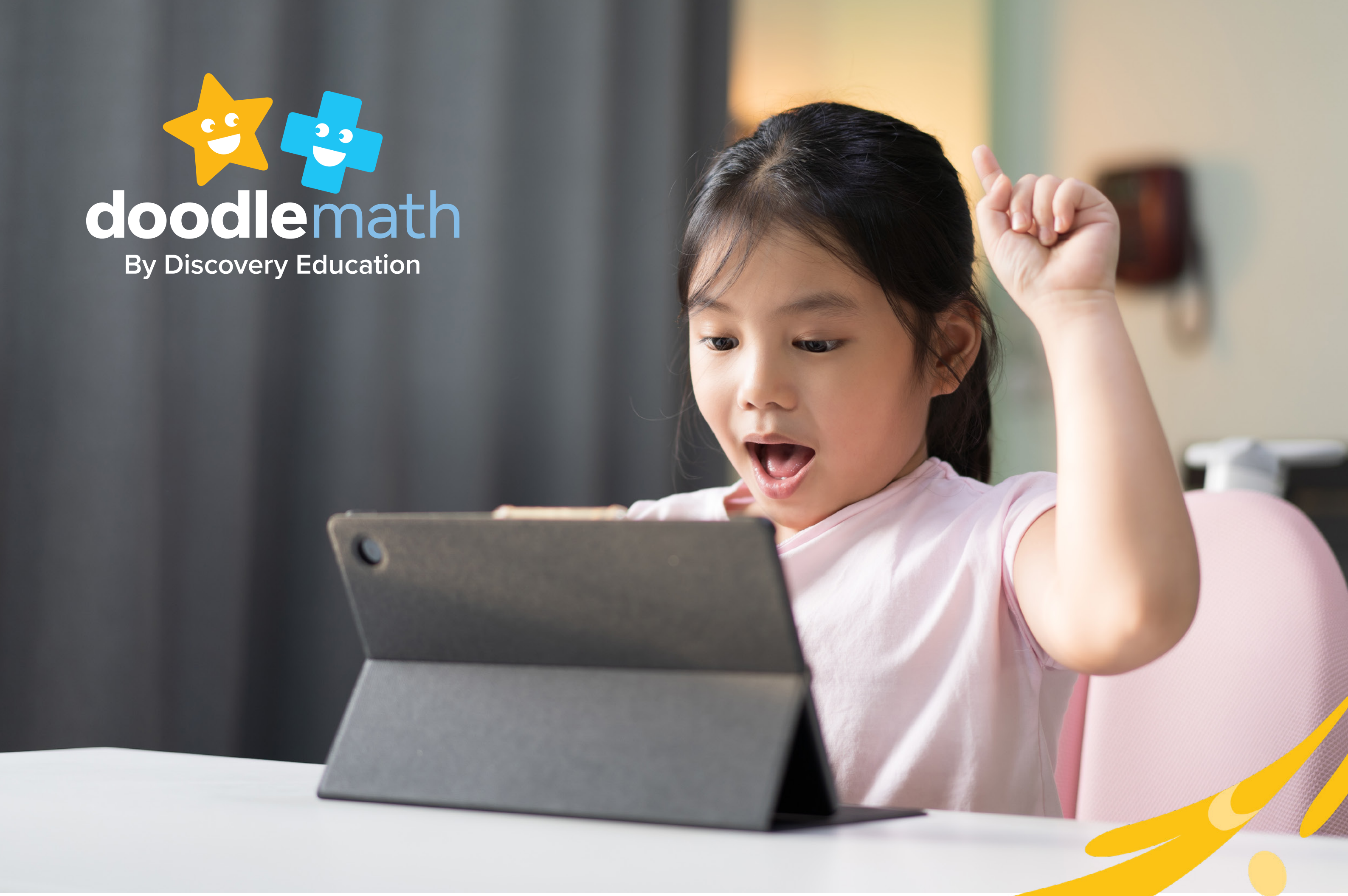

Effects of a Mathematics Educational App on Children's Mathematics Performance Over the Summer Vacation

DoodleMath executed two studies that investigated the effect of a mathematics educational app on children's mathematical performance over the summer. Study 1 involved ten-year-old children (72 females, 62 males) who were given a pre-test and a post-test to assess new knowledge gains in math. Participants had unlimited use of a math educational app during the duration of the study.

Study 1 Results

- Children who did not use DoodleMath and those who did not use it frequently showed no improvement in their mathematics performance over the summer.
- In contrast, children who used DoodleMath frequently demonstrated a significant improvement in mathematical performance.

Study 2 involved ten-year-old children (66 females and 73 males), who were randomly assigned to a condition where the children had unlimited access to DoodleMath over the summer, or to a control condition where the children did not have access to DoodleMath. Both groups were given a pre- and post-test to assess new knowledge in mathematics.

Study 2 Results

- Children who were assigned to use DoodleMath showed significant improvement in their mathematics performance after the summer vacation compared to children in the control condition.

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Introduction

Summer learning loss is defined as the loss of learning associated with the return of children to school after the summer vacation. Cooper, Nye, Charlton, Lindsay, & Greathouse, (1996) conducted a meta-analysis and reported that, on average, children scored one-tenth of a standard deviation lower after the summer vacation compared to their scores prior to the summer vacation, which is equivalent to approximately one month of instruction.

Furthermore, they reported that summer learning loss is not consistent across all academic areas. Summer learning loss in mathematics was found to be greater than in reading and language, especially in mathematical computational skills. One possible explanation for summer learning loss in mathematics is that these factual and procedural skills require multiple opportunities for practice for learners to develop and retain these skills (Cooper & Sweller, 1987; Geary, 1995) and that during summer vacation children do not have the opportunity to practice. Furthermore, summer learning loss is greater for children from low socioeconomic status (SES) backgrounds than for children from high SES backgrounds (Alexander Entwistle & Olson, 2007). Children from higher SES backgrounds tend to engage in more educational activities during the summer than children from low SES backgrounds, and this difference is thought to result in greater summer learning loss for children from low SES backgrounds than for children from high SES backgrounds (Alexander Entwistle and Olson, 2007)

Concern over summer learning loss has led to the development of a number of summer learning programs with the aim to reduce summer learning loss. Kim & Quinn (2013) reported a meta-analysis of these programs in mathematics and found that children who attended these programs out performed children who did not attend. However, school-based programs are expensive (McCombs, et al., 2011) and this has led to number of researchers to argue for the development of low cost, home based, digital programs (Allington, et al., 2010, Lynch & Kim, 2016; Walters & Sorenson, 2013), which could provide children with individualized instruction and instant feedback, and tackle the problem of summer learning loss.

Educational apps are an example of digital technology that potentially could provide this kind of support. Recently, Apple Vice President, Greg Joswiak announced that over 200,000 educational apps have been developed for Apple devices (Apple, 2018) and Pelton and Pelton (2012) identified approximately 4000 mathematical educational apps in 2012.

Unfortunately, these apps are largely unregulated and untested (Haßler, Major, & Hennessy, 2016). Hirsh-Pasek, et al., (2015) have developed a set of principles for the design of educational apps based on what is known about how children learn and develop. They argue that apps that are active, engaging, meaningful, and socially interactive could facilitate the children's development in general and mathematical skills and abilities in particular. Furthermore, Outhwaite, Faulder, Guilford, and Pitchford (2018) argues that these apps can provide individualized mathematics practice targeted to children's needs.

Recently, a number of studies have investigated the effectiveness of these apps. Several have reported a positive impact on mathematical ability after using theses apps for preschool children (Shacter & Jo, 2016; Shacter & Jo, 2017; Schacter, et al., 2016) and primary school children (Outhwaite, Guilford and Pitchford, 2017; Outhwaite, et al., 2018; Pitchford, 2015; van der Ven, Segers, Takashima & Verhoven, 2017), and Berkowitz, et al., (2015) reported a study that showed that the use of these apps had a beneficial effect at home. Herodotou, (2018) conducted a systematic review conducted a systematic review of the effectiveness of educational apps and reported positive effects on mathematics learning. Furthermore, Zosh, Lytle, Golinkoff, & Hirsh-Pasek, (2017) argue that they could be particularly useful for children from low SES backgrounds and recent research supports this claim (Outhwaite, Guilford and Pitchford, 2017; Shacter & Jo, 2016; Shacter & Jo, 2017; Shacter et al., 2016). For example, Schacter & Jo (2016) found that preschool children from low SES backgrounds who used Math Shelf for 15 weeks, at school, learned approximately 1 year more mathematics than those children who did not use Math Shelf and participated in their regular classroom mathematics curriculum. These studies show the enormous potential of mathematical educational apps, especially for children from a low SES background.

To date there has been no investigation of their use for reducing summer learning loss. The closest was a study by Lynch & Kim, (2016), who investigated the effect of Tenmarks (an online mathematics program) on children's mathematic achievement and engagement with mathematics over the summer. The program adapted curriculum materials to children's individual skill levels as they worked. It also included embedded text and video 'hints' that students could click on for assistance, and digital games that children could play as rewards for completing worksheets. The program developers intended for students to complete three worksheets each week for ten weeks. They found that Tenmarks did have a positive impact on students' engagement with mathematics over the summer but it did not reduce summer learning loss. Lynch & Kim, (2016) argue that one reason for these findings was that the math activities in the program were not engaging enough to attract and maintain the children's attention during summer. Mathematical educational apps frequently use games to try increase children's engagement and participation and there is evidence that shows they can increase engagement (van der Ven, Segers, Takashima & Verhoven, 2017) and in turn increase achievement in a school context (van der Ven et al., 2017).

Therefore the main aim of this paper is to report two studies that investigate the effect of a mathematical educational app to try and engage children in mathematical activities over the summer. Study 1 investigated the impact of different levels of engagement with the mathematical educational app over the summer on children's mathematical performance. We expected the greater the engagement the greater the benefit. Furthermore, study 1 investigated whether children's socioeconomic status and attitudes towards mathematics impacted the beneficial effects of the educational app. We expected that children with greater access to home resources, high levels of mathematics confidence, and low levels of mathematics anxiety would participate at higher levels and would benefit more from the educational app. Study 2 randomly allocated children to either an experimental condition, where they had access to the math app over the summer, or a control condition, where they did not. It found that children in the math app condition showed a significant improvement in their mathematics performance.

Study 1

2.1 Method

2.1.1 Participants

One hundred and thirty-four children (72 females, 62 males) participated in the study (mean age of 10.31 years and SD = .31). They were recruited from four schools located in the East Midlands and South West of England (two free schools, one faith school, and an academy).

2.1.2 Design

The study used a between participants quasi-experimental design. The children were placed into three groups depending on how much they used the math app over the summer. Half the children (n=66) did not use the math app (no use group) and the rest of the children were split into two groups: a low use group (n = 34) and a high use group (n = 34) by using a median split on the amount of time they used the math app over the summer. The low use group played with the math app for a mean of 20.03 minutes (SD = 14.30) and the high use group played with the math app for a mean of 143.79 minutes (SD = 91.34).

2.1.3. Mathematical Educational App

The mathematical educational app used in this study was DoodleMath and it was designed to support UK primary school math. It covers key stages one to three (ages 4-16) and utilizes touchscreen technology to allow children to interact with the math app in various intuitive ways. For example; children can tap on the correct answer, swipe objects into sets (see figure 1), and use moveable tools (e.g., protractors) to find answers.

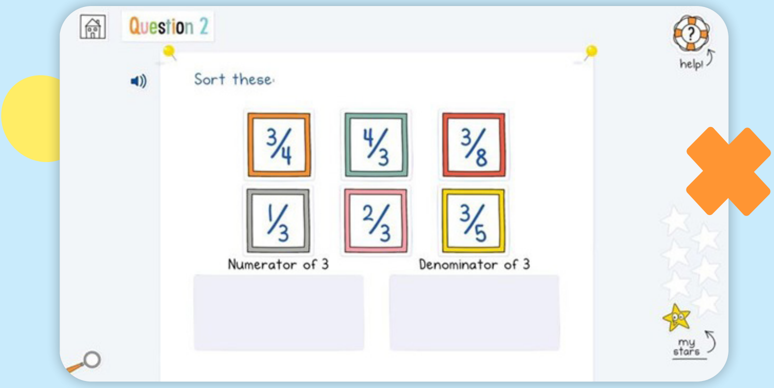

Figure 1: Example of a DoodleMath Question where students sort objects into sets

DoodleMath delivers an active, engaging and meaningful learning environment that provided individualized targeted practice tailored to the individual child. It is a suitable candidate for investigating whether these apps can address summer learning loss in mathematics, because it aligns with guidance provided by Hirsh-Pasek et al., (2015) and Outhwaite et al., (2018).

2.1.3. Materials

i. Mathematics Test

The Hodder Access Mathematics Test (AMT) was used to measure the children's mathematical performance. The AMT is aimed at children from ages 6 years and 6 months to 12 years and 0 months, with evaluation of the assessment showing a raw test score correlation with age = 0.70 [Education Endowment Foundation (EEF), 2013). The test provides a mathematics assessment that is aligned to the UK national curriculum with a correlation between raw test score and national curriculum level = 0.88 (EEF, 2013). By having corresponding A (pre-summer) and B (post-summer) forms, the AMT was suitable for measuring the impact of the math app over the summer.

ii. Socioeconomic Status

The children's postal code was used as an indicator of SES. The postal code is entered into the Streetcheck tool, which uses the MRS Social Grade algorithm and returns the proportion of residents in that postal code who are in each of the 4 social classes (AB, C1, C2 and DE).

iii. Intrinsic Motivation Inventory

The Intrinsic Motivation Index (Deci, Eghrari, Patrick, and Leone, 1994) was used to measure children's feelings of interest/enjoyment, perceived competence, perceived choice, and social relatedness of the math app. It contained 15 items (4 items per subscale, except social relatedness, which had 3 items) and the children responded on a seven point Likert scale, which ranged from 'Not at all true' (1) to 'Very true' (7).

iv. Math Confidence

Students were asked one question about their math confidence (e.g., I am good at math and) and the children responded on a seven point Likert scale, which ranged from 'Strongly disagree' (1) to 'Strongly Agree' (7). This item was adapted from Fredricks and Eccles, (2002) scale.

v. Math Anxiety

The Mathematics Anxiety Questionnaire was used to measure worry and negative reactions to mathematics in students from 6th through 12th grade (Wigfield & Meece, 1988). This scale consisted of eleven items that were rated on a 4-point Likert-type scale, Not at all like me (1), to Very true of me (4).

2.1.4. Procedure

Before the study started, consent to participate in the study was obtained from both the parents and the children. The children were pre-tested in the final week of year 6, before the summer vacation. They were informed they would be doing a test and were shown the math app application. Both the test and the math app training were carried out in the children's classrooms. Following completion of the Hodder Maths A test and the demographic questionnaire, each class received a demonstration of how the math app works, this included a walk-through guide of how to log in and the different features and tasks available. The children were shown examples of the different questions they would face in the application and the different actions required to answer them (e.g., swiping, inputting numbers). After each child was given their own login details, the experimenter and assistants went round the class and ensured each child was able to log in independently. By the end of the session, each child had completed the initial assessment independently, which indicated they knew how the application worked and how to answer questions.

Following the pre-summer tests and the math app training, children were given unlimited and free use of the math app over the 7-week summer vacation. The children could use the math app as much, or as little, as they liked. Any time a child did used the math app, the information was uploaded to the math app server and could be accessed via the math app dashboard. The dashboard was checked on the first day of the summer vacation so any progress could be returned to zero. At the end of the last day of summer vacation all the performance data was retrieved from the dashboard and stored in a database.

Children completed the Hodder Maths B test in the first week in school after the summer vacation. The post-tests took place in the same classrooms as the pre-tests under the same conditions and followed the same procedure. The testers and scorers of the pre-test were blind to the group the children were assigned.

Results

Table 1.

Differences between three usage groups at pre-test

	No Use		Low Use		High Use	
	M	SD	M	SD	M	SD
Mathematics Pre-test	27.41	11.196	28.56	11.043	32.35	11.962
Mathematics Anxiety	2.46	0.30	2.33	0.34	2.49	0.27
Mathematics Confidence	2.98	0.98	3.24	0.71	3.15	1.00
SES	2.48	0.35	2.42	0.36	2.55	0.38

A preliminary analysis was carried out to compare the three usage groups at pre-test on a number of variables that are known to have an impact on mathematics performance (see table 1). We found that the high use group had a significantly higher pre-test score than the low usage group and the low use group had a higher pre-test score than the no use group, but this difference was not significant [$F(2,131) = 2.15$, $p > 0.05$, $\eta p2 = 0.03$]. There were no significant differences between the three usage groups in terms of math anxiety [$F(2,122) = 2.63$, $p > 0.05$, $\eta p2 = 0.04$], math confidence [$F(2,131) = 0.95$, $p > 0.05$, $\eta p2 = 0.02$], socioeconomic status [$F(2,122) = 1.08$, $p > 0.05$, $\eta p2 = 0.02$] and gender[Chi square (2,1, n = 134) = 3.57, $p > 0.05$, $\varphi = .0334$].

Table 2.

Pre-Test, Post-Test and Change Scores

	Pre			Post		Change	
Usage	N	M	SD	M	SD	M	SD
No use	64	27.41	11.20	26.81	12.07	-0.84	5.27
Low use	32	28.56	11.04	28.13	11.16	0.25	4.44
High use	32	32.35	11.96	36.25	12.18	2.63	3.45

Table 2 shows the pre-test, post-test and change scores of the three usage groups. There was a significant difference between the three groups in terms of the change scores [F (2,125) = 5.88, p < 0.05, ηp2 = 0.08]. Post hoc analysis using the Tukey HSD test revealed that there was a significant difference between the high use group and no use group [p = 0.001]. There was no difference between the low use group and the no use group [p = 0.493] but there was a marginally significant difference between the low use group and the high use group [p = 0.09].

The math performance of the children in the no use group was worse in the post-test compared to the pre-test, but this difference was not significant [t (63) = -1.28, p > 0.05, d = 0.16]. The children in the low use group showed a slight improvement, but this difference was not a significant improvement in performance [t (31) = 0.318, p > 0.05, d = 0.056]. However, the children in the high use group showed a significant improvement in maths performance after the summer [t (31) = 4.3, p < 0.0005, d = 0.78].

The three usage groups also differed in terms of intrinsic motivation (see table 3). The high use group and the low use group had very high scores for interest and there was a significant difference between the three groups [F (2,115) = 11.78, p < 0.05, ηp2 = 0.170]. Post hoc analysis revealed that the high and low use groups found using the math app more interesting than the no use group. The scores on competence were also very high for both the low and high use groups and there was a significant difference between the three groups [F (2,115) = 18.54, p < 0.05, ηp2 = 0.244]. Post hoc analysis revealed that the high use group felt more competent than the low use group and the no use group. Furthermore, the low use group felt more competent than the no use group. There was also a significant difference between the three groups in terms of perceived choice and once more the scores were high for all three groups. Post hoc analysis revealed that the low use group perceived they had more choice than the no use group [F (2,115) = 4.15, p < 0.05, ηp2 = 0.067]. There was no difference between the high use group and the other two groups. Unlike the other measure of intrinsic motivation, the measure of social relatedness was very low (overall mean = 1.78, SD = 1.22) and there was no difference between the three groups in terms in social relatedness [F (2,115) = 0.40, p > 0.05, ηp2 = 0.007].

Table 3.

Differences between the three usage groups in terms of intrinsic motivation

	No Use		Low Use		High Use	
	M	SD	M	SD	M	SD
Interestingness	3.76	1.48	4.67	1.56	5.30	1.30
Perceived Competence	3.72	1.43	4.61	1.50	5.59	1.10
Perceived Choice	4.57	1.10	5.29	1.36	5.14	1.33
Social Relatedness	1.82	1.28	1.89	1.36	1.62	0.96

Finally, we investigated whether children's use of the math app was related to their socioeconomic status, mathematics anxiety, and mathematics confidence. Interestingly there was no relationship between use and socioeconomic status ($r = 0.12$, $n = 129$, $P > 0.05$), mathematics anxiety ($r = 0.09$, $n = 125$, $P > 0.05$) or mathematics confidence ($r = 0.04$, $n = 131$, $P > 0.05$).

Discussion

Study 1 found that the mathematical performance of children who did not use the app had deteriorated over the summer holiday, although this difference was not significant. In contrast, the children in the low use group showed slight improvement and the children in the high use group demonstrated significant improvement. Furthermore, children's mathematical performance in the high use group improved significantly more than children in the no use group. Interestingly, there were no significant differences in the pre-test between the three groups in terms of mathematical performance, mathematics confidence, mathematics anxiety, and socioeconomic status. Furthermore, there was no relationship between use of the math app and mathematics anxiety, mathematics confidence, or socioeconomic status. These findings support the argument that using these educational apps over the summer can have a significant and beneficial impact on summer learning loss. However, the main limitation with study 1 was that it was not a randomly controlled experiment and that there may be other factors, which could have explained the differences between the three groups. Study 2 overcame this limitation by conducting a randomly controlled experiment, where half the children were given the math app to use over the summer and half of the children were not given access to the math app over the summer.

Study 2

3.1 Method

3.1 Participants

The children (n = 139) were from six schools in the southwest of the UK, four faith schools (three catholic, one Church of England), and two state schools. Their average age was 10.30 years (SD = 0.30) and there were 66 females and 73 males.

3.1.2 Design

Study 2 used a between participants experimental design. The children were randomly allocated to two conditions: the math app condition and a control condition. Children in the math app condition played with the math app over the summer, whereas children in the control condition did not. The control condition was "business as usual" and the children were allowed to participate in whatever mathematics activity they would normally participate in over the summer. If they tried to log in to the math app, they were prevented from accessing the program. Children were allocated to the two conditions within a class, so children in a class were either in the math app condition or the control condition.

3.1.3. Materials

The materials used in Study 1 were used in Study 2.

3.1.4. Procedure

The procedure used in Study 2 was very similar to the procedure used in study 1, the only difference was that children in the control condition were NOT given access to the math app over the summer.

Results

Table 4.

Differences between the Math App Group and Control Group at pre-test

	Control		Math App Group	
	M	SD	M	SD
Mathematics Pre-test	36.04	11.10	37.01	11.62
Mathematics Anxiety	1.75	0.49	1.76	0.52
Mathematics Confidence	3.63	0.78	3.49	0.88

The two groups were compared on a number of variables at pre-test that are known to have an impact on mathematics performance (see table 4). We found that the math app group had a slightly higher pre-test score than the control group, but this difference was not significant [t (137) = 0.50, p > 0.05, d = 0.08]. There was no significant difference between the two groups in terms of math anxiety [t (136) = 0.14, p > 0.05, d = 0.02], math confidence [t (137) = 0.91, p > 0.05, d = 0.17] and gender [Chi square (1, n = 139) < 0.001, p > 0.05, φ <0.001].

Table 5.

Pre-Test, Post-Test and Difference Scores

	Pre			Post		Change	
Condition	N	M	SD	M	SD	M	SD
Control Group	57	36.04	11.10	36.49	11.89	0.46	4.25
Math App Group	82	37.01	11.62	39.18	11.69	2.11	4.62

Table 5 shows the pre-test, post-test, and change scores of the two groups. There was a significant difference between the two groups in terms of the change scores [F (137) = 4.59, p < 0.05, ηp2 = 0.03]. The math app groups improved significantly more than the children in the control group. The children in the control group did show a slight improvement in math performance but this improvement was not significant [t (56) = 0.81, p > 0.05, d = 0.11]. In contrast, the performance of the children in the math app group showed a significant improvement in math performance after the summer [t (81) = 4.28, p < 0.05, d = 0.47].

In terms of measures of intrinsic motivation, the children rated the math app high on interest (M = 4.96, SD = 1.6), perceived choice (M = 4.90, SD = 1.10), and perceived competence (M = 5.08, SD = 1.28), but as in study 1, they rated the math app low on social relatedness (M = 2.05, SD = 1.19).

Discussion

The aim of this paper was to report two studies that investigated whether the math app, a mathematical educational app, could improve children's math performance over the summer. Study 1 found that children who did not use the math app showed a slight reduction in math performance, whereas children in the low use group showed slight improvement and the children in the high use group showed significant improvement. Moreover, before summer there was no difference between the three groups in terms of mathematical performance, mathematics confidence, mathematics anxiety, or socioeconomic status. Study 2 randomly allocated children to either an experimental condition, where they had access to the math app over the summer, or a control condition, where they did not. It found that children in the math app condition showed a significant improvement in their mathematics performance after the summer vacation compared to children in the control condition. Thus, study 1 and study 2 both show that children who used the math app over the summer significantly improved their mathematics performance.

There are certain features of the math app used in the current study that could explain these beneficial findings. It was designed to provide an active, engaging, and meaningful learning environment that provides children with individualized and targeted practice, which is important for the development of mathematics (Hirsh-Pasek et al., 2015, Outhwaite et al., 2017, 2018). The math app used in the current study was very engaging to use and this may also explain the difference between our findings and those reported by Lynch and Kim (2017), because they reported that the online system they used was not very engaging. Another contributing factor for the beneficial findings observed in the current study was that the math app was designed to be used on tablets and smartphones, which are easy and familiar to use by children (Outhwaite et al., 2017). Furthermore, smartphones and tablets can be used on the move which provides the child with more control over when and where they play the math app. Thus, we suggest these features may be important for the success of the math app. However these are only suggestions, and as others have remarked (Hirsh-Pasek et al., 2015; Haßler at al., 2016), further work is required to fully explore what design features are important for the success of educational apps in general and mathematical education apps in particular, especially as there are a number of alternative explanations for these findings that have nothing to do with the design of the math app. First, these apps are played in a social context and their introduction may change that social context, which in turn could play an important role in their success. For example, in the study by Berkowitz et al., (2015), the use of the app changed the conversations between the parent and child and it was those conversations that were important in the success of the program and not the program itself.

Second, the observed benefits may not directly be the result of children using the math app but simply the extra time children had learning math over the summer (Foster, Anthony, Clements, Sarama, & Williams, 2016; Ginsburg & Smith, 2016). To unravel the effect of extra time from the effect of the math app would require a further time equivalent control (e.g. Outhwaite et al., 2018). In a time equivalent control children would receive the same amount of time engaging in a different mathematics activity. These controls are used in school-based studies where children could be engaging in equivalent activities for the same amount of time, however, research conducted during the summer vacation is different from school-based research. Children have more control and choice over the activities they participate in over the summer than they do at school and research on summer learning loss has shown that the vast majority of children do NOT engage in math activities over the summer. Thus, the finding that children given access to the math app engaged in a math activity completely voluntarily and this engagement resulted in improvements in their math over the summer is significant, especially as Lynch & Kim, (2016) using a similar intervention did not report such a benefit. However further research is required to unravel the effect of extra time engaging in math from the effect of the math app.

Another interesting finding in these studies was that children rated the math app very highly on interestingness, perceived choice, and competence, but scored very low on social relatedness. Social relatedness refers to the desire to feel connected to others (Deci & Ryan, 2000). The version of the math app we investigated did not support this need and this finding suggests an avenue for further development. Since the current study was conducted, the math app has undergone further development and has introduced a number of social features to support this need. These features enable children to send pre-determined messages to each other, for example 'liking' each other's progress. When a child has been sent one of these messages they are prompted to open up the app. These new social features have increased the number of sessions an average child completes per week from 2.6 to 3.1, and increased the time children have spent in the app by 20%. Thus, showing the potential for supporting social relatedness in educational apps.

This study has important implications for addressing the problem of summer learning loss. We did not observe summer learning loss in the two studies reported in this paper. Summer learning loss has NOT always been reported in the UK (Wiseman & Baker, 2004) partly because in the UK the school summer vacation is generally between 6 and 7 weeks compared to 12 weeks in the USA. However, a recent study in the UK has reported significant summer learning loss (Shinwell & Defeyter, 2017) and it is a major concern in the USA, especially for children who come from a low socioeconomic background (Alexander Entwisle & Olson, 2007). It was therefore reassuring to find in study 1 that there was no difference in use of the math app or performance of children from a lower social economic background. Summer programs in the USA have been developed and have successfully tackled this problem (Kim & Quinn 2013), but they are expensive (McCombs et al., 2011). Therefore to find that a low-cost educational app could address this problem has obvious advantages and suggests that a replication in the USA would be important, especially as the benefits could be even larger in the USA because of the longer summer vacation.

Therefore, in conclusion, we found that using the math app over the summer improved children's mathematics performance. The children found the math app engaging and it gave them the opportunity to practice mathematical skills over the summer in an individualized learning environment. These findings are very encouraging and suggest that it may be possible for an educational app to change summer losses into summer gains.

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