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Commercially available Digital Game Technology in the Classroom: Improving Automaticity in Mental-maths in Primary-aged Students.

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Abstract: *In this paper we report on a study of the implementation of handheld game consoles (HGCs) in 10 Year four/five classrooms to develop student automaticity of mathematical calculations. The automaticity of mathematical calculations was compared for those students using the HGC and those being taught using traditional teaching methods. Over a school term, students (n=236) who used the HGCs and Dr Kawashima's Brain Training showed significant improvement in both the speed and accuracy of their mathematical calculations. Data collected in interviews during the intervention period from students, staff and parents were analysed to provide further information on the implementation and efficacy of this approach. This exploration identified that the HGCs contributed to positive learning, motivational, and efficiency outcomes. These findings highlight opportunities for using commercially available digital games to achieve classroom objectives.*

Keywords
Digital game-based learning, Improving learner engagement, Mathematics, Automaticity.

Let's accept the inevitability of things to come – and play with them!
(Thiagarajan, 2001, p. xiii)

Introduction

Is it not inevitable that children who have grown up using digital games will expect education and play to be intertwined? To appreciate this sentiment one only has to observe toddlers in prams using phones and tablets and project forward. Surely these toddlers will enter school having a much different view of digital technology than their parents or others from previous generations. Such speculation has probably triggered the research interest in the role of digital tools (particularly in the guise of games) in the educational lives of students (Gee, 2003; Oblinger & Oblinger, 2005; Prensky, 2001, 2006, 2010; Rosas, Nussbaum, Cumsille, Marianov, Correa, et al., 2003; Rosen, 2010) and learners in general (All, Núñez Castellar & Van Looy, 2014, 2015, 2016; Núñez Castellar, Van Looy, Szmalec & De Marez, 2014, 2015). Indeed, Prensky (2001, p. 2) hypothesised that digital game-based learning (DGBL) and its more 'sophisticated successors' will be taken for granted by learners in the future.

Whereas Prensky and like-minded scholars predict the ubiquity of DGBL in schools, many educators are resistant to this viewpoint (Logie & Della Sala, 2010; Purcell, 2005). So the research interest in ‘game playing’ within DGBL is both the basis for optimism and for cynicism – the latter in terms of cost, distraction from real learning objectives, social isolation and reduced attention spans (Marquis, 2013). To explore the potential of DGBL for mental-maths skill development we conducted a pilot study involving 59 primary students using HGCs (Handheld Game Consoles) utilising *Dr Kawashima’s Brain Training* program (designed to develop mental alertness through a series of activities). The finding indicated that students using HGCs made significantly more improvement in mental-maths automaticity than those who developed skills via typical classroom approaches (Main & O’Rourke, 2011). In this article, we report on an extension of the earlier study. The number of students and primary schools was increased so that stronger generalisations about the capacity of digital tools to enhance mathematical automaticity might be made from the findings. Further, we interviewed students involved in this study, along with their parents and classroom teachers, at regular intervals over a school term to elicit their thoughts on whether the HGCs were easy to implement, engaging, and enjoyable for students, and whether the students’ parents were satisfied that this was a positive approach for developing mental-maths skills. This paper reports on the student achievement data for the project and then draws together the authors previously published research on the qualitative elements of this research, subjecting these data to additional analysis in order to provide a comprehensive picture of the impact of the intervention.

Literature review

Digital Games Based Learning (DGBL) in the Classroom

Several researchers have identified the efficacy of DGBL in classrooms (for example: Clark, Tanner-Smith, & Killingsworth, 2016; Condie & Simpson, 2004; Erhel & Jamet, 2013; Groff, Howells, & Cranmer, 2010; Main & O’Rourke, 2011; Miller & Robertson, 2009, 2011). However, researchers also found scepticism among academics and practitioners that using digital games (particularly those normally associated with leisure activities) is worth the time and financial investment (Bennet, Maton, & Kervin, 2008; Logie & Della Sala, 2010; Sardone & Devlin-Scherer, 2010), especially when more traditional approaches could be just as successful (Prensky, 2001). Concerns about the use of digital technology in education often focus on the resulting increased screen time and the associated health risks that come with this (Houghton, Hunter, Rosenberg, Wood, Zadow, Martin, & Shilton, 2015). As with much change, some classroom practitioners understandably lament for lessons past, or as Tapscott (2009, p. 128) points out in his exploration of learning in schools for students of the ‘net-generation’; “old paradigms die hard”. A report on digital games in the classroom found that teachers who played digital games for pleasure were much more likely to use digital games in their classrooms than those who did not (Takeuchi & Vaala, 2014); therefore, it is not surprising that some classroom teachers have expressed a need for guidance on how to use DGBL effectively (Greenhow, Robelia, & Hughes, 2009; Jukes, McCain, & Crockett, 2010; O’Rourke, Main, & Ellis 2013).

Digital Games and Mathematics

The school subject that appears to have benefitted most from the intervention of digital technology, and specifically DGBL, is mathematics (Miller & Robertson, 2009; 2011).

Coley, Cradler and Engel (2000) in an early exploration of technology in American schools reported positive outcomes in drill and practice computational programs. McFarlane, Sparrowhawk, and Heald (2002) in a large study involving twelve primary and secondary schools in the UK, found digital games were effective when developing algebra skills. Ke (2008) investigated the use of drill and practice computer games for a small group of Year 4/5 students (n=15) and found limited testing gains at the completion of the research phase, but enhanced motivational attitudes toward maths. Miller and Robertson (2009; 2011) investigated the use of HGCs to develop automaticity in mental-maths skills for Scottish Year 4 and 5 students and found significantly higher scores in both accuracy and speed in mental-maths for students using the HGCs than those in comparison classes using non-digital methods to develop mental-maths skills. Likewise when we replicated this study on a smaller scale, (n=59 students), we found significant differences in mental-maths accuracy and enhanced self-concept toward mathematics for students using the HGCs compared to those in comparison classrooms (Main & O'Rourke, 2011).

Chang, Wu, Weng, and Sung (2012) investigated the use of game-based problem solving for mathematics with four fifth grade classes in Taipei and found that students had more flow experiences, and higher problem-solving and problem-posing abilities than those in the comparison group. Another study, involving 193 American secondary students and 10 teachers, exploring the effects of a 3D computer game on mathematics achievement and motivation, found that there were significant improvements in mathematics achievement for students using the program compared to a comparison group using a more traditional approach (Kebritchi, Hirumi, & Bai, 2010). A relevant finding from Kebritchi et al. (2010), in the context of this current study (where the HGCs were embedded in the classroom rather than used in a separate setting), was that students who played the games only in the school's computer laboratory reported being less motivated than those who played the game in their classrooms and laboratory. A recent review of 60 studies involving mobile technologies for mathematics instruction, including HGCs, found that students' attitude to the use of this technology was mostly positive and student engagement with the learning activities increased (Fabian, Topping, & Barron, 2016). Further, their meta-analysis of student achievement data indicated an effect size of 0.48.

The performance of Australian students in mathematics continues to be an area for concern with the release of the Trends in International Mathematics and Science Study (TIMSS) and Programme for International Student Assessment (PISA) data. Data from TIMSS indicates that less than 10% of Australian students attain the advanced international benchmark (Thomson, Wernert, O'Grady, & Rodrigues, 2017), while PISA results reveal that Australia's performance in mathematics declined significantly between 2012 and 2015 (Thomson, De Bortoli, & Underwood, 2016). Professor Gordon Stanley, Chairman of the Review Panel of the National Numeracy Review Report (Commonwealth of Australia, 2008) suggests that part of the reason for continued poor performance of Australian students in mathematics; "is [that it is] not generally perceived as a popular subject among young people" (p.1), nor is it, "recognised as an easy subject to learn or to teach" (p.1).

It has been asserted that one of the biggest challenges to student success is disengagement (Appleton & Lawrenz, 2011; Parsons, Nuland, & Parsons, 2014) and, arguably, DGBL offers a potential remedy for the apathy experienced in some primary maths classrooms. Whereas 'fun' has rung classroom alarm bells for educators in generations past (Harp & Mayer, 1998), it is now seen as appropriate in well-structured learning environments (Elton-Chalcraft & Mills, 2013; Mathers, 2008). There is mounting evidence that the strategic and thoughtful implementation of digital games has the capacity to facilitate a fun and productive environment for learning mathematics (Kebritchi et al., 2010; Somyürek, 2015). First and foremost, many digital games such as *Dr Kawashima's Brain Training* demand and reward improvement, and as such the stimulation, motivation, and learning associated with improved game performance are all closely aligned (Hamari, Shernoff, Rowe, Coller, Asbell-Clarke, & Edwards, 2016; Jukes et al., 2010).

Given that classroom teachers are being held increasingly accountable for numeracy standards via national standardised testing (for example, NAPLAN, 2016), they must be confident that the tools they employ are easy to instigate and clearly focussed on student success. In the case of mental-maths automaticity, the Australian Curriculum identifies ‘understanding and fluency’ as a key proficiency strand in developing primary students’ number sense; consequently, strategies that enhance this development are vital. McIntosh, Reys and Reys (1997) concluded the reason for enhancing number sense by mental computation is that it provides students with an “intuitive feel for numbers and their various uses and interpretations.” It is this ‘feel’ that enables automaticity in individual’s use of numbers in everyday situations (McIntosh et al., 1997). Whether this ‘intuitive feel’ can be enhanced by digital technologies is uncertain, but the evidence towards improved mental-maths performance when using these technologies is growing (Miller & Robertson, 2009; 2011; Main & O’Rourke, 2011).

The approaches presented thus far may strike a chord for many teachers in Australian schools and assist in reimagining what maths lessons could look like. And while it is hard to dispute that today’s students are spending alarming amounts of time on screens in their homes (Green, Brady, Olafsson, Hartley, & Lumby, 2011; Houghton, et al., 2015), it is also clear that there is more going on when students use digital games than mindless entertainment. Nonetheless, the criterion for the selection of these classroom technologies has typically been a source of conjecture (Prensky, 2010; Purcell, 2005).

Evaluating Digital Game-based Learning

Veteran American education reformist Cuban (1993) identified a number of concerns expressed by teachers regarding the selection of emerging technologies including; the ease of its use, flexibility, reliability, the availability of technical support, whether the outcomes for the student were worth the time required to learn the technology, and whether the technology compromised the teachers’ management of the learning environment both behaviourally and academically. Johnson (2006) summarised Cuban’s concerns in a single question for educators: “Will it [the technology] facilitate my efforts to create an orderly learning environment and motivate students?” and concluded that, “digital technologies that fail to meet these criteria have a low probability of adoption” (p. 18).

In pursuing more detailed evaluations of digital technology, a recent study conducted in the Netherlands by All et al., (2015) reviewed the feedback from 33 stakeholders in organisations that either used or supported users of DGBL (including DGBL researchers, higher education institutions, secondary and primary schools, e-learning companies, public utility companies and large private companies). They assert that there were three categories of desired outcomes when using this type of learning approach; enhanced learning, increased motivation, and acknowledged efficiency outcomes. Within All et al.’s., (2015, p. 32) research, stakeholders reported differing levels of importance for these outcomes depending on their context. For example, corporate entities were focussed more on cost efficiencies and schools on time efficiencies; as such DGBL efficacy is considered context-dependent. All et al., (2015) attempted to ‘conceptualise and operationalise’ a definition of DGBL effectiveness, and concluded if it achieved high ratings in any outcomes associated with learning, motivation and efficiency (without diminishing any of these outcomes) compared to other instructional methods it was seen as effective.

Aims of the Research

This research is the first large-scale empirical research in Australia focussed on measuring the efficacy of HGCs in primary classrooms. The researchers sought to investigate the use of the HGCs *Nintendo DS lites* with the software *Dr Kawashima's Brain Training* in a number of Western Australian schools after the success of their earlier pilot study (Main & O'Rourke, 2011). The impetus for this research was the results of similar studies in Scotland by Miller and Robertson (2009; 2011), the awareness that overall there remains a need for continued research on digital game usage in formal settings (Kebritchi et al., 2010), and that existing research is derived from numerous digital game platforms with very few focussed on HGCs.

The overarching question that the researchers sought to answer when embarking on this research was whether the HGCs *Nintendo DS lites* with the software *Dr Kawashima's Brain Training* were more effective in developing students' speed and accuracy in mental-maths than traditional classroom mental-maths instruction. In the context of this research, efficacy was determined by improvements in students' scores on a timed assessment of basic math functions. In addition, the researchers were interested in what the students and teachers thought about using the HGCs for mental-maths. Including whether students were engaged when using the HGCs. Drawing from Shernoff's (2013) definition, students were deemed engaged when they were observed to be displaying interest, enjoyment and concentration simultaneously.

To summarise the researchers' intentions, it aligns with Kirriemuir and McFarlane (2004) cautionary thoughts on DGBL enquiry in that it should be a rigorous enquiry that can be replicated in other classroom settings, employ digital games that are not 'fads', and be used in conjunction with sound classroom practice to maximise learning outcomes. And further, it acknowledges the concerns of Bennet et al., (2008, p. 14) that evidence presented in regard to DGBL should ensure that it "includes the perspectives of young people and their teachers and that [it] genuinely seeks to understand the situation".

Method

Ten classes of students (six Year 4, four Year 4/5) from seven different schools were involved in quasi-experimental design research to explore the use of *Nintendo DS lites* with the *Dr Kawashima's Brain Training* software to improve speed and accuracy in mental-maths functions.

Procedure

After ethics approval had been granted by the researchers' university, the WA Department of Education, and Catholic Education WA, the school principals of the selected schools were approached and the parameters of the research discussed. Upon principal approval, the researchers visited the seven classroom teachers to explain each school's involvement.

Students in the experimental ('intervention') classrooms used *Nintendo DS lites* and *Dr Kawashima's Brain Training* for 20 minutes at the beginning of each day over a 10-week school term to develop their mental-maths skills. *Dr Kawashima's Brain Training* game is based on research on the use of mental agility tasks to slow cognitive deterioration (Kawashima et al., 2005); however, the researcher's reason for selecting this program was the prevalence of games involving the rapid recall of mathematical facts. *Dr Kawashima's Brain Training* involves several maths-related computation games that focus on speed and accuracy.

The classroom teachers using HGCs were given an overview of the recommended classroom practice, including timeframes, setting responsibilities for class members in regard to charging and packing away the HGCs, and encouraging students to set goals in terms of speed and accuracy of mental-maths recall. The teachers were also given a *Nintendo DS lite* console with the *Dr. Kawashima's Brain Training* program prior to commencement of the school term so that they could familiarise themselves with the functionality of the console and the game.

When using the HGCs the students were directed to spend at least half their daily sessions on a game, in which 20 random single digit addition, subtraction and multiplication sums appear on the screen. Students enter their answers using a stylus on the HGC touch screen and are given a time and a description of the game speed on completion of each set. Figure 1, for example, shows a student obtaining 'rocket speed' for completing the sequence under 10 seconds. There is no set level of difficulty for the 20 random questions and progress is gauged by speed and accuracy. After they had completed the *x 20* session, students were free to choose from other maths-oriented games; one appealing element of *Dr Kawashima's Brain Training* is that the more sessions played, the more games become available. The researchers and research-assistant visited the classrooms on *day one* of the intervention to ensure all students had set-up their HGCs appropriately, and to determine whether the intervention protocols were being adhered to.

The teachers of the comparison classes were also visited by the researchers prior to the beginning of the new term and encouraged to commit to the 'effective practice' strategies and other highly engaging classroom teaching methods for mental-math, such as those identified by Swan (2007).

Both groups were told that their students' mental-maths recall would be measured at the beginning and the end of the term and to encourage students to set speed and accuracy goals for their daily 20-minute classes over the term. In the interest of equity, the comparison classes were given the HGCs to use in the following term.

Participants

There were two hundred and seventy eight Year 4 and 5 students, (aged between nine and eleven years) in ten classrooms from diverse socio-economic backgrounds in the Perth metropolitan area, involved in the study. Complete data were obtained for 236 students, of whom 120 students were female and 116 male. The seven schools were selected on the basis of proximity to the researchers' university as well as approaches made by teachers after a conference presentation on the use of the HGCs (Main & O'Rourke, 2009) and media publicity following the success of the initial pilot study (Hiatt, 2009). Four schools were public schools and three were from the Catholic education system. Five classroom teachers were female and three were male (two of the teachers doubled up with separate classes). The teachers represented a cross section of experience and classroom styles. None of the teachers had previous experience implementing DGBL in classrooms prior to this study.

Data Collection

The data collection methods included observations, semi-structured interviews and standardised assessments. As with the pilot-study (Main & O'Rourke, 2011), we employed the Westwood *One Minute Test of Basic Number Facts* to measure numeracy skills. The *One Minute Test of Basic Number Facts* (Westwood, 1987) is a norm referenced assessment consisting of four 33-item tests, one for each of the basic maths functions (+, - , x and ÷), with a test-retest reliability of .88 to .92 according to each sub-test (Westwood, 2003). Students had one minute in which to complete the 33 questions for each mathematical function and the score for the overall test is determined by adding together each of the subtests, with the total score for the test being 132. At the end of the term prior to the research intervention, all participating students were given the Westwood *One Minute Test of Basic Number Facts* and were re-tested in the final week of the term in which the research took place.

While measuring student performance is critical in determining the efficacy of the HGCs utilised in this research, this is not the only measure of educational value when judging the use of digital technology (Johnson, 2006). Beavis, Muspratt and Thompson (2015) assert the importance of gaining the perspectives of the students when evaluating the use of DGBL in classrooms and, in addition to observing and interviewing the students, we also sought feedback from teachers and parents on their perceptions of the impact of the HGCs on student engagement and performance.-Semi-structured interviews were conducted with a sample of 36 students (four were selected by each of the classroom teachers to represent a cross section of abilities in the class) and eight classroom teachers: prior to the commencement of the intervention, during the course of the term, and on completion of the intervention. Only three parents were available to be interviewed. Interview questions were focused on identifying the interviewees' opinions on using the HGCs as learning tools, student enjoyment of HGCs, changes in attitude to mathematics, concerns and apprehensions about using this technology, opportunities imagined with the HGC, and changes in teaching roles as a result of implementing the HGCs.

The research assistant conducted weekly visits to observe the mental-maths sessions. Classroom observations were also conducted in the comparison classes to identify the teachers' approaches to mental-maths and student engagement, but these observations were limited due to time constraints and were only undertaken to ensure that the students in these classes were receiving comparable time and instruction in mental-maths.

Figure 1: A student achieves rocket speed for 20 single digit sums in nine seconds.

Data Analysis

Parametric and non-parametric statistics were used to test for differences between the comparison and intervention classes on the *One Minute Test of Basic Number Facts*. Observations and interviews were examined for common themes using the open coding method established by Strauss and Corbin (1998).

Key findings from the qualitative data on student engagement and the role of the teacher have been published in earlier papers (O'Rourke, Main, & Ellis, 2012; 2013), but are reported here with the previously unreported student achievement data to provide a more complete set of data from which to assess the efficacy of the DGBL used in this study. Further, these data are examined against the criteria identified by All et al., (2015, p. 29), to evaluate the efficacy of DGBL, and used to frame the discussion on the overall efficacy of the intervention.

Findings

Student achievement data is presented first as the primary research question was whether the HGCs *Nintendo DS lites* with the software *Dr Kawashima's Brain Training* were more effective in developing students' speed and accuracy in mental-maths than traditional classroom mental-maths instruction. This is followed by a summary of the qualitative data, including reporting on already published data and examining additional data, to elucidate perceptions of the intervention and student engagement.

Analytic Approach

To test for differences between the comparison and intervention classes on the *Basic Number Facts* test we used both parametric and non-parametric statistics. Analysis of covariance (ANCOVA), with pre-test as the covariate, was our preferred approach, because the comparison/intervention groups were based on intact classes rather than random assignment of individual students and it could not be assumed the two groups would be equivalent on the pre-test.

Our choice of ANCOVA is consistent with much of the literature on the analysis of pre-test/post-test designs (e.g., Dimitrov & Rumrill, 2003; Owen & Froman, 1998; Rheinheimer & Penfield, 2001; Wright, 2006). However, not uncommonly for classroom-based research, the data did not meet two of the underlying statistical assumptions of ANCOVA: conditional normality (or normality of residuals) and homoscedasticity (equality of variances). These breaches were possibly due to a ceiling effect whereby students who achieved a perfect or near perfect score on the Basic Number Facts pre-test were not able to demonstrate any further improvement at post-test. Transformation of the data did not redress the problem. Although the ANCOVA is relatively robust against violations of statistical assumptions (Barrett, 2011; Field, 2006; Olejnik & Algina, 1984); the breaches reported herein do cast some doubt on the validity of the results and, as such, we also report the results of non-parametric Mann-Whitney *U* tests based on the students' gain scores (i.e., post-test score minus pre-test score).

Improvement in Number Fact Nnowledge

A graphic representation of the average gains from pre-test to post-test made by each class on the *Basic Number Facts* test is provided in Table 2, and the means and standard deviations for the combined comparison and intervention groups in Table 1. The apparently superior average gain made by the intervention group (20.41, versus 3.78 for the comparison group) was confirmed by the results of the parametric and non-parametric tests. Independent *t* test analysis of the pre-test scores revealed no significant difference between the two groups before commencing the intervention ($t_{(234)} = -1.263$, $p = .208$). At post-test, however, the intervention group performed significantly better than the comparison group ($F_{(1,233)} = 79.686$, $p < .001$) after controlling for the effect of pre-test performance. This pattern was also borne out by the non-parametric analyses on students' gain scores (Median gains: comp. = 5; exp. = 19; $U = 2771$, $p < .001$) using the Mann-Whitney *U* test.

Further analysis was conducted using two-way ANCOVA to check for the possible influence of gender on the results. However, there was no significant main effect of gender ($F_{(1,231)} = 1.895$, $p = .170$), nor significant interaction between gender and group ($F_{(1,231)} = 1.256$, $p = .264$).

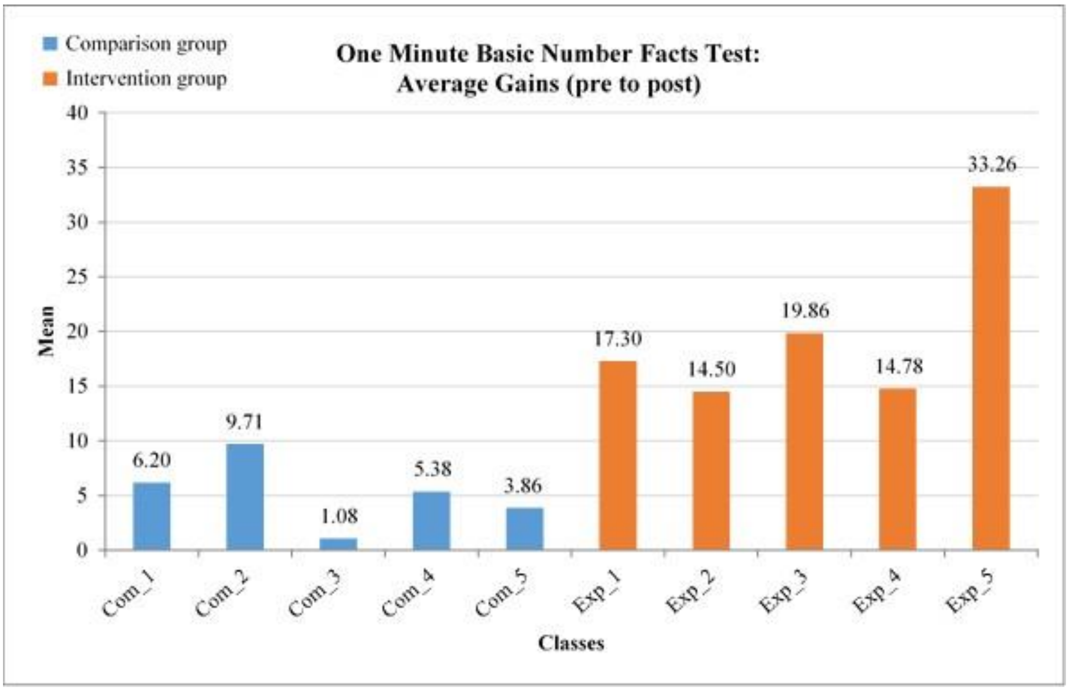

Figure 2: Average gains of Individual Classes on the Basic Number Facts Test.

	Pre-test		Post-test			Gain	
	mean	(SD)	mean	(SD)	Adj. mean*	mean	(SD)
Intervention (n=124)	57.34	(21.43)	77.75	(27.91)	79.70	20.41	(15.91)
Comparison (n=112)	61.23	(25.88)	66.79	(28.26)	64.64	3.78	(21.29)
Test statistic	$t_{(234)} = -1.263^{(1)}$		$F_{(1,233)} = 79.686^{(2)}$			$U = 2771^{(3)}$	
Significance	$p = .208$		$p < .001$			$p < .001$	
Effect size			$\eta_p^2 = .255$			$r = .519$	

* Adjusted mean
(1) Independent samples *t*-test, pre-test only
(2) ANCOVA, post-test with pre-test as covariate
(3) Non-parametric Mann-Whitney *U* test, gain scores

Table 1: Mean Pre-test, Post-test and gain Scores on the Basic Number Facts Test.

Table 2 contains a breakdown of the group means for each of the *Basic Number Facts* sub-tests: addition, subtraction, multiplication and division. Results of ANCOVA using the pre-test scores as covariate, again show the intervention group performed significantly better on each sub-test than the comparison group. Non-parametric Mann-Whitney *U* tests on the sub-tests using gain scores also showed significant differences between the comparison and intervention groups (see Table 2). Further Table 3 highlights the median gains in each discipline area and again identifies significant differences between the groups.

	Means							
	Addition		Subtraction		Multiplication		Division	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Intervention[1]	21.09	26.15	16.76	22.33	12.83	18.79	6.68	10.51
Comparison [2]	21.79	23.24	16.77	18.22	13.48	14.94	9.20	10.39
ANCOVA	$F_{(1,233)} = 42.704$		$F_{(1,232)} = 45.918$		$F_{(1,233)} = 63.476$		$F_{(1,233)} = 13.643$	
Significance	$p < .001$		$p < .001$		$p < .001$		$p < .001$	

[1] n = 124
[2] n = 112

Table 2: Basic Number Facts sub-test means

	Median Gains			
	Addition	Subtraction	Multiplication	Division
Intervention[1]	5	5	5	3
Comparison[2]	1	0	1	1
Mann-Whitney *U*	3870.5	3632.0	3149.5	5268.0
Significance	$p < .001$	$p < .001$	$p < .001$	$p = .001$

[1] n = 124
[2] n = 112

Table 3: Basic Number Facts sub-test median gains.

As noted earlier, for equity reasons the classes from the comparison group received the HGC intervention in the following school term. Their progress was measured at the end of the 10-week intervention using the *Basic Number Facts* test. Since three sets of test scores (i.e., pre, post1, post2) were available for these classes, we conducted a repeated measures analysis to determine whether the greater progress previously seen for the intervention group would be replicated. Because the data violated the assumptions of normality and sphericity, and data transformation did not redress the problem, we used a non-parametric Friedman test rather than repeated measures ANOVA.

Complete data for the repeated measures analysis were available for 84 of the students. The results of the Friedman test showed a significant difference in test scores over time, $\chi^2_{(2)}$ =112.663, $p < .001$. Post hoc comparisons were conducted using the Wilcoxon signed-rank test, with Bonferonni correction applied (.05/2) so that the significance level was set at $p < .025$. The medians and interquartile ranges (IQRs) for the pre, post1 and post2 tests were 57.5 (44.25 to 71.0), 64.5 (46.5 to 78.0) and 81.0 (62.5 to 101.75), respectively. The effects of maturation meant there were significant differences between both the pre and post1 tests (no intervention), $Z = -5.251$, $p < .001$, $r = 0.33$, and post1 and post2 tests (after using HGCs), $Z = -7.625$, $p < .001$, $r = .48$). However, the results support our initial finding that the HGCs had a greater effect on the students' mental-maths performance (as measured by the *Basic Number Facts* test) than traditional classroom approaches. There was no follow-up in regard to maintenance of these gains from the experimental groups as this was not within the scope of the research.

Teacher Practice

Classroom observations and interviews with teachers were seen as important sources of data in determining the impact of the intervention. Observations were undertaken in both the intervention and comparison classrooms to determine the potential influence of teacher practice. All classroom teachers involved in the study (in both intervention and comparison classrooms) were observed taking time to review student awareness of mathematical concepts, and encouraging students to share strategies with their peers at set times during the week (as per researcher guidelines). Teachers in the comparison classrooms were observed using modelling and explanations, drill and practice strategies, and completion of mental-maths worksheets. Specific strategies observed by the research assistant included rhyme and repetition, 'rocks, papers, scissors' exercises (where students in small groups held up the number of fingers in a group to answers times-table questions), and mini mental-maths quizzes using buzzers. These observations suggest that the teachers in the comparison classrooms were selecting strategies intended to engage students in mental-maths activities. Observation of a variety of teacher practice in the intervention classrooms (described by O'Rourke, Main, & Ellis, 2013) as 'the guiding teacher', 'the facilitating teacher' and the 'interactive teacher'), illustrated that regardless of the different teaching approaches when using the HGCs, these classroom pedagogies appeared to have little influence on the positive student perceptions and improvements in mental-maths skills. It was evident in classroom observations that by maintaining set classroom structures the HGCs had the capacity to engage and motivate students, irrespective of the approach of the teacher (O'Rourke et al., 2013).

The interviews with teachers were conducted on three occasions during the term and provided information on their perceptions of how the HGCs influenced their practice as well as that of their students. The semi-structured interviews were analysed for themes using a line-by-line open coding approach (Strauss & Corbin, 1998). The teachers' feedback was overwhelmingly positive with 64.4% of their comments relating to improved student engagement and motivation, enhanced problem solving, choice making, goal-setting and collaboration, and becoming more organised and independent (see O'Rourke, Main, & Ellis, 2013 for full exposition of teacher feedback). While teachers were supportive of the intervention approach, 5% of interview material suggested that students could become overly competitive when using the HGCs. While the possible benefits and risks of competition in the classroom are not within the scope of this paper, competition (or self-competition) is an element of typical game playing and the students who enjoyed competition were motivated by this aspect of the intervention. Some teachers (2% of key themes) also noted technical issues when using the HGCs, but these concerns were alleviated by researcher support and on occasion, student problem solving.

Of the comments affirming the use of the HGCS, 24% were directed towards the changing roles of teachers in classrooms employing digital game technology. These roles have been explored in more detail in O'Rourke, Main, and Ellis (2013), but for one teacher the HGCs provided an assurance of quality instruction:

> *[The DSs] Just makes learning their tables fun. Saves me doing it and whichever way teachers try to do it…it's all pretty time consuming and it's all pretty boring. This way [using the DSs] I can basically keep an eye on them and they go for it…*

As an indicator of teachers' perceptions of the intervention, several of the teachers requested using the class-sets of HGCs in the following years indicating positive affirmation of this process of learning.

Student Engagement

In order to answer the research question pertaining to student engagement, interviews with students were recorded, transcribed then analysed using an open-coding method (Strauss & Corbin, 1998) common themes, patterns and tensions were revealed. The following vignette recorded by the research assistant, who visited classrooms on a weekly basis, provides a snapshot of the level of student engagement and classroom behaviour when students were using the HGCs:

> ***8.50 am****: "Oh yeah we are doing DS", chorus the students. General discussion on scores and personal bests. Student X says he is catching up to the classroom teacher. Distribution of DSs - mostly done individually, some picked them up for their friends. Very little teacher direction. Students are very well organised – folders are out and DSs ready to go. Students stand up when all set. Student X and Y prepare for battle. Instructions simple, no issues of behaviour. Four students undertaking Sudoku, square games while others are completing x 20.*
> ***9.00 am****: Students still concentrating on tasks. One student distracted, not feeling well.*
> ***9.02 am****: Postures of students range from normal upright position, to legs pressed against the table top, turned in chair with head on back of chair, sitting diagonally to slumped positions. Comments of the different strategies used for faster times: writing smaller, getting in the zone.*
> ***9.05 am****: Sharing of scores by a few when completing a round. Faces of excitement when achieving a good score. Faces of disbelief when achieving an inadequate score.*
> ***9.07 am****: Students complete paper work; time sheet (students have been filling these in themselves each week); what I need to remember (little recorded here);*

and scrap paper to record times – they are crossed out when they achieve a better time.

***9.10 am**: Time is up. Students finish games and pack away quietly and orderly.*

Further themes that emerged from the semi-structured interviews with students (see Figure 2) were that the HGCs: were fun, easy to use, novel, challenging, provided choice and allowed students to develop strategies (and subsequently self-regulate their efforts) (see O'Rourke, Main, & Ellis, 2012 for the full analysis of this data). Although limited, there was negative feedback from students related to technical issues. Specifically, the frustration they experienced when the *Dr Kawashima's Brain Training* program did not recognise their writing and therefore indicated a wrong answer. Additionally, some students recognised that the format of the game resulted in their classmates becoming overly competitive. As previously stated, the issue of competition in the classroom is complicated and beyond the scope of this paper; however, it is acknowledged that the effects of competition can be anxiety inducing for many students (PISA, 2015) and as such needs to be given consideration.

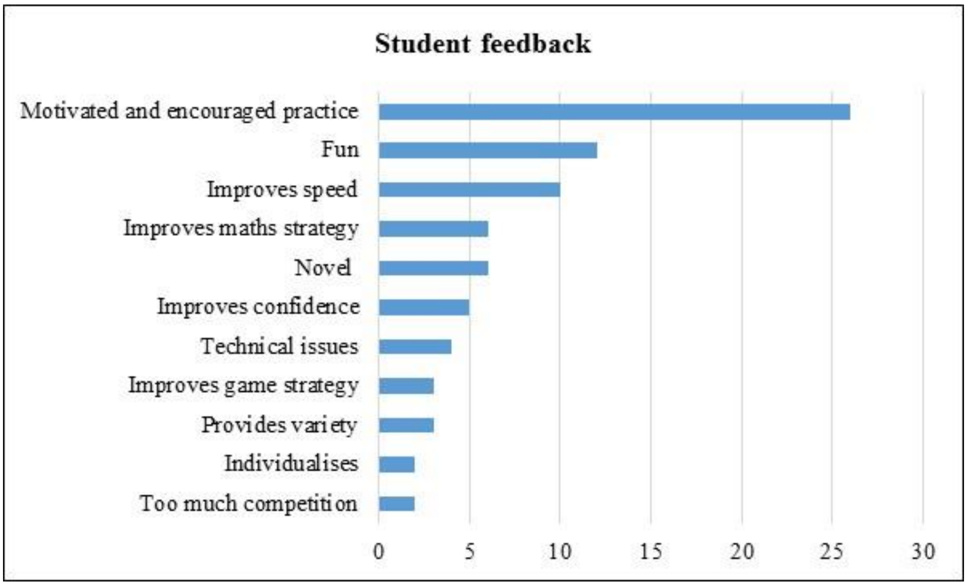

Figure 2: Sub-themes from interviewed students derived from open-coding method (85 interviews reviewed).

Some students appeared genuinely surprised by their improvement in mental-maths computations using the HGCs and this suggested movement towards the 'intuitive feel' identified by McIntosh et al., (1997).

Student A: Well I'm learning well, I've wrote [sic] *the sums quicker than I ever have before, like, when we're doing a sheet, I don't do it as quick for some reason, it's just when you're so concentrated on .....you just do them.*

Student B: I know I can do it and it's just I have a feeling to get past it!

Only three parents were available to be interviewed to determine their perceptions on their child's use of the HGCs in the classroom. The limited number of parents available for interview means that their feedback may not be indicative of all parents' views. Parents' responses were interrogated to identify areas of concern and indications of student engagement with the HGCs. There were initial concerns about the potential lack of strategic input from teachers, but once the intervention commenced it became evident to parents that teachers were providing this input and this issue was not raised in subsequent interviews. One parent did express concern that *Brain Training* was directed toward more surface learning, when a deeper appreciation of mathematical concepts would have been beneficial, but this is a criticism that could be levied at other forms of drill and practice used to teach basic math concepts. In subsequent interviews all parents reported that their children were motivated by the HGCs and that their attitude to maths had become more positive (O'Rourke, Main, & Ellis, 2012).

Discussion

The purpose of this study was to examine whether the use of a digital game using *Dr Kawashima's Brain Training* could increase Year 4 student engagement and automaticity in mental-maths in seven different primary schools in Perth, Western Australia. To provide a framework for assessing the effectiveness of this approach, a brief summary of the three *desired* outcomes of All et al's., (2015) conceptual framework for assessing the effectiveness of DGBL is provided. All et al., (2015, p. 29) proposed that operationally DGBL was effective when users "achieve similar or higher scores compared to other instructional methods" via:

1. *Enhanced learning outcomes* as a result of increased interest in the subject matter, improvement in performance or transfer of skills to real-life situations.
2. *Increased motivational outcomes* through enjoyable experiences of playing the game, or increased enthusiasm toward use of the DGBL, and
3. *Acknowledged efficiency outcomes* through time-management and cost-effectiveness.

Results of this study and previous research (Main & O'Rourke, 2011; O'Rourke, Main, & Ellis, 2012; 2013) indicate that use of the HGCs achieved most of All et al's., (2015) desired outcomes.

Given the significant statistical improvements in mental-maths skills of the students in the HGC intervention classrooms, when compared to those in the comparison classrooms, the qualitative feedback from students on enjoyment of using the HGCs, improvement in speed and accuracy, and motivation/enthusiasm towards learning, *outcomes one* and *two* of All et al's., (2015) framework appear to be satisfied. Teachers too were satisfied with their students' improvements in mental-maths accuracy and capacity to strategise. Further, there was clear evidence that the implementation of the HGCs in the intervention classes resulted in transfer of skills to real-life applications and settings via student feedback and improvements in mental-maths recall in standardised testing situations.

While schools' perspectives on 'cost-effectiveness' were not measured it is worth reflecting on that none of the schools purchased a class-set of the HGCs post the interventions. Several schools asked to use the class-sets again, but school administrators did not see purchasing HGCs as an investment appropriate for school funds. While this may indicate that the schools did not see the HGCs as cost effective in terms of meeting the needs of their student's learning, De Grove, Bourgonjon and Van Looy (2013) point out that schools have limited budgets for technology and as such principals may be more inclined to purchase equipment that has perceived stronger utility in a number of curricular materials.

Finally, it could be argued that the HGC intervention provided classrooms with time efficiencies (and thus met at least part of All's et al., (2015) *third outcome* of effective DGBL) via enhanced student engagement. In an earlier pilot study by Main and O'Rourke (2011) exploring the implementation of the HGC, video footage (taken three times during the term) and classroom observations were analysed to determine classroom behaviour. An overall estimate of the time students spent on engaged/non-engaged behaviours was obtained by amalgamating and averaging the coding data. This data indicated that students were, on average, *engaged* (using the HGCs on their own) for 65% of the 20 minute session with only 10% of the time being spent in *non-specific* activities (off-task behaviour and conversations not related to the use of the HGCs). Of the remaining time, approximately 15% was spent on *sharing* (student shares their progress with the teacher and their peers, often in the form of high scores) and 10% on *assisting* (student assists another with the operation of the HGC e.g., student takes a leadership role in collaborating with fellow students to address technical issues and strategies [see O'Rourke, Main, & Ellis (2013) for a full exploration of student classroom behaviour]). While such analysis was not conducted in the current research, the vignette presented in the results section challenged the perception that many students in primary settings meet maths classes with antipathy and non-enthusiasm. In this case the classrooms observed (along with others using the HGCs), had well-structured and time focussed lesson protocols, universal design for learning features (via student choice making), strategy development, student collaborations and lesson reflections. These antecedents impact on the "amount of time and energy a student is willing to devote to learning" (Churchill et al., 2011, p. 124) and in combination with a popular digital tool such as the *Nintendo DS lite* can result in academic gains. Overall, the students' use of the HGCs resulted in a high degree of student engagement and significant improvement in their addition, subtraction, multiplication and division over the school term.

Limitations

While the results of this research support the implementation of HGCs in primary classrooms, we are aware there are many variables that could have impacted on the students' mathematical improvement and these limit the generalisations that can be made from this study. In this research the mental-maths approaches undertaken in the comparison classes could not be controlled, which 'muddies the water' for the comparison statistics presented (All, et al., 2014). Nonetheless, because we closely followed the protocols of an earlier pilot study (Main & O'Rourke, 2011) and similar research conducted in Scotland, the consistent results are promising. Further, while the authors do not see this as a 'cure-all' for disengaged primary aged maths students, they recognise this approach aligns with contemporary Universal Design for Learning (UDL) approaches (Rose & Meyer, 2002) and is an intervention that, if used strategically, is appropriate in a variety of settings (Main, O'Rourke, Morris, & Dunjey, 2016).

As O'Neil, et al., (2005, p. 465) described: "Games themselves are not sufficient for learning, but there are elements in games that can be activated within an instructional context that may enhance the learning process." Thus, it is the digital game in combination with classroom exigencies that impact on student learning. Classroom observations provided additional information on the situation under which the HGCs were used, which indicated that implementation and outcomes were similar even when the teaching style differed. Regardless of these differences (O'Rourke, Main, & Ellis, 2013), the teacher's role was still vital in supporting students with strategies to be successful with their mental math (e.g., unpacking mental-maths strategies on the board, acknowledging and encouraging student improvement, assisting students to self-regulate their mental-maths progress).

All et al., (2015, p. 37) suggest, "a DGBL intervention is effective when it achieves similar or higher scores in comparison to 'business as usual' in relation to [sic] learning, motivational or efficiency outcomes, without significantly diminishing any of the others." It is acknowledged that further testing to determine if gains were maintained by the intervention group would have solidified the findings, but the collected research data on improved mental-maths performance over the term, along with positive feedback from students and teaching staff on enhanced learning, motivation and classroom efficiencies, indicate that the HGCs align (in the most part) with All et al's conceptual framework on DGBL efficacy, and provide the impetus for future investment in interventions using commercially available digital games in the maths classroom.

Conclusion

Despite the limitations of this research, we contend the findings demonstrate that commercially available digital games, such as the *Nintendo DS lite*, can be useful tools in the primary classroom. The *Nintendo DS lite* was simply one of the technologies engaging children at the time of the research, but thoughtful implementation of this technology resulted in academic gains for the students using it. Cuban's (1993) concerns about technology in the classroom, namely, whether it was easy to use, whether support was needed and available, whether the outcomes for the student were worth the time required to learn the technology, and if the technology had an impact on the teachers' ability to manage the learning environment both behaviourally and academically; all appeared to be addressed within this classroom intervention. Perhaps it is all summarised succinctly, by one of the interviewed students who, when asked why he preferred the HGC over non-digital approaches to mathematics, simply responded: "Because it's more fun - it encourages you to do more!" Further, as Elton-Chalcraft and Mills (2013) in their exploration of creative and fun curriculum, found: "Children, students and teachers all agreed learning is more effective when children have more control over their learning and when activities and learning environment were both fun and challenging" (p. 495). Thus, the implication for teachers, and teacher educators, is to look beyond technology specifically designed for classrooms to the technology that our students choose to access away from these settings. In this space we may find tools that are easy for our students to access independently, provide fun and challenge, and result in desired learning outcomes.

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