Digital Games for Learning Mathematics: Possibilities and Limitations

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Drawing from Gee's learning principles developed from the digital games environment, we provide a critical analysis of the difference between using these principles in a literacy environment as opposed to a mathematical environment. Using stimulated recall, primary school-aged students played with a number of contemporary digital games. Feedback was sought. This was compared with the descriptions provided by experienced adult gamers. Both players provided insights into the cognitive process used by gamers when engaging with games. Collectively, these sources allow us to propose that the learning principles may restrict deep learning processes for mathematical learning.

Drawing on a number of sources from a large, three-year project, this paper explores the possibilities of digital games to offer engaging, and deep learning, environments for digital natives. Digital natives are described by Prensky (2001) as the generations who have been raised in digital worlds and have developed learning styles and dispositions that have been shaped by these digital worlds. His contention is that young people are differently disposed to learning, problem solving, and feedback because of their exposure to digital media. These dispositions are different from previous generations (digital immigrants) who were raised in print-based worlds. These different worlds have created very different experiences that ultimately shape the habitus of those raised in these worlds. Prensky argued that many of the young people entering schools and work have dispositions that are at loggerheads with the practices of education and work. Furthering this work, Gee (2003) has examined the digital games environments to explore the principles used by the gaming industry to engage players in games. As a highly competitive industry where millions of dollars can be spent on developing games, the industry has designed games that engage players for extended periods of time. Gee's principles have been used to justify reforms in education that will engage the digital natives as they enter schools. Gee and his advocates have argued that the current practices in school are failing to cater for learners (digital natives) and that the thirty-six principles used in games designs could radically shape new learning environments that cater for learning and learners in the digital era. This paper draws on this body of work to examine the potential of games to create opportunities for learning mathematics but also to explore the possibility of new forms of mathematical learning and mathematical understandings to evolve from these worlds.

Digital Games: New Possibilities

A catalyst for this study was the work undertaken by Lowrie (2005) where he worked with eight-year old students using the Pokemon environment. In this work, Lowrie found that the children worked well beyond the experiences being provided in the standard school curriculum in terms of spatial representation and visualisation. This work highlighted the possibilities of the digital games environment for enhancing mathematical learning and understandings that were beyond the realms of standard pencil-and-paper representations. At the other end of the digital native continuum, Jorgensen's (Jorgensen (Zevenbergen), 2009; Zevenbergen & Zevenbergen, 2008) work with young workers found that there were

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very different dispositions towards and using digital tools in the workplace and those young workers deferred cognitive labour to digital tools so as to enable them to move quickly through their nominated tasks. These dispositions were not recognised, and often not valued, by employers (or teachers). To this end, the findings reported in this paper draw from a three-year project that sought to clearly identify the possibilities of digital environments, namely games, to enhance mathematical learning and create new mathematical dispositions (or habitus) for young people (digital natives).

Gee's (2003) analysis of digital games has created thirty-six learning principles. Drawing on three discourses (situated cognition, new literacy studies, and connectionism), Gee provides a comprehensive account of the possibilities of games to create exciting and engaging learning opportunities. Primarily, Gee focuses on how the games environment allows for new forms of literacy learning and engagement in literacy texts. The literacy demands of these digital worlds are substantially different from the linear text models of the printed media which has dominated literacy since the industrial revolution. It is beyond the scope of the limited page length here to outline each of these principles Fundamental to Gee's principles are the notions that gamers identify with the game and develop an identity (and affinity) with the game that aids engagement. Once in the game, the player then is further engaged through its underlying structures where there is a progression through the game from simple activities that progressively increase in difficulty. As the player engages with these increasing complexities, he/she is strongly scaffolded through a range of design principles including low-failure, where failure is not public so that there is encouragement to engage. The game is also structured so that skills learnt in one level will be used and extended in subsequent levels. These principles, Gee argues, need to be embedded in school learning. It is beyond the scope of this paper to expand and explain all thirty-six principles. We have elected to focus on four principles to illustrate how they were enacted by the participants and their links to new learnings in mathematics.

Method: Video Stimulated Recall

Drawing on the literature using stimulated recall (Lyle, 2003; Zanting, Verloop, & Vermunt, 2001). Stimulated recall is an "introspective method that can be used to elicit people's thought processes and strategies when carrying out an activity or task" (Henderson & Tallman, 2006, p. 55) and utilises a support mechanism to enhance recall (Gass & Mackey, 2000; Henderson & Tallman, 2006). In this study, participants were given a Nintendo DS and '*The Legend of Zelda: Phantom Hourglass'* game and were asked to play the game as much as possible over a two-week period. The participants were then videotaped, for approximately 30 minutes, at the natural progression in the game. Thus, the game-playing episode was at a novel point that was 'new' to the participants. Two camera angles were utilised, one focused on the two screens of the Nintendo DS and the other was a front view of the participant. These two video files were edited using Studiocode software to create video footage that presented both the screen view and the front view simultaneously. Semi-structured interviews were conducted with the participants after the game playing episode to elicit their reactions to the experience and to encourage the participants to describe their game playing patterns over the duration of the activity.

Within a week, the participants undertook a stimulated recall session which involved them watching the video footage of their game playing episode and answering a pre-designed set of semi-structured and open-ended questions based on particular points and moments in the game that were significant (as identified by an expert who had previously played the game and to elicit participant thinking of a particular action). The games were then played back to the players who described their thinking as they navigated through the game. Split screen video recording was employed so that there was one camera recording the videotape being played to the player and another camera focused on the player. Coordinating the two images was critical for analysis to coordinate the points in the game with the player's comments. In total, seven players were involved in the stimulated recall with two games being played. Three boys and four girls played the games and their ages ranged from 10 years to 14 years. The stimulated recall participants were selected through an expression of interest sent out through the University system. The expression of interest sought to identify students in middle school who were willing to play specific hand-held games and be prepared to participate in the three-week study.

Recognising that the players were young and may not be able to articulate their thinking, older gamers were also asked to play the same games and develop descriptions (written) of their processes as they navigated through the games (Jorgensen & Lowrie, 2011). Some triangulation between novices and experts enriched the descriptions of the thought processes. While the experienced gamers' descriptions were richer in terms of their detail and capacity to write for an audience, there was considerable synergy in the processes used by both players in how they navigated through the games, and their processes used to solve problems/obstacles as they navigated through the worlds.

Prior to this very detailed (and labour-intensive) part of the project, a large survey (n=428) was administered across two states of Australia to identify the more popular games to use for this part of the project (Lowrie & Jorgensen, 2011). In this paper we draw on the stimulated recall for one of the games used - *The Legend of Zelda: Phantom Hourglass'*. This game was chosen as it was an *Adventure* game, which was a popular game type amongst survey participants (Lowrie & Jorgensen, 2011). The *Legend of Zelda* game challenged the player to navigate around various environments in order to locate a lost person. Like many adventure games, the game play had scaffolded activities which had to be completed before moving to the next phase of the game. The game was also selected because it was a game used on hand-held consoles and therefore could be played in various contexts and settings, and it facilitated curriculum-based mathematics ideas (e.g., problem solving, two-and-three dimensional space, and position).

Learning Principles: Opportunities and Constraints

In the remainder of the paper, we analyse four learning principles – for the opportunities that it provided for mathematical learning and how they constricted the learning opportunities. In this latter analysis, we premise the notion of "constraint" on the current reforms in mathematics education that promote deep and complex learning over rote-and-drill learning. While we entered this project with the hope that the games environment would enable new ways of learning mathematics that were engaging and rich (based on our reading of Gee and Prensky cited earlier in the paper), our data have challenged this assumption. Both the stimulated recall with young players and the descriptions provided by experienced gamers have illustrated a very narrow approach to game playing and one which is the antithesis of reform pedagogy.

In the following section, we draw on the data from the interview with one student, Zane an 11-year-old boy from a regional city in Australia. Zane played *The Legend of Zelda: Phantom Hourglass'* game and was a relatively accomplished player. He regularly played digital games on both hand-held consoles and larger, fixed consoles such as an Xbox360 or a PC. Our aim in this section is to link the data with the most appropriate learning principle described by Gee to provide illustrative examples of the learning principles, their application to mathematics at a generic level, and how the principles were observed within the digital games stimulated recall. The purpose of these data is to provide illustrations from one student. The extracts could be applied to other learning principles and other players. However, for the purposes of this paper we are seeking to illustrate the experiences and processes used by the player in terms of possibilities for mathematics learning and mathematical concepts/processes. If Gee's principles can be applied to mathematics as they have been done in literacy education, then we contend that there is a radical possibility for new learnings. We use four principles to explore the possibilities of and for learning mathematics: 13) Ongoing Learning Principle; 15) Probing Principle; 12) Practice Principle and 6) "Psychosocial Moratorium" Principle. Within the limited confines of a conference paper, we have elected to use these principles as they are quite diverse in their propositions and as such serve as illustrative examples of both our approach to studying the phenomenon as well as illustrating how the principle was lived out in this game and with this gamer. An outline of each principle is drawn from Gee's descriptions in the literature, . We then provide our interpretation of how such a principle would be lived out in the mathematics classroom and give examples from the stimulated recall transcript to illustrate how this gamer (Zane) interacts with the game. In selecting these extracts, we seek to demonstrate how the principle is lived out when framed within a mathematical context and to note the affordances and constraints of such principles as they apply to mathematics.

13) Ongoing Learning Principle

> The distinction between the learner and the master is vague, since learners, thanks to the operation of the "regime of competency" principle listed next, must, at higher and higher levels, undo their routinized mastery to adapt to new or changed conditions. There are cycles of new learning, automatization, undoing automatization, and new re-organized automatization.

Within the context of mathematics education, such a principle is useful in terms of expansive learning where the student will revise previous learnings and concepts and modify these in light of new learnings. A simple example of this is as the students develop proficiency with addition facts, they develop a schema for addition being an increasing process but as this proficiency becomes an automatic process, negative numbers are introduced and the increasing schema must be modified to accommodate the learning. The concept for addition is substantially revised to incorporate new experiences. Learning occurs on a particular trajectory where principles can be intuited and developed into more complex principles as further learning experiences are provided. The scaffolding to enable on-going learning supports the current learning but in subtle ways also expands learning to include anomalies so as to build new, more complex understandings.

In this extract, the player has been working his way through the world and has had to devise a strategy where the statues can be manipulated so that he progresses through this level. He is aware that there is a problem that needs to be addressed in order to move forward. Initially, he had devised a strategy where he thought that if the statues were activated but this was not successful. He realised he needed a different strategy. Earlier learning has created some traces in his game memory of how to get objects, in this case the statues, to be manipulated. While the strategy involved some trial and error to see what might work, there was some progressive refinement of strategies that would enable progress.

> Q: So, we're just going to pause it there; we just want to ask you can you tell us about what you were thinking as you completed that last section that we just watched?
> Zane: How do you turn the statues around?
> Q: Yeah.
> Zane: Before I worked out that you could turn them around, I thought you only needed to activate the three and then, the door would open, but then I worked out that you could turn them around.
> Q: How did you work that out? What did you do?

Zane: Well I just tapped them, yeah.

The highly visual aspects of the learning environment scaffold the gamer to play and continue to play in the game in order to build new understandings of the game and how to progress through the worlds in which he plays.

15) Probing Principle

Learning is a cycle of probing the world (doing something); reflecting in and on this action and, on this basis, forming a hypothesis; reprobing the world to test this hypothesis; and then accepting or rethinking the hypothesis.

In Lowrie's work with Pokemon, this principle was very evident. Young children created visual maps of the worlds that extended beyond the parameters of the small visual screens. These worlds were also three-dimensional. As such, they were far more sophisticated than is possible in the traditional formats of paper environments. To create these complex visualisations, players create mental images and then control the Pokemon to move into these spaces and to test the validity of these mental maps. This creation is made possible through the games environment but not in traditional school environments.

In the following extract from the interview with Zane, the student has been navigating his way around the world, but making a few errors. Rather than simply using a trial-and - error method, he has referred to the second screen on the DS console to check his progress and to monitor the success of that strategy. At first, it appeared that the strategy was based on trial-and-error but appeared to be somewhat more advanced:

Q: So what were you doing here?
Zane: I was mapping a way to get around and I made a few mistakes.
Q: What sort of strategy did you use to map, like how did you know where to go, apart from the top screen, was there anything else that you use there to help you?
Zane: Not really at that area.
Q: Okay. So, how did you know you'd made a mistake too?
Zane: I looked at the top screen and then looked at the bottom and they didn't match.

12) Practice Principle

Learners get lots and lots of practice in a context where the practice is not boring (i.e. in a virtual world that is compelling to learners on their own terms and where the learners experience ongoing success). They spend lots of time on task.

Some of the heaviest criticisms of mathematics teaching and learning is the reliance on drill-and-practice as a pedagogy. Reform pedagogies have attempted to shift the ideology of drill and practice to one where the learner engages with deep learning so that there is a clear shift from procedural thinking/learning to conceptual thinking/learning. The degree of change in approach to teaching mathematics is somewhat circumspect. In his definition of the role of practice, Gee's proposition is quite different from the rote-and-drill practice regimes of many classrooms on two key points. First, he points out that the practice is not boring and that the practice becomes engaging and compelling for the gamer. This principle links with many of his other principles around scaffolding progress. These include the notion that the learning (or failure) is not public so that others are unaware of the mistakes as the gamer moves through the game. He also contends that for the gamer there is low risk in what is being done so that if a mistake is made, then he/she does not make any substantial losses. This is discussed in the following principle. For example, this is evident in where a mistake may be made but the gamer is not sent back to the start of the game, but to the start of a level. The capacity and willingness to practise "lots and lots" as per the definition is contingent on these key considerations. Finally, the practice also means that the game spends considerable time on task while he or she is practising. This is both physically with the gaming device but also cognitively as he/she practises, makes errors and refines strategies (even if the strategies are trial-and-error). This type of strategy is evident in the first principle (and transcript) discussed in this paper where Zane indicates he just “tapped them” to find out if the statues were a vital clue in moving forward in the game. As found across our cohort of students, the use of these strategies was commonplace, in part, due to the game encouraging some speed in decision making. In most games the imperative of staying alive to combat and defeat enemies requires the gamer to make decisions as he/she moves through the game based on previous experiences and which may not demand too much cognitive labour. Trial-and-error strategies were commonly observed across all players, in part due to the low risk consequences if errors were made.

In terms of the practice principle, this was highly evident in the stimulated recall scenarios with all players. There was a heavy reliance on practice in order to move forward in the game. The practice enabled players to develop their skills and knowledge of the game environment and thus be able to negotiate new levels. Often this practice aligns with trial-and-error methods as the gamer navigates through new scenarios, drawing on previous knowledge but where those learnings may not be effective but provide cues on how to move forward in the game.

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6) "Psychosocial Moratorium" Principle

> Learners can take risks in a space where real-world consequences are lowered.

As noted in the previous section there is a need for low risk for the player to engage with the game. This low risk is also associated with failures not being a public display. Much of the acknowledgement of success (and failure) in mathematics is quite public. Inadvertently this public display of failure discourages students from taking risks. In the digital games environment, not only is failure private, it is often low risk. The player who is not able to pass a level will only have to go back to the start of the level rather than suffer a substantial setback. In such an environment, the consequences for failing are low and the possibility for ris- taking great.

In the mathematics classroom, this aspect of Gee’s work is quite scant. Mathematics has historically been one of the most hegemonic of the school discipline areas and as such associated with quite high risk failure. It is not uncommon to hear of risk aversion, math phobia, or other similar terms that connote an aversion to mathematics or reforms that try to encourage risk-taking behaviour in mathematics, but overall the practices are largely in contrast to this principle. The attitude of having a try at something and not having to worry about failure is evident throughout the games environment and is exemplified in the comment by Zane:

> Q: I notice you had a bit of a.. you-don’t-really-mind-if-you-die type attitude, does that sound about right, like, you don’t mind if you get hit?
> Zane: Yeah.
> Q: Yeah why was that?
> Zane: Because I knew that I could always do it again.

Conclusion: Interesting Trends

We entered this project with the hope that Gee's work would provide some valuable insights into how the games environment may offer potential for new forms of mathematics learning and understandings. We have confirmed many of Gee's strategies are evident in the games, and the strategies are articulated by the gamers. There were many cases where mathematical concepts and processes were being used and many opportunities for new forms of learning. For this paper, however, we have focused on the principles and how they were evidenced by the gamers and their relationship to mathematics teaching and learning.

What we have observed across the case studies of all the players, was that the principles identified by Gee are in evidence. However, what was surprising from the data –consistently across the responses, as evidenced in the quotations provided – was the common theme where players tended to practice many skills and rely on trial-and-error tactics to work their way through worlds. Most of the strategies used did not encourage higher order thinking but were based on speed. Players were not rewarded (or punished) for making errors so there were few consequences for making errors; there was little to no incentive for trying more complex ways of working through worlds. Unlike literacy education where there appears to be quite deep levels of new literacies being made available through the games environment, this is less apparent in numeracy/mathematics education.

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