN: 2155-6849 • eISSN: 2155-6857

An official publication of the Information Resources Management Association

Editorial Preface

Research Articles

The *International Journal of Game-Based Learning* is indexed or listed in the following: ACM Digital Library; Bacon's Media Directory; Cabell's Directories; DBLP; ERIC – Education Resources Information Center; Google Scholar; INSPEC; JournalTOCs; MediaFinder; ProQuest Advanced Technologies & Aerospace Journals; ProQuest Computer Science Journals; ProQuest Illustrata: Technology; ProQuest SciTech Journals; ProQuest Technology Journals; PsycINFO®; SCOPUS; The Standard Periodical Directory; Ulrich's Periodicals Directory; Web of Science (All Journals); Web of Science Emerging Sources Citation Index (ESCI)

Using Formal Game Design Methods to Embed Learning Outcomes into Game Mechanics and Avoid Emergent Behaviour

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ABSTRACT

This paper offers an approach to designing game-based learning experiences inspired by the Mechanics-Dynamics-Aesthetics (MDA) model (Hunicke et al., 2004) and the elemental tetrad model (Schell, 2008) for game design. A case for game based learning as an active and social learning experience is presented including arguments from both teachers and game designers concerning the value of games as learning tools. The MDA model is introduced with a classic game- based example and a non-game based observation of human behaviour demonstrating a negative effect of extrinsic motivators (Pink, 2011) and the need to closely align or embed learning outcomes into game mechanics in order to deliver an effective learning experience. The MDA model will then be applied to create a game based learning experience with the goal of teaching some of the aspects of using source code control to groups of Computer Science students. First, clear aims in terms of learning outcomes for the game are set out. Following the learning outcomes, the iterative design process is explained with careful consideration and reflection on the impact of specific design decisions on the potential learning experience. The reasons those decisions have been made and where there may be conflict between mechanics contributing to learning and mechanics for reasons of gameplay are also discussed. The paper will conclude with an evaluation of results from a trial of computer science students and staff, and the perceived effectiveness of the game at delivering specific learning outcomes, and the approach for game design will be assessed.

KEYWORDS

Elemental Tetrad, Game Based Learning, Games Design, MDA Model, Source Control, Subversion

INTRODUCTION

In the field of games design, designers have long recognised the role of learning in games. Crawford (2011, p. 15) makes the assertion that "the fundamental motivation for all game playing is to learn" claiming that the purpose of games was to learn about the game domain, solve the problems and beat the challenges it presents by developing the required skills to do so. Koster (2010, p. 46) makes a bold claim that, "Fun is just another word for learning." and that games are ultimately teachers.

In the field of education, the benefits of practical application and experiential learning have also been points of interest. Of particular interest is the idea of active learning, which Bonwell and Eison (1991, p. 2) summarise as involving "students in doing things and thinking about the things they are doing". It is proposed that game-based learning fits neatly under the banner of active learning, but

DOI: 10.4018/IJGBL.2017070106

also that the design of game based learning is critical to its success. Prince (2004) identifies three distinct types of active learning. They are collaborative learning, cooperative learning and problem-based learning.

Often the goal of game- based learning is engagement with learning material. For players, the games they play are often very engaging. Gros (2007, p. 23) points out that, whilst beneficial, engagement and motivation are "not enough for educational purposes" and alludes to games sometimes having undesirable emergent outcomes. However, the goal of winning a game represents an extrinsic motivator, one that is separate from the task in hand, as opposed to intrinsic motivation that comes from the task itself. Pink (2010) identifies several negative effects of extrinsic motivators, including an inability to see the bigger picture beyond an extrinsic motivator. This could be argued is imperative in game-based learning otherwise the risk is the student learns how to play and win the game without gaining an understanding of the learning outcomes themselves. Desirable learning outcomes must be well aligned with any extrinsic motivator in order to mitigate against any potential negative effects.

Habgood (2005) highlights the need for learning material to be intrinsically integrated into a game. In particular, games designed for learning should, "embody the learning material within the structure of the gaming world and the player's interactions with it, providing an external representation of the learning content that is explored through the core mechanics of the gameplay" (p. 6). When playing a game for learning, students may well be engaged in the game, but that does not necessarily mean they are engaged in the learning. It is proposed that by integrating learning outcomes into game mechanics then the experience of playing the game and understanding the strategies available to achieve the game's goal can become a more genuine learning experience.

Marne et al (2012) offer a framework of patterns to enable teachers to communicate more effectively with game designers. This framework begins with pedagogical objectives and domain simulation, again placing learning outcomes at the heart of the game mechanics. Identifying the desired learning outcomes from the outset is held in high regard.

Game Design Methodology

Schell (2008) describes the elemental tetrad as a conceptual tool for better understanding games design. Four elements of game design are linked to form a diamond. The elements are aesthetics, story, mechanics and technology. Arguably there are stronger links between aesthetics and story, and between mechanics and technology, but the general purpose of the conceptual tool is to consider if all four aspects are working together, in a consistent and synergistic way. The elemental tetrad of games design is shown in Figure 1.

Game design is a difficult process that requires a great many decisions making it a daunting and time consuming task. It may be tempting to create game based learning artefacts by "skinning" an existing game by adding the learning content as a theme, paying attention only to aesthetics. An example of this might be adapting an existing game by changing the story, for example. Given the complexity of designing a game from scratch it is easy to see how this might be an attractive option to educators who want to combine the engaging powers of a game with learning outcomes related to their teaching, however with this approach some elements of the tetrad are not intrinsically integrated because they will have been developed independently of the new story. Furthermore, because the mechanics may be entirely independent it may be possible to achieve the extrinsic goal of winning the game whilst also completely bypassing the story-based learning elements.

Schell (2008) describes games as designed experiences whilst also making the point that an experience is unique to an individual, and that even when two people share an experience they each have their own individual experience of the same thing. This is an important point when considering games as designed experiences, or educational games as designed learning experiences, as experiences are personal to an individual, and there may be a disconnect between the designer and the player. This is also a key tenant of the MDA model of games design, which is shown in Figure 2.

Figure 1. The Elemental Tetrad (Adapted from Schell, 2008, p. 42)

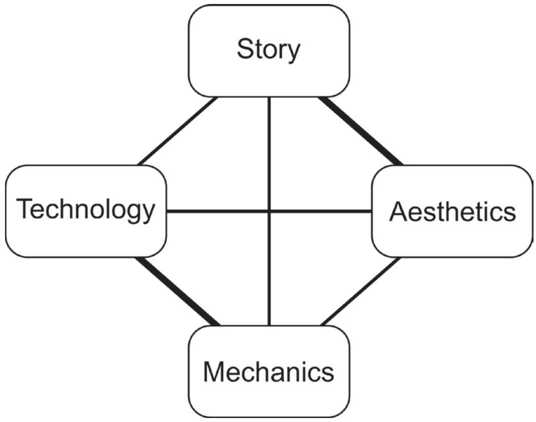


Figure 2. The MDA model for game design (Adapted from Hunicke et al., 2004)

The MDA model (Hunicke et al, 2004) identifies a gap between the role of a game designer, who creates the rules of a game (Mechanics) and the player who enjoys the overall emotional experience of the game (Aesthetics) recognising a distinction between game designer and game player. In between the rules is emergent behaviour (Dynamics) that comes about as a result of the rules. Dynamics can be unpredictable and could enhance the gameplay or could be detrimental to the experience. As an example of dynamics Hunicke et al (2004) offer the concept of bluffing in poker, or bullying players with fewer resources with which to bet. These behaviours are not explicitly in the rules, but rather they represent strategies that come about as a result of the rules.

A similar phenomenon to the dynamic emergent behaviour described by Hunicke et al (2004) exists outside of games. Briefly, in a separate study to measure engagement of students with a particular course, the authors collected data from a sign-in attendance registration mechanism for practical laboratory classes. When students attend scheduled practical programming activities they are required to sign in through an IP-locked web based system, with persistent failure to register attendance resulting in remedial action. Analysis of attendance in practical programming activities shows only a very weak correlation with students' performance in the module. In the same activities, the work given to the student requires them to interact with source control which requires them to upload changes to a central server several times during each session. In a comparison of times students registered their attendance and times when students interacted with the source control system it was noted that for 35% of registered attendances there were no interactions with the source control system for two hours either side of that attendance. In this example the mechanics or rules are that students must sign into the lab at the appropriate time or face remedial action. The desirable dynamic is that they attend the lab, complete the lab work and achieve the learning outcomes. The observed dynamic is that students engaged with the attendance monitoring system, but because of the lack of interaction with the source control system it seems that they often failed to engage with the teaching material.

Using Pink (2010) we identify the remedial action for persistent lack of attendance as an extrinsic motivator, motivating students to engage with the attendance monitoring system. The frequency with which students circumvented the attendance monitoring system also showed no significant correlation with performance, highlighting that students were willing to cheat the system regardless of their ability.

Although Schell (2014, p. 43) makes the point that in his elemental tetrad "none of the elements is more important than the others" it is proposed that when designing game based learning experiences the learning outcomes should be intrinsically integrated into the core mechanics in order to avoid incentivising potentially undesirable emergent behaviour that exists in the MDA model between the mechanics and the aesthetics.

METHOD

It is proposed that experience of the use of source control is a valuable skill for any computer scientist. Further to this, it is also proposed that the benefits source control offers a complimentary to students who are learning to program. Without source control experimenting in code carries a risk of introducing bugs, or breaking the code entirely. Source control adds the ability to revert code to any previous version, reducing the risk of experimentation and therefore increasing the opportunity for learning.

In this study, we attempt to create a card game to teach students how centralized source code version control software works. Inspiration has been taken from the MDA model of game design, the elemental tetrad, and the idea of intrinsic integration of learning outcomes, placing game mechanics front and centre of all design principles. This section will guide the reader through the design process. As with Marne et al.'s (2012) approach the first consideration was pedagogical objectives and defining the learning outcomes. Next additional constraints were considered relating to the practicality of what is possible and appropriate in a teaching environment. Once a core set of mechanics were developed based upon the defined learning outcomes initial play testing began. During play testing several mechanics were trialed and discarded. However, for the purposes of clarity in this document a description of the final game is offered before details of which mechanics were removed and why. This should give the reader some context in which to understand the design decisions that were made.

Learning Outcomes

Centralized source code version control software allows multiple programmers to work together on the same source code by editing a local working copy, committing their changes to a centralized 'golden' copy and updating their local working copy with changes from other programmers. The learning outcomes of this game were to increase students' awareness of the terminology used by a specific implementation of a centralized source code version control system called Subversion (or SVN) as well as an appreciation for the underlying operations employed by SVN and help overcome the learning curve that students face when they are first introduced to source control.

Additional Constraints

Other practical constraints were also considered. One restriction was the fact that there could only be a finite number of physical game artefacts (in this case cards) with which to play, where as in reality the digital artefacts that these physical artefacts represent (files, changes to files, etc.) are practically limitless. Another additional constraint was that of playing time. The original goal was that the game could be learnt and played twice in a one hour session.

Design Approach

In order to embed the learning outcomes and core components of the game mechanics a card based simulation of source control was created, representing the game state through files in players' local Working Copies, and the centralised Golden Copy. Players can change the game state by using action cards, which also closely represent the learning outcomes.

Action cards are drafted in rounds adding an element of chance to the game, whilst providing players with meaningful choices. Additional mechanics were added in order to create a non-trivial problem. Without these mechanics, it was easy to avoid some of the more complex interactions with source control. The change deck cards represent work that must be completed. This adds to the narrative and also places constraints on which files can be changed in the Working Copy. The change deck also creates a clear goal of committing all changes to the golden copy within a limited number of rounds (or days) before a deadline.

Final Game

It would be helpful to first have an understanding of the final game, entitled *Check It Out!*, in order to understand some of the decisions made in the designing the game. *Check It Out!* is a cooperative card game that simulates the process of creating a website as a team using a centralised source control system. Played over seven rounds, each player has a personal Working Copy of the website. An example of the game being played can be seen in Figure 3.

Over the course of the game each player acquires Change cards that represent changes they must make to the website. In each round players draft Action cards that they can use to make changes to their Working Copy. The game also features a shared Golden Copy of the website. Players must use action cards to Commit changes from their individual Working Copies to the shared Golden Copy. Players can also use action cards to Update their individual Working Copies. Players are prevented from performing an action that would overwrite any existing changes. This is managed by using ten-sided dice placed upon files in both the golden copy and the working copy to track revision numbers of each file. The game is won if all the changes are committed to the Golden Copy before the end of the last round.

Table 1 shows a summary of the game mechanics, why they were included, whether they any unexpected emergent behaviour was observed and whether that behaviour is perceived to have a significant impact. Drafting provides meaningful choices, and allows players (who understand what they should do) the opportunity to influence their success. Change cards provide an easy to understand expression of the goal of the game as well as presenting limitation on what files a player can edit, which increase the likelihood of conflicts occurring. As there is a practical limit on the number of files available the add file card has a special set of rules that ensure that only the limited files available can be added; this caused some confusion amongst players. A rule which states that players must attempt to play all action cards increases the likelihood of conflicts and gives students more opportunity to understand what every action does.

Discarded Mechanics

During the first stages of testing some different mechanics were trialed and discarded because of the apparent dynamics that they created. One mechanic that was quickly discarded was an attempt to simulate programmers' use of source control independently by playing and resolving action cards in two separate phases. Actions were played in order face down, and then resolved one after the other preventing players from predicting the exact state of the golden copy when they play their cards. This proved time consuming and made cooperation between players difficult and so was replaced with a system where Action cards are resolved immediately as they are played.

Another mechanic that was refined was the win condition. Initially the game was competitive. At this stage, there were no change cards and the win condition was based upon how many commits had been made, and which player committed files most recently. Behaviour emerged as a result of the competitive win condition when another player was likely to win, and other players would work explicitly to prevent that player from winning. As software development is a collaborative process, and source control is a collaborative tool, this seemed inappropriate. However, an argument was made that, in order to successfully block a player from winning, other players require a good understanding of source control, and so there was still potential for learning whilst having a competitive goal. Another

Figure 3. Check It Out! being played

effect of this blocking behaviour was that the time taken to play a game was extended and became unpredictable, so the decision was made to make the game a cooperative one. This demonstrates the potential detrimental effect that undesirable emergent behaviour could have on students achieving learning outcomes.

Another strategy tested was to make the game semi-cooperative by introducing individual secret goals, however this often served to make players behaviour unpredictable and frustrating for others. As a result, the game was changed to become entirely cooperative which is more in line with the purpose of source control. The goal now was simply to make a certain number of commits.

At this stage, any player could make changes to any file, and the result was that players adopted specific files and only made changes to those files. This is a good strategy when using source control in a practical application to avoid some of the more complicated events that occur when an attempt is made to overwrite one person's changes with another. However, this meant that players of the game got no experience of those events bypassing some of the intended learning outcomes, and that winning became trivial. This problem was addressed by introducing the Change cards, which restrict which files can be changed by players and make it likely that multiple players are forced to work on the same files at some point.

In summary, mechanics were discarded because they either had a negative impact on artificial constraints such as the desired playing time, or because they promoted emergent behaviour that was contrary to the nature of the use of source control or compromised the learning outcomes. As a result of these mechanics being removed behaviours arose that meant some of the more advanced learning outcomes were no longer being met because they were easily avoided. To remedy this, the additional constraint of the change cards, was introduced to increase the likelihood that these advanced learning outcomes would arise at some point during the game.

Table 1. Game mechanics, their motivation and resulting dynamics behaviour

Mechanic	Motivation	Unexpected Emergent Behaviour	Potential Impact (Low, Medium, High)
Drafting Actions	Provide players with meaningful choices	None observed	N/A
Change Cards	Increase likelihood of conflicts	None observed	N/A
Working Copy/ Golden Copy Simulation	Learning Outcome	None observed	N/A
Action Card - Add File	Learning Outcome	None observed	N/A
Add file distinctive rules	Practical game constraints	Added confusion	M
Action Card - Edit File	Learning Outcome	None observed	N/A
Action Card - Commit Changes	Learning Outcome	None observed	N/A
Action Card – Update	Learning Outcome	None observed	N/A
Action Card - Resolve Conflicts	Learning Outcome	Some participants seemed to view this as a waste of an action and made a point of using it first every round.	L
Action Card - Revert Changes	Learning Outcome	Some students seemed to view this as a waste of an action and made a point of using it first every round. Failing to use this first sometimes resulted in students reverting changes unnecessarily.	M
All action cards must be played	Increase likelihood of conflicts	This combined with card order lead to some students reverting changes unnecessarily.	M

RESULTS

During the final stage of play testing, students and staff were invited to play *Check It Out!*. Participants who volunteered to take part in the study were asked to fill out a survey before and after playing and were observed throughout.

The Likert scale was used to provide responses to all the survey questions. Prior to playing the game participants were asked how well felt they understood source control terminology and how well they felt they understood centralized version control systems. They were also asked whether they enjoyed playing board games. During the post-game survey the first two questions were asked again for comparison, and participants were also asked if they felt that their understanding had improved. The post-game survey also included questions on whether participants thought the game was an effective method for teaching students about source control, and whether they found the game to be fun.

There were a total of 23 participants who played the game in 6 groups. One group was made up of 5 members of staff whilst the other 5 groups were made up of students.

The Likert scale responses were converted to numbers by encoding the values strongly disagree, disagree, neither agree nor disagree, agree and strongly agree with numbers from -2 to 2. For the questions that were repeated before and after the game concerning the perceived understanding of source control terminology and centralised source control mechanisms, the student participants showed an average increase of 0.44 and 0.78 respectively. In response to the statement "My understanding has improved", the majority of students answered positively with students answering agree or strongly agree 8 times each. Staff participants typically did not report an increase in their understanding because they indicated that they already had a good understanding of source control.

Table 2 shows a summary of the responses to the remaining post-game questions for all groups. The game received a very positive reception from the majority of participants. Perhaps one of the more surprising aspects was the positive response to the game being fun. This was not a strong consideration when designing the game, and so it could be argued that this lends supportive evidence to Koster's (2010, p 46) assertion that "fun is just another word for learning".

Observations

Although it was not explicitly stated in the rules, all groups that played the game chose to share information on what they needed to do at some point in the game. Some groups explicitly commented about the importance of communication throughout the game.

Despite many players being familiar with source control it seems that many had used source control, but perhaps did not appreciate some of the intricacies, so still appeared to have a positive learning outcome.

One of the learning outcomes concerns the conflict, which is a source control term used when an update pulled from the centralized golden copy would overwrite a change in the local working copy. Every group experienced at least one conflict whilst playing the game, which was one of the desired effects of the change deck mechanic.

One student complained that under the rules of the game, cards apply to all files in the working copy, when source control systems often allow the same commands to be applied to individual files. It could be argued that applying these sorts of operations to individual files may represent bad practice so this restriction is deemed acceptable. However, the potential for students to learn that this restriction is the only way to interact with version control is a little concerning.

Once students seemed to understand what was going on, they appeared to care about the outcome. The game seemed well balanced in that groups either marginally won or marginally lost.

Participants played in groups of 3, 4 or 5 players, whilst the game supports up to 6 players. It was intended that the game length should be the same for all group sizes. For that reason, much of the decision making during the drafting phase occurs in parallel. However, although the drafting mechanic should ensure the length of the drafting phase is the same for groups of all sizes, the action playing

Table 2. Post-game survey responses concerning efficacy and fun

	Strongly Disagree	Disagree	Neither Agree Nor Disagree	Agree	Strongly Agree
"Check It Out" is an effective method of teaching aspects of source control	0	0	1	13	9
Learning through playing a game was more engaging than more traditional methods	0	1	0	5	17
The game was fun	0	1	0	12	10
I would play the game again	0	1	0	9	13

phase took significantly longer. One group of five failed to finish the game in the time available to them. It also took longer for larger groups to grasp the rules.

All other groups either completed the game, or came very close to completing the game. In fact, all groups who fell just short insisted on playing an additional round to complete the task with one extra day. One potential and unanticipated reason for this might be the power of the narrative, in which each round represented a day, counting down the days to a deadline that must be met. It is proposed that had this been a score or some other more arbitrary method of keeping track of the rounds then the narrative, and the goal that it serves would be far less compelling. The countdown of days towards a deadline seemed to add a thematic element and a compelling feedback mechanism showing how close groups were to failure of success. Those that lost all played an additional round which allowed them to complete the game. The day tracker is shown in Figure 4.

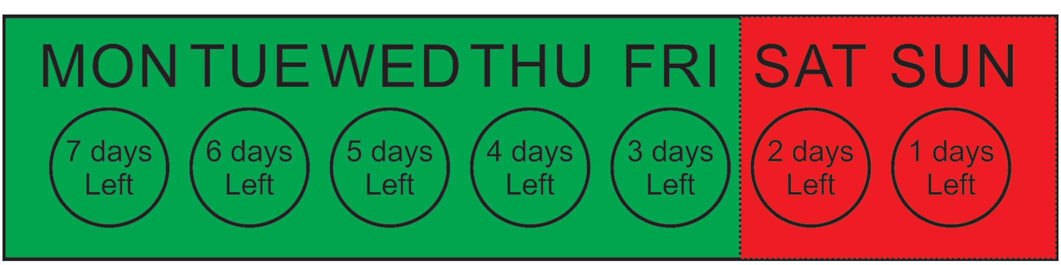
Two observations lead to the consideration of future changes to the game rules. The first is that some students commented that it seemed there was too many of one card or another, in particular those cards that were used to resolve conflicts. One group made a habit of always playing those cards early in the round, which was noted as emergent dynamic behaviour. As a result of this the number of these cards may be reduced.

The second observation that may lead to a rule change is that the biggest factor in the success or failure of groups to beat the game appeared to be how quickly they were able to add all required files. This could be remedied by changing the way that a failed add file action is dealt with. In order to prevent the game state from getting impractically confusing there are only four Add File cards – one for each file that can be added. Under current rules once a file that was added using an Add File card is successfully committed to the golden copy at that point the Add File card is removed from the game. This is deemed necessary to stop the state of the game becoming unworkable, which is the likely outcome if players start adding different versions of the same files to their working copies. If the change that added the file is reverted the Add File card is put in the discard pile. In this case, players must wait until all the remaining action cards in the action deck are used, and a new action deck is created by shuffling the discard pile. One way to remedy this might by to instead put the Add File card on the top of the action deck when an Add File card's action is reverted instead of being put into the discard pile. Then that card could be played again by someone on the next turn instead of having to wait for it to be dealt again later in the game.

CONCLUSION

The goal of Check It Out was to design a game- based learning experience by embedding the learning outcomes into the core mechanics in an attempt to avoid undesirable emergent behaviour that may be counterproductive to the learning experience of the players. Whilst this was for the most part a success, emergent behaviour was still evident as a result of other mechanics that were introduced to overcome practical constraints imposed upon the game world that do not always exist in the real world. The practical constraints are sometimes unavoidable, so this experience not only highlights the

Figure 4. Thematic day tracker



importance of embedding learning outcomes into core game mechanics, but also ensuring that any other game mechanics introduced do not compromise the learning outcomes by introducing unwanted dynamics. In this case however, careful consideration of the process has kept this emergent behaviour to a minimum and the learning outcomes are deeply integrated as a core aspect of the game mechanics.

Perhaps the most surprising result is that players appeared to have fun playing the game. This is surprising because fun was never a consideration in designing the game. There was a greater expectation that the game would provide an effective learning experience but would not be fun. Using the categories provided by Hunicke et al. (2004) it is perceived that fun was derived from the games narrative, challenge and the aspect of fellowship provided by the cooperative game experience.

The results of the survey are encouraging, showing that the majority of students thought the game was valuable, that they learned something and that it was fun. It was disappointing that it could not be tested with more students. It would have been especially interesting to test with more student who were less familiar with source control systems.

One aspect that could be improved is the ratio of different types of cards. The number of cards in the change deck is altered according to the group size to ensure that the challenge of completing all the work is appropriate with a fixed deadline of 7 days. It may be appropriate to also change the ratio and number of action cards according to the group size, but in order to do so further modelling of the problem might be appropriate. This falls under the category of further work.

On the topic of teaching source control using game based learning there is scope to design a digital game that uses an SVN client as the interaction mechanism. The focus of the card game is on relevant terminology and mechanics concerning how SVN works. In order to use SVN a student needs a piece of client software. It is proposed that an entirely different game could be designed in which students us the client software to change the game state. Whilst this might not expose the inner workings of source control as explicitly at the card game that has been presented, it would give students practical experience of using source control in a game-like context.

In conclusion, the goal was to design a game to teach students about source code control. Inspiration was taken from the MDA model for game design and the elemental tetrad, which lead to an approach of embedding learning outcomes as intrinsically integrated game mechanics. It is proposed that this approach encourages players to understand the learning outcomes in order to be successful in the game. This aspect seems to have been successful with 89% of students who participated indicating that their understanding of the specific source control system had increased as a result of the experience playing the game. When adding additional mechanics for pragmatic reasons care was taken to minimise any undesirable emergent behavior, and through careful observation of players very little undesirable emergent behaviour was identified. Elements of aesthetics and narrative that were added through game artefacts provided added synergy with the mechanics as well as the unexpected observation of an additional element of motivation for most players.

ACKNOWLEDGMENT

The authors would like to express their thanks to all of the staff and students who took part in this study, and acknowledge the support and encouragement of the wonderful members of the Playful Learning Special Interest Group.

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International Journal of Game-Based Learning

Volume 7 • Issue 3 • July-September 2017 • ISSN: 2155-6849 • eISSN: 2155-6857
An official publication of the Information Resources Management Association

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