Race in the Outback: Investigating Technology Designed to Support Number Development in a Preschool Serving an Under-Resourced Community

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There is growing evidence that socioeconomic-related differences in mathematical knowledge begin in the preschool years and can become entrenched over time. Children from low-income backgrounds enter school with less mathematical knowledge than their more affluent peers. This paper reports on the use of a tablet-based computer application developed and implemented in a NSW preschool serving a lower SES community. The study sought to: (i) determine the educational effectiveness of the number application in developing children's early number knowledge and (ii) identify specific features of the application's design that supported or inhibited early number knowledge development.

Recent research has identified that the relationship between early and later mathematical knowledge is roughly twice as strong as that between early and later reading achievement (Claessens, Duncan, & Engel, 2009; Duncan et al., 2007). Coupled with this is the concern that children from low-income backgrounds enter school with much less mathematical knowledge than their more affluent peers (Bowman, Donovan & Burns, 2001; Starkey, Klein & Wakeley, 2004). These early differences can have long-term consequences, as they are maintained over time. Children that start behind in the early years of primary school tend to stay behind.

Siegler (2009) reported on an intervention that reduced the gap in performance in early numeracy by producing large, rapid, and broad improvements in the mathematical competence of low-income preschoolers. The intervention, which involved playing a board game, ameliorated the gap in performance in early numeracy between children from low-income families and their wealthier counterparts. Roughly, an hour of playing a simple linear number board game produced gains in numerical magnitude comparison, number line estimation, counting, and numeral identification.

In recent times, tablet-based applications (known as 'apps') designed for preschoolers have become increasingly popular. Shuler (2012) found that 58% of the top-selling apps in the Education category of the iTunes App Store targeted preschoolers. However, the educational designs of popular apps (for example, Fish School) tend to rely on traditional preschool topics of letter recognition, colours, as well as sorting and categorising. Often these apps lack an explicit pedagogical focus and have poor design with superfluous screen and audio embellishments (Highfield & Goodwin, 2013). Other apps for preschoolers draw on popular characters from children's television such as *Postman Pat*, *Dora the Explorer, Peppa Pig* or *Fireman Sam*. Preschool apps are rarely based on the outcomes of research in number acquisition.

A recent study, conducted as part of the larger *Ready to Learn* initiative, examined how a 'transmedia' intervention assisted children from under-resourced communities develop basic, early mathematics skills (Pasnik & Llorente, 2013). The ten-week study provided curricular activities based upon early childhood mathematics practices, digital resources

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and technical support to assist the integration of technological resources into instruction, and ongoing teacher professional development. The study found the four- and five-year old children's basic mathematics skills increased significantly after using transmedia resources that were accompanied by teacher support and professional learning materials.

The study reported in this paper sought to evaluate the effectiveness of a purposefully designed number app, *Race in the Outback,* developed for preschoolers. The app was based on the linear number representation used in Siegler's research (2009). It used a story context depicting Australian animals, as shown in *Figure 1*, on an adventure that involved quantifying and counting experiences. The app's design was informed by research evidence about the fundamentals of counting and numeral recognition or identification that children from disadvantaged backgrounds typically lack (Wright, 2002; Wright, Martland & Stafford, 2006). This study endeavoured to determine if Siegler's (2009) results would carry through when the linear number representations were presented in a digital format (app).

Figure 1- A screen shot of the *Race in the Outback app's narrative introduction.*

The *Race in the Outback* app was developed to a design provided by the Leader in Numeracy of the NSW Department of Education and Communities *Early Action for Success* strategy (NSW Department of Education & Communities, 2013). A linear and didactic design was utilised to explicitly teach basic number concepts. Three areas of number learning were explicitly addressed in the app:

1. Numeral recognition or identification as shown in *Figure 2*
2. Forward number word sequence knowledge as depicted in *Figure 3*
3. Matching numerals to quantity (e.g. dot patterns) as shown in *Figure 4*

Six games were included in the app, addressing each of these number concepts twice.

Figure 2- A screen shot of Game Two.

Figure 3- A screen shot of Game One.

Figure 4- A screen shot of Game Three.

As a design study this trial examined the educational effectiveness of the *Race in the Outback* app in terms of disadvantaged preschoolers' early number knowledge. It explored

how the app was utilised in conjunction with regular numeracy activities in a real preschool setting. The following research questions guided the study:

1. How effective was the *Race in the Outback* app in developing preschoolers' early number knowledge?
2. What factors impacted on the *Race in the Outback* app's effectiveness?

Method

A preschool in NSW was purposefully selected to participate in the trial of the initial build of the app. The preschool serves children from low-income families and is attached to one of the *Early Action for Success* schools (NSW DEC, 2013). The school has an Index of Community Socio-Educational Advantage (ICSEA) value almost 2 standard deviations below Australia's mean index (ACARA, 2012). The preschool is open to children turning 4 years of age before 31st July in their year of attendance.

Two iterations of the study were conducted both for five weeks in duration. The first iteration involved one cohort of students who attended the preschool on Monday and Tuesday and alternate Wednesdays (n=16) and the second iteration involved the students who attended preschool on Thursday, Friday and alternate Wednesdays (n=18). The first iteration was conducted between August and September 2013 and there were 12 opportunities for the students to use the app. The second iteration occurred during October and November 2013 and there were ten opportunities for the students to use the app. The average age of the students who participated in the trial was 5 years and 1 month.

The *Race in the Outback* was the only app installed on the ten iPads throughout the trial period. The students did not use any other apps during the trial period, apart from the camera for unrelated purposes. The students used the *Race in the Outback* app as part of their overall mathematics learning experiences and the teacher maintained 'regular' numeracy tasks that included interactive whiteboard experiences, incidental counting tasks and hands-on number identification tasks with concrete materials. No planned learning experiences were implemented to deliberately support the app. The students used the app independently or with a partner and were supervised by the teacher or support staff member at all times to provide scaffolding and additional technical and learning support.

An 'improvement research' approach was utilised to provide quick and timely feedback about the design and effectiveness of the app (Carnegie Foundation, 2013). Similar to a design study, this approach involves synthesising research and practice, quickly developing and testing prospective improvements, deploying new understandings about what works in classrooms and adding to the broader knowledge base. Multiple data sources were utilised and included: (i) pre- and post-intervention one-on-one number monitoring interviews conducted by the preschool teacher; (ii) semi-structured interviews with the preschool teacher throughout the intervention period; (iii) video data of students using the application; (iv) observation and anecdotal notes from both the researcher and teacher (a logbook was maintained throughout the trial period); and (v) Google analytic data to determine the frequency and app usage patterns.

Triangulation of data occurred through the collection of multiple sources of data. Both quantitative and qualitative analysis methods were employed to identify pertinent themes. Improvements in students' number knowledge were quantified with data from the one-on-one assessments conducted before and after the intervention period. Data from the teacher interviews, teacher logbook, site visits and video recordings of the students using the app were coded and recurring themes identified and recorded in a theme matrix. The Google

analytic data that tracked the app's usage was also used to corroborate the findings and this data was also included in the theme matrix. The theme matrix not only elucidated key findings but also provided a trail of evidence to assist in nullifying the possible impact of researcher bias.

Results and Discussion

Educational Effectiveness

Results of the one-on-one number monitoring interviews indicated improvements in the students' performance on the post-intervention assessments. In both iterations the median scores for oral counting improved, as exemplified by *Figure 5*. The participating teacher agreed that whilst most of the students' oral counting had improved between the two assessment points, she cautioned against attributing this gain solely to the app because the app only dealt with numbers to 15 and many children could count beyond this number at the post-intervention assessment.

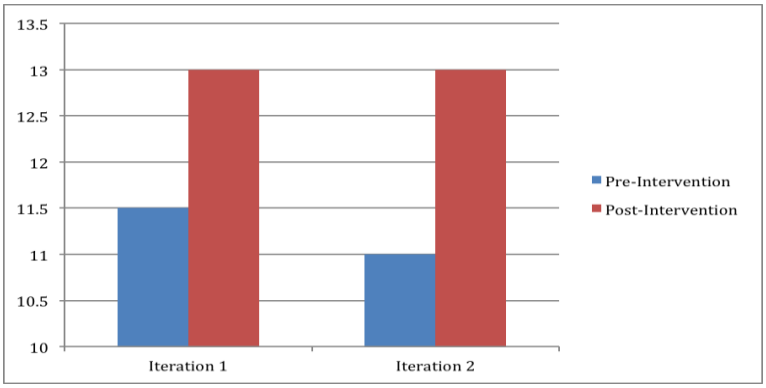

Figure 5- Median pre- and post-intervention assessment scores for oral counting task.

Most students' scores remained consistent between the two assessment points for the interview tasks involving numeral recognition and identification and the matching numeral to quantity task, as reflected in Table 1. However, there were changes between some students' performance on the pre- and post-intervention interview tasks assessing numeral identification and matching numerals to quantity, as shown in Table 1. When individual student performances were considered for the numeral identification task 26% of students' scores increased between the two assessment points, 65% remained constant and 9% decreased. Similarly, in the matching numeral to quantity task 26% of the students recorded an improved score in the post-intervention interview and only one child achieved a lower score than they did on the pre-intervention interview. The teacher asserted that the students' improvement in matching to numeral quantity task was possibly related to the experiences contained within the app, particularly Games Three and Six. These games involved counting eggs and matching quantities. Game Three is shown in *Figure 4*. These data suggest that the *Race in the Outback* app may be effective in developing young children's numeral identification and matching numeral to quantity skills. These findings warrant further investigation.

Table 1
Changes in Students' Interview Performance Between Pre- and Post-Intervention Interviews

Performance at Post-Intervention	Numeral Recognition (n=34)	Numeral Identification (n=34)	Matching Numeral to Quantity (n=34)
No change	24	22	24
1 more correct item	4	6	6
2 more correct items	1	3	3
1 less correct item	4	3	1
2 less correct items	0	0	0
3 less correct items	1	0	0

Factors Impacting on the Apps' Educational Effectiveness

Technical Issues - The teacher's logbook, interview data and site visit data revealed significant and ongoing technical issues with the app. The app froze repeatedly at particular points in and/or a black screen would be superimposed over the screen image, rendering the screen difficult to read. The teacher observed the students holding their finger on the screen or repeatedly touching the screen and suggested that this may have caused the app to crash. However, it was also reported that the app would freeze intermittently even when being used correctly. As a result, the students became frustrated and disengaged with the app when repeated technical issues occurred. Whilst some students were happy to re-open the app and start again, ongoing technical issues caused much frustration for the students and resulted in some electing to prematurely finish their session with the app. These technical issues were reported to the app developer, but the problem could not be rectified during the trial period. This trial has reiterated the critical importance of having a robust app, especially for young learners who frequently tap screens. This finding also highlights the critical importance of play-testing apps with the intended audience to identify possible logistical and/or technical problems that may result because of the way in which they use the app.

App Design - The precision of the students' finger-tapping was also a source of frustration at times, as the hot-spot in several games was very particular and required precise fine-motor skills on the learner's behalf to obtain a correct answer. The teacher observed some of the students verbally stating the correct answer, but these students were then unable to precisely tap the correct answer on-screen, resulting in frustration. The manner in which preschoolers use and interact with a tablet device is markedly different to older children and presents unique design considerations for developers. This finding suggests app developers must carefully design apps that consider the developing fine motor skills of preschoolers.

As a prescriptive app, with a linear design format (Highfield & Goodwin, 2013), the teacher reported that *Race in the Outback* had the most scope for mid-achieving students, as opposed to high- or low-achieving students. The low-achieving students struggled with some of the games, particularly Game One and often disengaged with the app at this point. The Google analytic data reflected this level of disengagement with a 48% and 55% exit rate with Game One (a screen shot of this game is displayed in *Figure 3*) for Iterations One

and Two respectively. The teacher explained that the students disengaged for one of two reasons: (i) technical issues; or (ii) if they were using the one-player mode there was a lag time between when the student interacted with the app and when the on-screen character performed their corresponding task. This finding exemplifies how critical it is for apps to be appropriately paced to sustain learner engagement.

The low-achieving students benefited most from the matching quantity games (Games Three and Six), an example of Game Three is shown in *Figure 4*. However, this was the third and sixth games and the low-achieving students infrequently accessed these because they had often given up by this point and/or had experienced technical difficulties. The teacher proposed that the app could be enhanced with the provision of an access menu. This would enable the teacher or student to launch individual games, rather than having to complete all of the prescribed games in the linear story format. This finding suggests that apps for preschoolers should be designed in a non-linear fashion to allow users and/or teachers to self-select individual games.

The teacher noted that the high-achieving students were adept at using the app. However, these students became frustrated and often disengaged with the app because it did not adequately challenge them. As a didactic, 'instructive' app (Highfield & Goodwin, 2013) there was a ceiling on what the students could learn. The more capable learners wanted to engage with larger numbers beyond 15 and wanted to add numbers greater than one or two but this was not possible within the scope of this app. A student lamented, "Man [sic], I wish I could get a six so I can get across the bridge quicker." There was no scope to progress to more difficult tasks, or unlock levels, as many students requested. The teacher affirmed, "The format of the app never changed. They were looking for the extra bits. For example levels to unlock. They were looking for the bells and whistles and they weren't there." Future app designs could present games that are incrementally more difficult to cater for varying student ability levels. This finding also suggests that apps, which respond to students' individual performance, may be suitable for preschoolers.

The video data and teacher observation notes identified that the animated introduction was a source of frustration for the students. The animated narrative was 1:47 minutes in duration and it automatically launched every time the app started. In Iteration One, 29% of students' total screen time was spent watching the introductory animation and in Iteration Two it was 34%. The purpose of the animation was to contextualise the learning task. However, there was no option to skip the introduction. After the students had watched this animation a couple of times they found it repetitive and monotonous. The teacher observed that the students often looked away from the screen during the narrative and then required significant re-orienting by the teacher to continue with the app. It appears that the lengthy app introduction, even with the inclusion of animations and audio, had an adverse effect on student engagement. The students responded more favourably to the other, much more succinct narrative introductions that were used to explain each of the other five games. Future app designs should consider a 'skip' function if the introduction is redundant.

The provision of instant feedback was identified as both a strength and limitation of the *Race in the Outback* app, depending on the students' ability level. When the high-achieving students made an error the delivery of instant feedback forced them to instantaneously reconcile their erroneous thinking. These students often articulated their mistake and identified the correct answer. However, the feedback was very generic and lacked specific detail about their error. For example, in Game One the incorrect answer feedback loop said, "Hmmm. I don't think that's quite right. Try again." The same feedback loop was delivered

each time the student entered the incorrect result. As a result the low-achieving students did not try to correct their error. Instead, they tended to tap the screen in an ad hoc fashion, hoping to obtain the correct answer by chance. This incessant tapping often resulted in the screen freezing and subsequent disengagement. This finding suggests that preschoolers require specific and detailed feedback and that frequent errors should be limited as it encourages guessing. It is critical that app developers strategically leverage the unique capabilities that instant feedback offers young learners.

The teacher also posited that the background music was distracting for some students. The same tune played constantly throughout each game. When multiple devices were being used this became somewhat of a noise issue. During the site visit some children were observed turning down the audio and/or muting it. Other children were heard humming the background tune when playing outside, away from the iPad. This suggests that the students had perhaps attended to the audio and not the on-screen content when using the app. When designing apps for preschoolers it is imperative that background music is used intentionally and also comes with the option of on-screen muting.

Time on Task - There was significant variation in how long the students engaged with the app. Analysis of the teacher's logbook data revealed that the students spent an average of 14 minutes using the iPad each lesson. This included multiple 'sessions' with the app due to technical issues. Some students attempted to use the app three times within the one lesson. The students in Iteration One spent an average of 3:42 minutes with the app each 'session' and the students in Iteration Two spent an average of 2:53 minutes with the app in each 'session'. The students had multiple 'sessions' because they had to close the app and re-launch it after it froze or had a black screen appear.

Teacher Involvement - This trial also exemplified the critical role of the teacher when using educational technology. The students were actively supervised when using the iPads and the teacher provided technical and instructional support as needed. The low-achieving students also did not appear to attend to the mathematical concepts presented in some of the games. The teacher explained, "The low-achievers did not connect what they were doing with number. For example, with the eggs in the nest and the wombat hole they just pressed until the answer was correct." The teacher needed to expand and consolidate students' on-screen learning and not assume that because they had progressed in the app that they have necessarily understood the concepts presented. This is particularly important if multiple-choice format is utilised. This finding supports the work of McManis and Gunnewig (2012), who also found that adult presence and guidance was required in order to optimise the use of educational technology in preschool contexts.

Limitations, Conclusions and Implications

A small sample size and a brief implementation period limit the generalisability and transferability of this study to broader contexts. While the findings may be applicable to other contexts, the specific findings may be unique to the app and student cohort who participated in this trial. This is a characteristic of improvement research. However, the preliminary results provide several interesting insights and some important caveats can be obtained from the analysis of the app's design. This study provides preliminary data to indicate that apps with an explicit curriculum focus may help young students develop their numeracy skills, especially in schools serving children who may be at risk for academic difficulties due to economic disadvantage. Larger scale and more in-depth studies are

required to determine if purposefully designed mathematical apps can improve young students' counting skills and assist in remediating poor early numeracy skills in disadvantaged children. A further study is recommended to determine if changes in the app's design result in improved learning outcomes.

Data from this study highlight some important design considerations for app developers and teachers. In particular, having the capacity to skip the introductory narrative is critical to sustain learners' engagement. In addition, learning tasks should be responsive to and contingent upon student performance, where possible. Scope for presenting more challenging tasks is also required to cater for the diverse range of student abilities. This study has also suggested that a linear, prescriptive story format without the capacity to 'bookmark' progress may not be ideal for preschoolers.

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