Effectiveness of an iPad Intervention to Support Development of Maths Skills in Foundation Year Children.

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Abstract

EuroTalk©, an educational publishing company have developed four maths applications (apps) aimed at supporting early maths skills development. The apps can be used on hand held devices, such as tablets and are yet to be formally evaluated in a UK classroom setting. Evaluating the effectiveness of learning technologies as a pedagogical tool to support children's early maths skills development is vital to ensuring that all children have a solid foundation in maths. This is the first study of its kind to formally assess the use of learning hand-held technology with UK foundation pupils. In light of the substantial limitations in the current research base, this study had three areas of interest. (i) To evaluate the effectiveness of the EuroTalk© maths apps in supporting development of maths skills in UK foundation year children. (ii) To expand the early maths skills development framework by examining the influence of underlying cognitive factors associated with scholastic progression, socio-economic status (SES) and the child's English as an additional language (EAL) status. (iii) To validate the general cognitive abilities measures in the new Unlocking Talent assessment app developed by Dr Pitchford and EuroTalk© against standardised clinical tests of cognitive abilities from the WPPSI-III. The assessment app also measures maths curriculum and concept knowledge. Twenty-six foundation pupils received the hand-held maths apps intervention, using an Apple iPad for six weeks. Maths ability was assessed before and after the intervention and learning gains were quantified against other students (foundation- year 3) receiving normal pedagogical practise. Wilcoxon signed-ranks tests showed significant learning gains were achieved by children in the intervention condition. Additionally, general cognitive abilities and SES were shown to be significantly correlated with pre-test maths scores. A significant difference was also observed in pre-test maths scores in favour of English native speaking pupils. The gap in EAL performance reduced following the intervention. However, the SES difference remained the same. The Unlocking Talent assessment app was shown to be reliable and moderately valid. Findings are discussed in relation to previous research and limitations, and directions for future studies are discussed.

1. Introduction

EuroTalk© an educational publishing company have developed a series of maths applications (apps) to support early maths development. The series consists of four apps; Maths 3-5, Maths 4-6, Counting to 10 and Counting to 20 that can be used on hand-held devices, such as tablets. The apps are yet to be formally evaluated in the UK. Such advances in hand-held technology have the potential to offer learner centred support in developing early maths skills.

Early maths skills can be defined based on the statutory framework for maths in the early years foundation stage (EYFS). This focuses on counting, understanding and using numbers, simple addition and subtraction, and shape, space and measures recognition (DfE, 2012). Previous technology based educational game research is not robust (Sanford et al., 2006) and mostly with older children. This study primarily aims to address these issues though examining the effectiveness of the hand-held EuroTalk© maths app series in supporting early maths development in foundation year pupils, regardless of their socio-economic background or first language. Additionally, there is vast research identifying cognitive abilities underlying maths development. This study aims to explore the role of intelligence, working and short-term memory, manual processing speed, motor co-ordination, and visual attention on early maths development. Furthermore, the new Unlocking Talent assessment app developed by Dr Pitchford with EuroTalk© to assess these abilities will be validated against standardised clinical measures of intelligence.

1.1. Background

It is important to support early maths development for three reasons.

Firstly, the EYFS provides the essential basis for children’s later achievement. Children considered to have developed well through the EYFS, exceed expected numeracy and literacy levels at the end of Key Stage 1 (KS1; DfE, 2010). Conversely, children who show less development and learning at the end of the EYFS are six times more likely to be in the lowest fifth of achievers at the end of KS1 (DCSF, 2008).

Additionally, the EYFS statutory framework emphasises the importance of learning through play. However, this approach shifts to more formal learning when children progress into KS1 (DfE, 2012). Ofsted (2004) highlights this dramatic shift can cause disruption during the EYFS and KS1 transition.

Finally, there are upcoming changes to the UK national curriculum. It aims to increase the standards of maths through a more demanding primary curriculum (DfE, 2012). The upcoming changes will only directly affect KS1 and 2 (DfE, 2014). However, based on the EYFS impact on children's later achievement and potential to further disrupt the EYFS to KS1 transition, as a result of these increased demands, it is currently important that all foundation pupils have a solid foundation in maths skills.

Interventions supporting young children's maths development need to consider predictive factors of early maths skills. This study will focus on general cognitive abilities associated with scholastic progression, socio-economic status (SES) and the child's first language.

1.2. General cognitive abilities

Numerous longitudinal studies provide empirical evidence to show general cognitive abilities, including intelligence, working memory, short term memory, processing speed, visual attention and motor co-ordination affect maths development in young children. These will be discussed below.

1.2.1. Intelligence

Intelligence (IQ), specifically non-verbal IQ can be assessed using block design tasks. The role of non-verbal IQ in early maths skills is well established.

Research showed that at the end of first grade (equivalent to UK year one) there was a direct relationship between non-verbal IQ and maths ability (Passolunghi et al., 2008). Further research examining the predictive power of children's IQ and working memory (WM) capacities on maths skills from ages five to eleven showed both cognitive abilities accounted for a significant proportion of the variance at both times of assessment (Alloway & Alloway, 2010). Despite the shared variance it is argued they are not the same and should be seen as separate predictors (Ackerman et al., 2005). In support, Alloway and Alloway (2010) found WM contributed to a larger proportion of the observed variance.

1.2.2. Working and short term memory

WM is defined as a processing resource allowing preservation of information while simultaneously processing the same or other information (Baddeley & Logie, 1999). Conversely, short term memory (STM) involves the storage of small amounts of information and the use of minimal long term memory resources when performing a task (Passolunghi & Lanfranchi, 2012). Digit span or Corsi Block tasks conducted forwards or backwards can assess STM and WM respectively. Similar to IQ, the importance of WM and STM in early maths skills is robust.

Research showed WM in Italian kindergarten pupils (equivalent to the UK EYFS), directly predicted maths skills at three time periods during the kindergarten year (Passolunghi & Lanfranchi, 2012). Similar UK findings show WM and STM are significant predictors of maths achievement in preschool and throughout the first three years of primary school (Bull et al., 2008). Furthermore, findings show maths difficulties were mediated by reduced WM capacity in kindergarten children with a mathematical learning disability or persistent low achievement in comparison to typically developing children (Geary et al., 2012). Overall, these studies demonstrate the important roles of WM and STM on maths achievement. Additionally, Passolunghi and Lanfranchi, (2012) and Geary et al. (2012) found processing speed also significantly related to early maths skills.

1.2.3. Processing speed

Processing speed (PS) is defined as the efficiency and speed to which a simple cognitive task is completed (Case, 1985). It can be assessed verbally, visually or manually. Other research showed PS was strongly related to maths knowledge in typical five to six year old children

(Taub et al., 2008) and accounted for differences in achievement in pre-term children compared to typical controls (Mulder et al., 2010). These findings demonstrate a robust effect of PS on early maths skills.

1.2.4. Visual attention

The effect of visual attention (VA) on early maths skills has briefly been examined. Research assessed five- six year old children's VA with a standardised visual search task. Results showed higher VA related to faster rates of maths development (Aunola et al., 2004). However, research focusing on VA in EYFS aged pupils is lacking.

1.2.5. Motor co-ordination

Fine motor skills can be assessed with tasks requiring manual dexterity and spatial organisation. Research shows fine motor skills independently contributed to American kindergarten pupils' entry skill levels and improvements in achievement across the year (Cameron et al., 2012). However, this research did not specifically study maths skills. Further research focusing on early maths abilities, found fine motor skills were a strong and consistent predictor of later maths achievement (Grissmer et al., 2010).

Overall, non-verbal IQ, memory and PS appear to demonstrate the most researched and robust findings in relation to early maths skills.

In order to assess all the general cognitive abilities discussed, Dr Pitchford has developed an assessment app with EuroTalk©. The tasks included are very similar to the tasks used in the previous research above and are discussed in detail in section 2.4. and illustrated in table 5. The app has the potential to offer an accessible form of assessment for professionals but needs to be validated against standardised clinical measures of intelligence, such as the WPPSI-III (Wechsler, 2002).

In addition to general cognitive abilities, Starkey et al. (2004) argue socio-economic status (SES) also needs to be considered in early maths development.

1.3. Socio-economic status (SES)

SES is measured by proxy variables such as, household income, parental educational level or eligibility for free school meals. Studies show children with low SES have significantly lower maths levels compared to their peers (Anders et al., 2012; Denton & West, 2002; Strand, 1997). In particular, Anders et al. (2012) highlighted a SES gap identified in preschool was maintained at later ages and Strand (1997) found SES pupils fell further behind their peers during KS1.

Siegler (2009) argues this SES difference in maths achievement is based on the quality of the home learning environment. Studies indicate higher income parents engage in more frequent maths based activities with their children compared to less affluent parents (Clements & Sarama, 2007). These types of activities are shown to influence children's early maths development (Blevins-Knabe et al., 2007). The vital role parents play in their child's learning can be explained through Vygotsky's zone of proximal development (1978; ZPD). ZPD refers to the distance between actual and potential development, which can be supported through adult guidance or collaboration with more capable peers. Through the ZPD, parents have the ability to facilitate learning through engaging and simulating maths activities (Wells, 1999).

Overall, the evidence suggests children with low SES are disadvantaged in early maths development. Therefore, effective maths interventions, which are not limited by the child's SES, are vital to providing all children with a foundation in maths skills.

However, neither SES nor cognitive factors should be considered alone within the early maths development framework. Recent evidence demonstrated that both factors significantly predicted Dutch kindergarten pupils' maths skills (Kleemans et al., 2012). This suggests research needs to simultaneously consider the impact of these predictors. In addition, other research highlights differences in maths development based on the child's first language.

1.4. English as an additional language (EAL)

EAL is defined as having another language other than English as the first language. Statistics highlight foundation EAL pupils develop less well compared to their non-EAL peers across the curriculum. Although the gap has gradually reduced since 2007, a difference still exists (NALDIC, 2013). More specifically, research focusing on maths found, similar to low SES, children from language minorities' families are disadvantaged (Denton & West, 2002). However, it is difficult to disentangle language differences and SES, as children from language minorities' families may also have a low SES. A limited research base sustains this difficulty. Yet despite, the lack of evidence, it is still important to address the EAL gap in maths achievement to ensure all children have a strong maths foundation.

In conclusion, all three factors impact early maths development; general cognitive abilities need to be assessed to understand the skills underlying maths development and interventions need to address SES and EAL differences. Technology based educational maths game interventions have the potential to offer effective support in developing early maths skills and address areas of difference.

1.5. Technology based educational games

The UK statutory framework for EYFS emphasises the importance of play in children's learning and development (DfE, 2012). Learning through play can be incorporated with technology to create tools that support maths development.

However, technology is often under used due to design and content limitations (Yelland & Kilderry, 2010) and previous technology based educational game research is not robust (Sanford et al., 2006). Several reviews argue there is no causal relationship between using technology based tools and increases in academic performance (e.g. Vogel et al., 2006). Opposing arguments in favour of technology based educational games highlight necessary features of this approach and how these features can benefit children's learning. These arguments are supported by empirical research and anecdotal evidence discussed below.

Technology based educational games have the capacity to address the differing abilities of individual students. Research shows this is achieved through multiple representations of information, such as through pictures, video and animation and varying levels of task difficulty (Rose et al., 2005). As well as, clear goals and rules, learner control, task feedback and repetition (Condie & Munro, 2007). Condie and Munro (2007) argue these features create an individualised learning environment, placing the child in active control of their learning. The impact of technology based educational games on children's learning is widely researched.

A recent meta-analysis examined thirty-nine studies from the educational gaming literature between 1990- 2012. Results showed technological game based approaches were significantly more effective in improving learning compared to typical instructional methods (Wouters et al., 2013). However, this meta- analysis examined learning in general across year groups. It did not specifically focus on maths development with younger children. Furthermore, research focusing on maths in the earliest years of primary schools is lacking.

A literature search of research examining technology based educational games with children in the first three years of primary school (Foundation- Year 2) or equivalent, identified two studies that reported sufficiently detailed results that would allow numerical cross comparison (Räsänen et al., 2009; Shin et al., 2006). Numerical comparison was based on within-subject pre and post-test scores of children exposed to the particular intervention. Effect sizes were calculated using Cohen's *d*. Where there were multiple measures of maths ability a composite effect size was calculated by mean averaging the individual effect sizes. An effect size of 0.2 is considered small, 0.5 is medium and 0.8 or above is large (Cohen, 1988). Table 1 summarises the results.

Table 1 Effect size analysis (Cohen's *d*) based on within-subject pre and post-test scores of children exposed to the particular study intervention.

Study	Intervention (*n*)	Effect size (Cohen's *d*)
Räsänen et al. (2009)	NumberRace (15)	0.40
	GraphoGame (15)	0.40
Shin et al. (2006)	GameBoy Addition and Subtraction (20)	0.57

Räsänen et al. (2009) studied the effectiveness of two computer assisted games on improving specific areas of maths skills in Finnish kindergarten children (aged six- seven; equivalent to UK year two) identified to have low numeracy skills. NumberRace aimed to develop number sense and GraphoGame focused on exact numerosity training. Results showed children exposed to the GraphoGame intervention made significantly more improvement in comparison to the control group, who received normal pedagogical practise over the intervention period. The NumberRace group also showed improvements in relation to the control group. However, the difference between these groups was not found to be statistically significant. This results pattern was observed at a delayed post-test assessment, suggesting the improvements were sustained.

Shin et al. (2006) examined the effectiveness of a hand-held technology based maths game aimed at improving addition and subtraction skills with American students in first and second grade (equivalent to the UK year one and two). The technology intervention was compared to a paper based maths game with the same aims. Results showed children who used the hand-held technology significantly outperformed the control group following the intervention. Overall, both of these studies demonstrate the positive impact of technology based educational games in supporting maths development in young pupils. This was likely to have been achieved through creating individualised learning environments that met the proposed necessary feature requirements discussed earlier (Rose et al., 2005; Condie & Munro, 2007). This conclusion is further supported by anecdotal and empirical evidence demonstrating the positive impact of the hand-held EuroTalk© maths apps, which also meet the criteria for creating individualised learning environments, in supporting children’s maths development in both developed and developing countries.

1.6. The present study

To date, the EuroTalk© maths apps (discussed in detail in section 2.3) have been trialled in UK thirty schools and are used in private homes. Anecdotal reports suggest the apps are an effective math learning tool. Furthermore, a recent randomised control trial conducted in Malawi provides empirical support (Pitchford, in prep.).

Pitchford (in prep.) randomly assigned Malawian pupils from standards one- three (equivalent to UK years one- three) to one of three groups. The experimental group received the hand-held EuroTalk© maths apps intervention in the local language for equivalent to thirty minutes a day over eight weeks. The first control group also received hand-held technology exposure, however, the apps lacked educational content. The second control group received normal pedagogical practise. Older children from standard four were also pre-tested to develop a typical maths development trajectory. Following the EuroTalk© maths apps intervention, results showed significant pre to post-test learning gains in conceptual and curriculum maths knowledge for younger and older students respectively, in comparison to controls. Moreover, the post-test scores of older students were higher than standard four pupils receiving normal pedagogical practise. Overall, these findings and the anecdotal reports suggest the hand-held EuroTalk© maths apps are an effective tool for enhancing young children's maths skills.

In light of the research evidence discussed above, the principal purpose of this study is to examine the effectiveness of the hand-held EuroTalk© maths apps in supporting maths development in UK foundation year pupils, regardless SES or EAL status. This will be achieved through pre and post-test assessments and quantifying the learning gains in relation to typical maths development of other children receiving normal pedagogical practise. Based on previous findings, it is predicted the EuroTalk© maths apps will significantly benefit pupils maths abilities, regardless of their background.

Additionally, this study has three secondary aims:

1. To validate the Unlocking Talent Assessment app measures of cognitive abilities associated with scholastic progression against standardised tests of intelligence. The assessment app was developed by EuroTalk© and Dr Pitchford. The app is expected to be valid, with positive correlations for graded tasks and negative correlations for timed measures.
2. To examine cognitive abilities in relation to early maths skills. Based on previous longitudinal research discussed above, it is hypothesised, that cognitive abilities will be correlated with pre-intervention maths abilities. Positive correlations for graded tasks and negative correlations for timed measures are expected.

3. To assess the impact of SES and EAL on early maths skills and evaluate whether the EuroTalk© maths apps intervention helps to close the SES and EAL gap in achievement. Pre-maths ability is expected to negatively correlate with SES and show a difference in favour of non EAL pupils. It is hypothesised the EuroTalk© maths apps will help close these achievement gaps.

2. Method

2.1. Design

Initially the study followed an AB-BA intervention design (illustrated in table 2) across two foundation classes within the same average sized community mixed gender primary school, across two sites (Office for Standards in Education (Ofsted), 2012). Both sites were located in a below average SES area in Nottingham (Office for National Statistics, Indices of Deprivation, 2010). Unfortunately, the foundation class at site B (referred to as foundation B) withdrew from the intervention phase of the study.

Therefore, a within-subject pre and post-test intervention design was adopted (see table 2). Children receiving the hand-held EuroTalk© maths apps intervention were foundation pupils from site A (referred to as foundation A). The intervention lasted for six weeks. Foundation A pupils were assessed on maths ability and cognitive skills associated with scholastic progression using the EuroTalk© Unlocking Talent Assessment app before and after the intervention. In order to identify a trajectory of typical maths development, other students (Foundation- Year 3) were assessed on maths ability alone before the intervention. Ethical approval for the study was granted from the University of Nottingham ethics committee.

Table 2 Illustration of an AB-BA intervention design, this study was initially designed to follow. Details highlighted in bold illustrates the within-subject pre and post-test intervention design adopted. As indicated by italics, some Foundation B pupils were also pre-tested for the developmental trajectory.

Class	Pre-test	Intervention Week 1-6	Post-test	Intervention Week 6-12	Post-test
Foundation A	**X**	**EuroTalk© maths apps**	**x**	Normal pedagogical practise	x
Foundation B	*X*	Normal pedagogical practise	x	EuroTalk© maths apps	x

2.2. Participants

Informed parental consent was granted in line with the British Psychological Society ethical guidelines for all participating children. Twenty-seven pupils in foundation A were recruited to take part in the EuroTalk© maths apps intervention. One child was excluded from the analysis based on their special educational needs and incompletion of post-test assessment. In total twenty-six children participated in the intervention. A further eleven foundation B pupils were pre-tested and thirty-nine older pupils (Year 1-3) were assessed on maths ability. In total seventy-six pupils' maths ability scores were included in the maths development trajectory. Table 3 shows the sample structure.

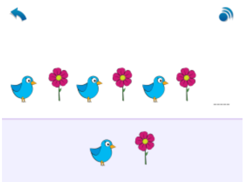
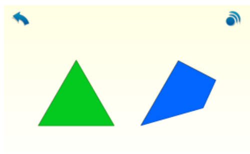
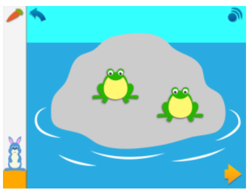
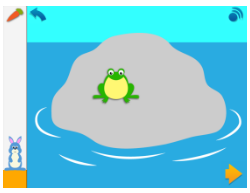
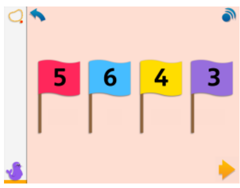
Table 3 Intervention and trajectory samples descriptive data including, sample size (*n*), mean age in months (standard deviation), minimum and maximum age range in months and gender (female: male).

Year	*n*	Mean age months (*SD*)	Age range months	Gender (F: M)
Foundation A	26	56.34 (3.71)	50- 61	13: 13
Foundation B	11	57.36 (4.30)	51- 62	6: 5
Year 1	14	69.10 (3.05)	65- 74	4: 10
Year 2	8	81.13 (2.95)	77- 85	3: 5
Year 3	17	92.53 (4.00)	88- 98	10: 6

2.3. *Intervention materials*

The intervention comprised of four apps developed by EuroTalk© (Maths 3-5, Maths 4-6, Count to 10 and Count to 20). The EuroTalk© maths apps offer child centred tuition based on content grounded in the UK National Maths Curriculum. All content is presented in attractive picture, audio and animation formats. The apps include interactive instruction, clear objectives and feedback which are consistent for all users. The Count to 10 and 20 apps consist of twenty-five colourful and engaging counting tasks. The Maths 3-5 and 4-6 apps consist of two parts subdivided into five or six subsections each dedicated to a specific topic area from the maths curriculum, such as, counting, patterns and shape recognition and addition and subtraction. Example tasks from each app are shown in table 4. Each subsection comprises of ten tasks based on a particular topic, including a quiz aimed to assess children's learning. Tasks progressively increase in difficulty and are able to be repeated allowing learner control and individual progression, which can be monitored by teachers or parents. 100% accuracy is required to pass the quiz, thus ensuring a thorough assessment of children's learning. Upon completion of a subsection, children were rewarded with a star sticker recorded on a specially designed star chart. The star rewards served as positive reinforcement and a measure of number of task completed. Children individually used the EuroTalk© maths apps on an Apple iPad mini supplied by EuroTalk©. The implementation of the intervention is discussed in detail in section 2.6.

Table 4 Illustrations of example tasks in each of the four EuroTalk© maths apps and what area of the UK national curriculum the tasks relates to.

Maths app	Example task and instructions	Aspect of the national curriculum
Maths 3-5	*"Which one comes next?"* 	Pattern recognition
Maths 4-6	*"One of these shapes is symmetrical. Which one? Touch it."* 	Shape recognition
Counting to 10	*"Put two frogs on the rock"*  *"Now touch one frog to take it away again"* 	Counting and subtraction
Counting to 20	*"Drag the flags to put the numbers in order. Put the smallest number first."* 	Understanding number order

2.4. Pre and post-test measures

Before and after the intervention all foundation A students were assessed using the Unlocking Talent app developed by EuroTalk© and Dr Pitchford. The app includes two assessments of maths curriculum and concept knowledge and six measures of cognitive abilities associated with scholastic progression. An introduction task was also included to allow children to practice the actions needed to complete the tasks. All tasks had a limited completion time and discontinuation rules allowing individually tailored progression. Children did not receive task feedback on completion times or scores. However, upon completion of the assessment app children received a star reward. The following cognitive and maths abilities were assessed in the reported order. Illustrations of the tasks are presented in table 5.

2.4.1. Manual processing speed (MPS)

A single finger tapping task was used to assess children's MPS. Children were required to continually tap a green box which caused a blue balloon to increase in size. The task was complete once the balloon popped. A MPS score was calculated from the mean completion time across two trials.

2.4.2. Motor co-ordination (MCO)

MCO was assessed using an alternating finger tapping task. Similar to the previous task, stimuli consisted of two green boxes and one blue and one purple balloon and the task requirements were similar. Children were required to alternatively tap the green boxes stimuli to pop the balloons. Balloons would only increase in size if tapped alternately. Children's MCO ability was indicated by the mean completion time across two trials.

2.4.3. Short term memory (STM)

A forward spatial span task was used to assess STM capacity. The task involved the presentation of a three-by-three grid of yellow circles. The game presenter showed children a pattern in which to press the yellow circles. Children were required to repeat the order they had been shown. The number of circles in the pattern increased in line with progression. The task discontinued after three incorrect trials. The number of correct trials indicated the child's STM

2.4.4. Visual attention (VA)

VA was assessed with a visual search task. Before the three experimental trials, children were presented with a single coloured dot followed by an array of 8, 12 or 16 same coloured dots, which they were instructed to select. In the experimental trials children were required to distinguish and select all the pre-experimental trial coloured dots from a different coloured dot display. Completion times for the three trials were mean averaged giving an index of VA.

2.4.5. Working memory (WM)

A backwards spatial span task was administered to assess WM capacity. The task followed the same layout and characteristics as the forward spatial span task, except that students were required to repeat the presented pattern backwards. The size of the pattern also increased in line with progression and discontinued after three trials. WM capacity was obtained from the number of correct trials.

2.4.6. Non-verbal IQ (IQ)

A two dimensional pattern processing task, similar to the three dimensional Block Design task seen in standardized measures, such as, the WPPSI-III was administered to assess IQ. The task required children to reconstruct a block pattern using simultaneously displayed pattern squares. The number of pattern squares available depended on the block pattern size required to be recreated. The task discontinued after three incorrect trial responses. An IQ score was derived from the number of correct pattern blocks reconstructed.

2.4.7. Maths curriculum knowledge

Maths curriculum knowledge was assessed through fifty quiz tasks based on content in the four EuroTalk© apps. Task difficulty increased with task progression and discontinued after three incorrect answers.

2.4.8. Maths conceptual knowledge

Maths concept knowledge was examined by forty-eight tasks that were similar to the Numerical Operations subset from the WIAT-II (Wechsler, 2005). Task difficulty increased with task progression and discontinued after three incorrect answers.

Table 5 Illustrations of the general cognitive ability tasks and the first three tasks of the curriculum and concept maths knowledge assessments in the Unlocking Talent assessment app.

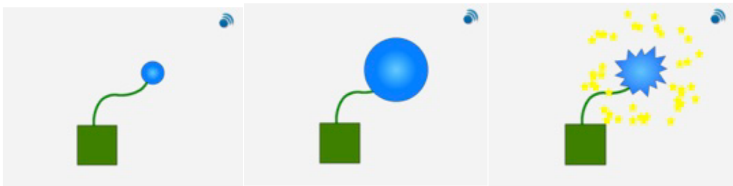
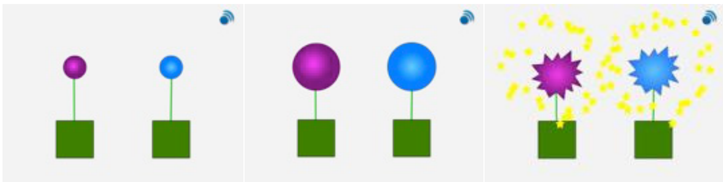
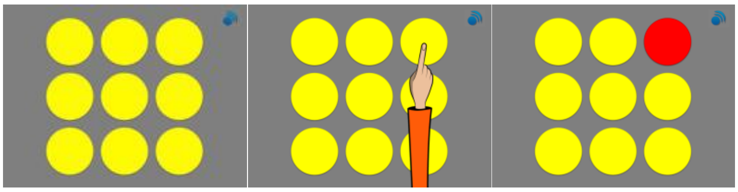
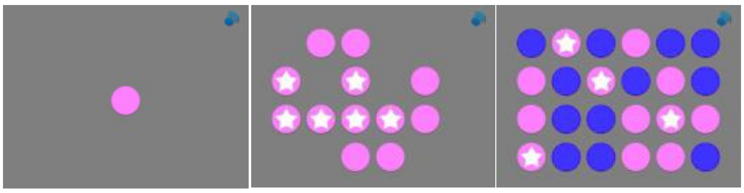
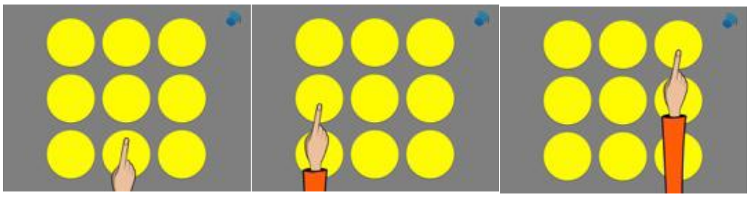
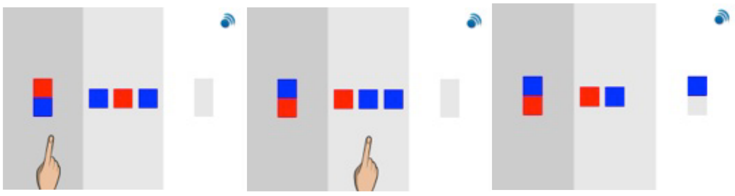
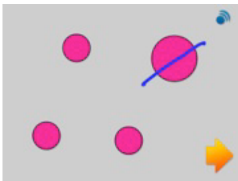
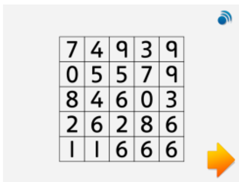
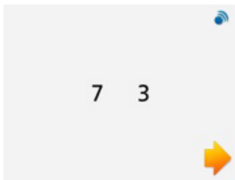
Task order	Ability assessed	Example task stimuli and instructions
1	Manual processing speed (MPS)	*"Tap the green square as fast as you can"* 
2	Motor co-ordination (MCO)	*"There are two green squares. Touch one square than the other as fast as you can"* 
3	Short term memory (STM)	*"Copy me"* 
4	Visual attention (VA)	*"Touch the pink dot. Touch all the pink dots as fast as you can. Remember touch just the pink dots"* 

Table 5 cont. Illustrations of the general cognitive ability tasks and the first three tasks of the curriculum and concept maths knowledge assessments in the Unlocking Talent assessment app.

5	Working memory (WM)	*"Watch me you do it backwards"* 		
6	Non-verbal IQ (IQ)	*"Look at this pattern. Use these blocks. Make the same pattern here"* 		
7	Maths curriculum knowledge (first three tasks)	*"Cross out the odd one out"* 	*"Drag the matching thing into the box to make a pair"* 	*"Touch two stars"* 
8	Maths conceptual knowledge (first three tasks)	*"Touch all of the numbers in the box"* 	*"Touch all the sixes in the box"* 	*"Touch the biggest number"* 

In order to validate the EuroTalk© Unlocking Talent Assessment App general cognitive ability tasks, two standardized measures from the WPPSI-III (Wechsler, 2002) were administered and are described below.

2.4.9. Block Design

The Block Design subtest consists of twenty items divided into parts A and B. The task started at the beginning of part B unless the child had suspected special educational needs. The task required participants to recreate block patterns displayed to them either physically or in the stimulus book using one or two coloured blocks in a specified completion time. The task is designed to test the child's ability to analyze and synthesize abstract visual stimuli, thus it is an assessment of non-verbal IQ. It also involves visual-motor co-ordination (Sattler, 2001). The test discontinued after three consecutive incorrect responses. Raw scores were used.

2.4.10. Symbol Search

The Symbol Search subtest comprises of large and simple symbols which participants must scan to identify whether the specified symbol is present in the particular sample. Children are required to respond by marking the appropriate symbol. The task assesses processing speed and involves abilities, such as, visual STM memory and visual-motor co-ordination (Sattler, 2001). Children have 120 seconds to complete the task. Raw scores were used.

2.5. Demographic data

A number of descriptive and demographic measures were obtained using a pre-study questionnaire completed by parents at the time of consent. Where data was missing, it was obtained through school records. The data collected included, child's name, gender, date of birth, post code, native language status and parent identified mathematics problems.

Children's age was calculated by month at the time the child was tested. Whether English was their first language and self-identified mathematics difficulties were answered with a yes or no tick box with the opportunity to add additional information in the mathematics problems question. However, the questionnaire was not reliably completed, thus, parent-identified maths problem responses were excluded from analysis.

The child's post code was used as a SES indicator, using the Income Deprivation Affecting Children Index (IDACI; DfE, 2014). The IDACI is a specific subset measure of the income deprivation domain from the Indices of Deprivation (Department for Communities and Local Government, 2011). It indicates the proportion of children under the age of 16 in an area who live in low income households. Low income households are defined as; in receipt of Income Support, Income based Jobseeker's Allowance or a household income of below 60% before housing costs for those receiving Working Families' Tax Credit or Disabled Person's Tax Credit and those who receive asylum seekers subsistence and accommodation support (Barnet Council, 2012-2013).

2.6. Procedure

All children were administered the Unlocking Talent assessment app using an iPad mini by the researcher in a quiet room separate from the main classroom. Assessments were conducted in small groups and tasks were first demonstrated by the researcher using a spare iPad mini. This procedure was repeated for foundation A pupils following the intervention. The WPPSI-III tasks were administered on a one to one basis by the researcher, also in a separate room.

Before the intervention, teachers and teaching assistants were trained how to use the equipment and apps by the managing director of EuroTalk©. Children used the apps with headphones once a day for thirty minutes across six weeks, in groups of fifteen at a time, under the supervision of the teacher or TA. Children were allocated an individual iPad mini for the duration of the study. Attendance and subsections completed were recorded by the teaching staff using a specifically designed register and star chart respectively.

3. Results

The distribution of eight measures (out of eighteen, see Appendix A) were shown through Kolmogorov-Smirnov tests, to significantly ($p < 0.05$) deviate from normality. When one or more measures in a specific statistical test were deemed non-normal, more conservative non-parametric tests were used instead of parametric analyses. All levels of significance are reported at a one-tailed level of probability.

3.1. Intervention

3.1.1. Curriculum and concept knowledge

Group mean scores for foundation A, based on the number of correct answers were calculated for maths curriculum and concept knowledge assessments at baseline (pre-test) and following the maths app intervention (post-test). In order to examine the effects of the maths app intervention, Wilcoxon signed-ranks tests were conducted across performance on maths curriculum and conceptual knowledge assessments at pre and post-test. To assess the strength of the intervention effects and allow cross comparison with previous research (Räsänen et al, 2009; Shin et al, 2006) effect sizes (Cohen's *d*) were calculated. An effect size of 0.2 is considered small, 0.5 is medium and 0.8 or above is large (Cohen, 1988). All results are summarised in table 6.

Table 6 Group mean (standard deviation) scores based on the number of correct answers in curriculum and conceptual maths knowledge assessments conducted before and after the maths app intervention. Wilcoxon signed-ranks tests show the differences between intervention and baseline scores were significant. Effect size (Cohen's *d*) analyses show the size of these differences.

Task	Mean score (*SD*) [Median]		Wilcoxon (*z*)	Effect size (*d*)
	Pre-test	Post-test	Intervention versus baseline	
Maths curriculum knowledge/50	10.85 (8.85) [11.50]	22.88 (10.44) [24.00]	-4.32**	1.24
Maths concept knowledge/48	9.42 (6.33) [11.50]	11.88 (6.42) [13.00]	-1.91*	0.39

**p <0.001
*p<0.05

Table 6 shows compared to baseline, children scored higher on the post-test maths curriculum and concept knowledge assessments following the maths apps intervention. The Wilcoxon signed-ranks tests showed these differences were significant. The difference in curriculum knowledge scores had a large effect size and the difference in concept knowledge scores had a small effect size.

3.1.2. Maths development trajectory

To quantify the learning gains made by children receiving the intervention, a typical maths development trajectory based on other children receiving normal pedagogical practise was developed using Spearman's correlation analysis. These analyses were based on group mean scores of other children (Foundation B- Year 3) and foundation A in maths curriculum and concept knowledge taken at time 1 (pre-test). Results are summarised in table 7. The group mean post-test maths curriculum and concept scores for foundation A pupils are overlaid against the developmental trajectory shown in figures 1 and 2.

Table 7 Group mean (standard deviations) scores based on the number of correct answers at time 1 for maths curriculum and concept knowledge for other typically developing pupils (Foundation B- Year 3) and children exposed to the intervention (Foundation A) and time 2 (post- test) group mean (standard deviation) scores for Foundation A students.

Task	Mean score (*SD*)	
	Time 1	Time 2
Maths curriculum knowledge/50		
Foundation A		22.88 (10.45)
Foundation (A+B)	10.68 (7.90)	
Year 1	16.86 (10.53)	
Year 2	28.00 (13.20)	
Year 3	42.31 (4.33)	
Maths concept knowledge/48		
Foundation A		11.88 (6.42)
Foundation (A+B)	10.19 (6.54)	
Year 1	13.79 (7.24)	
Year 2	23.28 (5.93)	
Year 3	30.81 (3.31)	

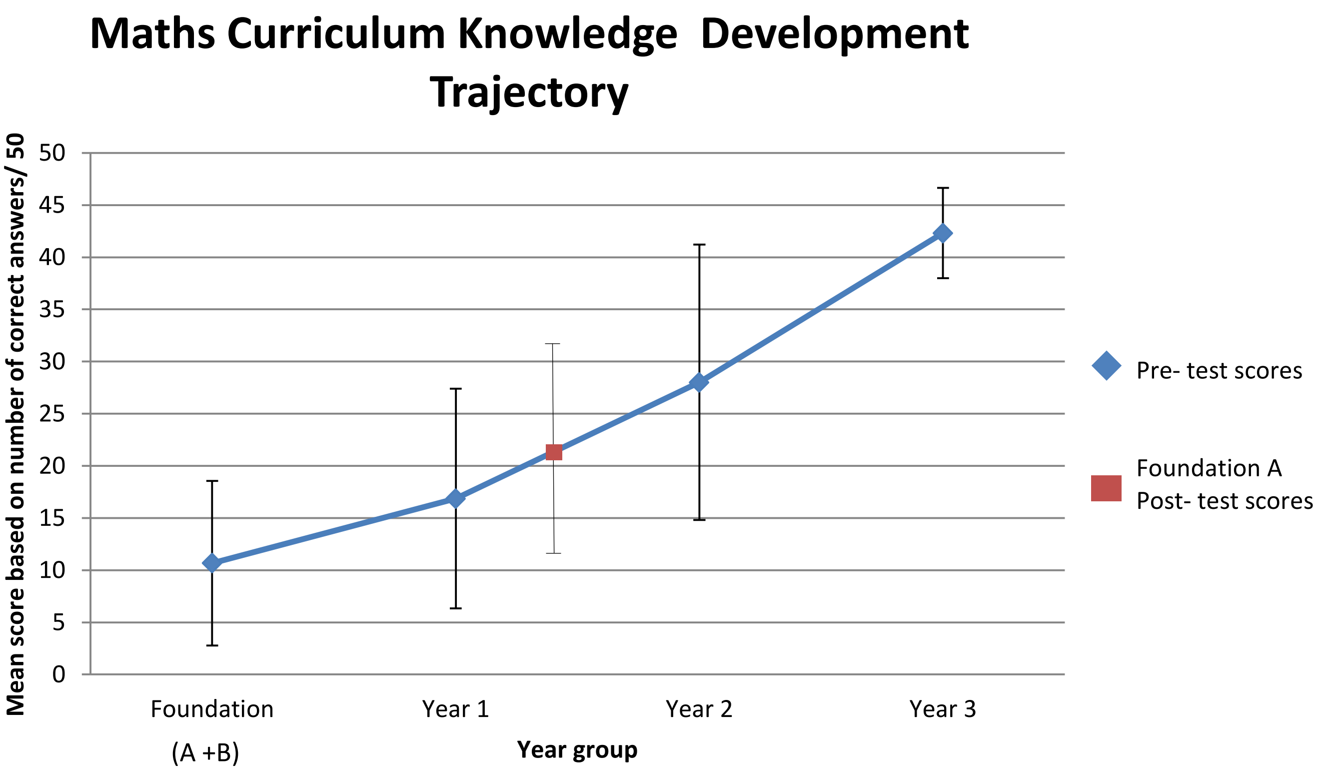


Figure 1 Group mean increased learning gains in curriculum maths knowledge made by Foundation A pupils following the intervention in relation to a typical maths curriculum knowledge development trajectory across Foundation- Year 3. This trajectory is based on a significant positive relationship between pupils' mean scores on curriculum maths knowledge assessed at pre-test and year group.

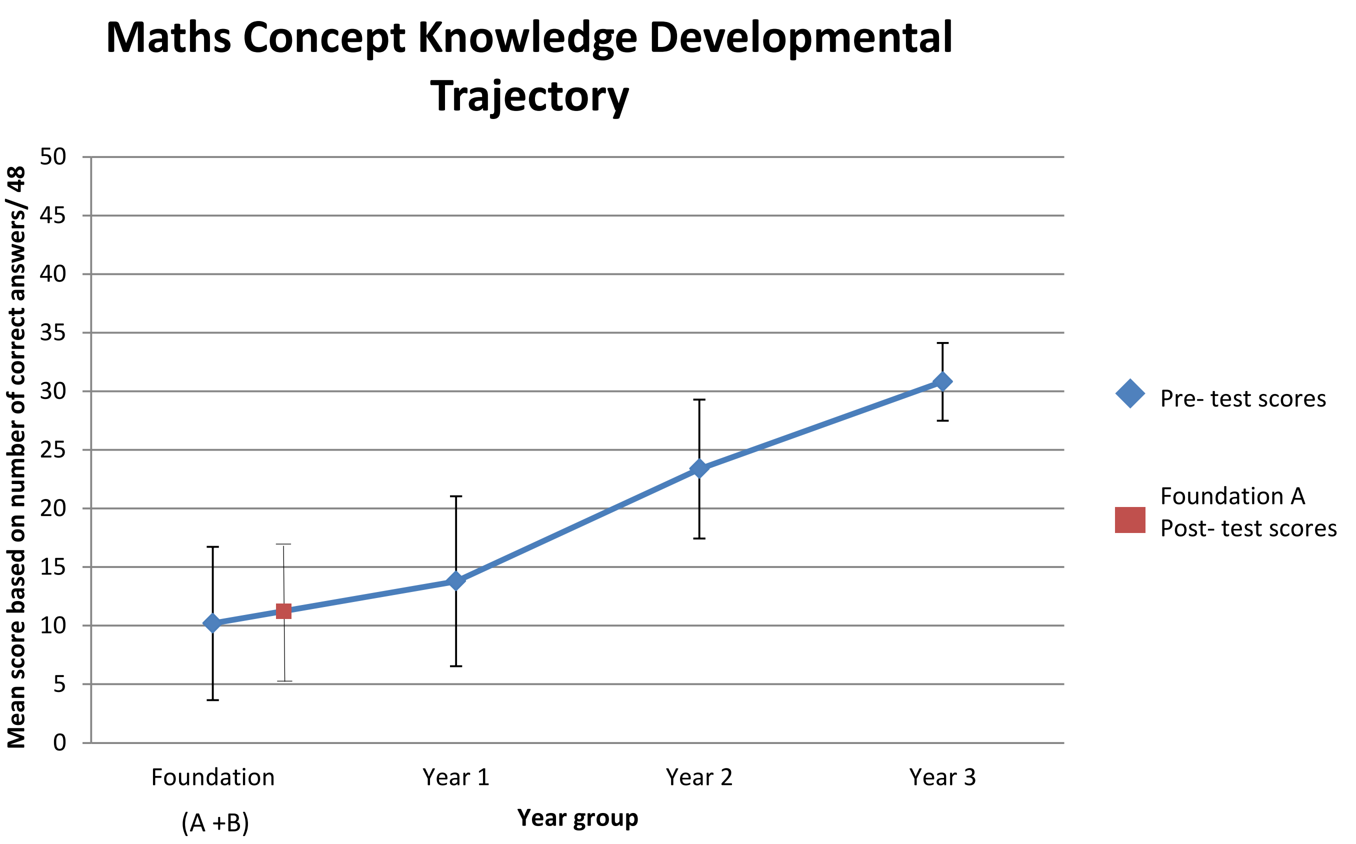


Figure 2 Group mean increased learning gains in conceptual maths knowledge made by Foundation A pupils following the intervention in relation to a typical maths concept knowledge development trajectory across Foundation- Year 3. This trajectory is based on a significant positive relationship between pupils' mean scores on concept maths knowledge assessed at pre-test and year group.

The foundation A pupils' significant learning gains in curriculum and concept knowledge can be quantified in relation to typical maths development of other children receiving normal pedagogical practise. Table 7 shows the mean curriculum knowledge score at time 1 increased in line with year group. Results demonstrated this relationship was significant, r_s= 0.74, p<0.001. Figure 1 shows the curriculum knowledge developmental trajectory. The mean post- test maths curriculum score for Foundation A pupils is overlaid onto this developmental trajectory.

Similarly, increases in mean conceptual knowledge scores at time 1 in relation to year group were significant, r_s= 0.76, p<0.001. Figure 2 displays this conceptual knowledge developmental trajectory. The mean post- test maths concept knowledge for foundation A pupils is included in this developmental trajectory.

3.1.3. Factors correlated with performance

A further series of correlational analyses were carried out to examine the influence of the number of sub- sections completed, using Pearson's r and the time on task measured in hours, using Spearman's rho on the difference in pre and post- test scores for both maths assessments. A possible relationship between number of sub-sections completed and time on task was also explored using Spearman's correlational analysis. Results are shown in table 8.

Table 8 Group mean (standard deviation) differences in curriculum and concept maths scores before and after the intervention, time on task in hours and the number of sub-sections completed. Correlational co-efficients identify possible relationships between time on task and number of sub-sections and both factors individually with difference in both maths scores.

	Mean (*SD*)	Correlation co-efficient	
		Time on task (r_s)	Sub-sections (r)
Difference in curriculum scores	12.04 (8.61)	0.98	0.55**
Difference in concept scores	2.46 (6.21)	0.22	-0.05
Sub-sections completed	6.50 (4.10)	-0.06	
Time on task	13.30 (0.98)		

**p <0.001

Table 8 shows the mean difference between curriculum knowledge scores at pre and post-test were significantly correlated with the mean number of sub-sections completed. A similar significant relationship between the mean difference in concept knowledge and sub-sections completed was not observed. Furthermore, there was no significant relationship between mean time on task and mean difference in maths curriculum or concept scores. There was also no significant relationship between number of sub-sections completed and time on task.

3.2. Validity and reliability of the Unlocking Talent assessment app

3.2.1. Validity

To assess the validity of the Unlocking Talent assessment app Spearman's correlations between the group mean of each cognitive task at pre- test and scores on the standardised Block Design and Symbol Search tasks from the WPPSI- III were calculated. Outliers, defined as two standard deviations above and below the group mean in timed tasks; VA, MPS and MCO, were excluded (see Appendix B). Results are shown in table 9.

Table 9 Validity analysis using Spearman's correlations between group mean scores (standard deviations) on the six general cognitive ability tasks taken at pre- test and mean group scores on standardised WPPSI-III sub- tests. Timed tasks are measured by completion time. Graded tasks and WPPSI-III tasks are measured by number of correct responses.

Task	Task mean (*SD*)	Correlation co-efficient (r_s)	
		Block Design	Symbol Search
IQ	2.92 (2.50)	0.44*	0.38*
WM	1.08 (1.16)	0.34*	0.56**
STM	4.35 (2.31)	0.15	0.43*
MPS	10.39 (1.74)	-0.02	-0.05
MCO	32. 28 (7.91)	-0.34 ~	-0.10
VA	0.87 (0.15)	-0.13	-0.04
Block Design	11.38(4.47)		
Symbol Search	8.46 (5.09)		

**p <0.001
*p<0.05
~p= 0.058

As shown in table 9 the Unlocking Talent assessment app measures of non-verbal IQ and WM were significantly positively correlated with the WPPSI-III Block Design task based on the number of correct responses. The negative correlation between MCO task completion time and Block Design response scores approached significance. Additionally, non-verbal IQ, WM and STM were also significantly positively correlated with the WPPSI-III Symbol Search task based on the number of correct responses.

3.2.2. Reliability

Reliability of the Unlocking Talent assessment app was assessed in two ways. Firstly, Spearman's correlational analyses examined the test re-test reliability of the graded cognitive ability tasks; WM, STM and IQ and the two maths measures. Group mean pre-test scores were correlated with post-test scores for each of the graded measures. Results are reported in table 10. Secondly, split half reliability analysis across the two or three trials at pre-test were calculated for the timed cognitive ability tasks; MPS, MCO and VA. Outliers were not excluded from this analysis. Results are summarised in table 11.

Table 10 Test re-test analysis of graded cognitive ability and maths tasks using Spearman's correlations comparing group mean scores based on number of correct responses at pre and post-test assessment times.

Task	Mean (*SD*)		Correlation co-efficient (r_s)
	Pre- test	Post- test	Pre- test verses post- test
IQ	2.92 (2.50)	5.30 (3.33)	0.52**
WM	1.08 (1.16)	1.08 (1.29)	0.14
STM	4.35 (2.31)	4.08 (2.48)	0.36*
Curriculum	10.85 (8.85)	22.88 (10.44)	0.67**
Concept	9.42 (6.33)	11.88 (6.42)	0.45*

**$p < 0.001$
*$p < 0.05$

Table 11 Split half reliability analysis across completion time responses for timed task trials at pre- test. Outliers not excluded.

Task (number of trials)	Correlation between forms
MPS (2)	0.35
MCO (2)	0.95
VA (3)	0.79

Table 10 indicates test re-test analyses for the graded measures showed significant moderate correlations for non- verbal IQ, STM and both maths measures at pre and post-test times of assessment. WM responses at pre and post- test were positively correlated but not considered significant.

As shown in table 11 the split half reliability analysis across the two or three trials at pre-test for the completion time based cognitive ability tasks indicated these measures are moderately to highly reliable.

3.3. Factors associated with maths development

3.3.1. General cognitive abilities

The relationships between early maths ability and children's general cognitive abilities were analysed with Spearman's correlational analyses. The correlations were based on group mean data and outliers in the timed tasks were excluded. Results are shown in table 12.

Table 12 Group mean general cognitive ability task responses correlated with group mean pre curriculum and concept maths scores.

Task	Correlation co-efficient (r_s)	
	Maths curriculum	Maths concept
IQ	0.59**	0.48**
WM	0.37*	0.41*
STM	0.47**	0.45*
MPS	-0.30	-0.28
MCO	-0.09	-0.06
VA	-0.18	-0.15

**p <0.001

*p<0.05

Table 12 shows pre- test maths ability significantly correlated with graded cognitive measures and negatively with timed tasks. The positive correlations were significant. However, the negative correlations were non-significant.

3.3.2. SES

Children's early maths ability and how children benefitted from the maths app intervention, both based on group mean data was examined in relation to SES using Spearman's correlational analyses. Results are shown in table 13.

Table 13 Range in children's SES as indicated by post code IDACI score (higher IDACI indicates higher deprivation) correlated with mean curriculum and concept maths scores at pre- test, post- test (means reported in table 6) and the difference between these scores (means reported in table 8).

Factor	Range	Correlational co-efficient (r_s)					
		Maths curriculum	Post curriculum	Diff. in curriculum	Maths concept	Post concept	Diff. in concept
SES	11-52	-0.41*	-0.41*	-0.17	-0.20	-0.01	0.28

*p<0.05

Table 13 shows a negative relationship between children's level of deprivation and pre and post-test maths performance. This was only significant for curriculum knowledge. There was no significant correlation between children's SES and difference in both maths scores.

3.3.3. EAL

The relationship between the child's EAL status (EAL or non-EAL) and children's early maths ability and how well they benefitted from the maths app intervention was examined using Mann-Whitney U tests. Group mean and median data and Mann-Whitney U tests and are reported in table 14.

Table 14 EAL and Non- EAL pupils 'group mean (standard deviations) and median curriculum and concept maths knowledge before and after the maths apps intervention and the difference between pre and post test scores. Mann- Whitney U tests and effect sizes examine the differences between EAL and Non- EAL pupils' maths performance at these different measurement periods.

Task	EAL status	Mean score (*SD*) [Median]			Mann-Whitney U (*z*) [Effect size (*r*)] EAL versus Non-EAL		
		Pre- test	Post- test	Diff.	Pre- test	Post- test	Diff.
Maths curriculum knowledge /50	EAL	7.08 (6.65) [4.00]	20.15 (8.24) [22.00]	13.08 (8.12) [14.00]	-2.11* [-0.41]	-1.39 [-0.27]	-0.62 [-0.12]
	Non-EAL	14.62 (9.38) [14.00]	25.62 (11.97) [32.00]	11.00 (9.29) [9.00]			
Maths concept knowledge /48	EAL	7.62 (6.37) [6.00]	10.38 (6.36) [10.00]	2.77 (7.99) [1.00]	-1.55~ [-0.30]	-1.23 [-0.24]	0.00 [-0.12]
	Non-EAL	11.23 (5.99) [14.00]	13.38 (6.37) [15.00]	2.15 (4.04) [3.00]			

The descriptive data in table 14 shows non-EAL children achieved higher maths curriculum and concept scores compared to their EAL peers at pre-test. Mann-Whitney U tests demonstrated curriculum knowledge pre-test scores for non-EAL pupils were significantly higher compared to EAL children. The difference between non-EAL pupil's conceptual knowledge scores at pre-test and their EAL peers' performance approached significance. Both had a small effect size.

However, there was less difference between the two groups across both maths assessments at post-test. The Mann-Whitney U test showed there was no significant difference between non-EAL and EAL pupils' post-test performance. The difference in pre and post-test scores indicative of learning gains made following the intervention, also show no significant differences between non-EAL and EAL children.

4. Discussion

This study primarily aimed to examine the effectiveness of the four hand-held EuroTalk© maths apps in supporting the development of early maths skills in UK foundation year pupils. Twenty-six children received the intervention for six weeks with teaching staff supervision. In line with the study's three secondary aims, (i) the newly developed Unlocking Talent assessment app was validated against standardised clinical measures of intelligence (WPPSI-III), (ii) the role of key cognitive capacities associated with scholastic progression and (iii) SES and EAL were all examined in relation to maths development and the intervention effectiveness. Key findings for each aim will be discussed in light of study limitations and directions for future research.

4.1. Intervention

In terms of the intervention, a clear pattern of results emerged. As expected, following the intervention, foundation A pupils showed significant learning gains in curriculum and conceptual maths knowledge. The increase in curriculum attainment levels were equivalent to eighteen months normal pedagogical maths practise. The rise in conceptual maths knowledge was equal to four months pedagogical practise. As predicted, the positive relationship between number of sub-sections completed and curriculum learning gains showed quality interaction with the apps content was an important factor of children's progress. Unexpectedly, amount of time on task had no impact. However, it is important to note there was little variance in this measure, with an average standard deviation equating to approximately one hour. Future assessment of time on task and its impact on the intervention effectiveness could follow an age matched between-groups design. For example, one group use the app for one school term and the other group for a whole school year. Overall, these findings demonstrate the effectiveness of the hand-held EuroTalk© maths apps intervention in supporting early maths development, even after six weeks use.

Furthermore, these results support previous interactive technology research in which older pupils achieved significant learning gains (Wouters et al., 2013; Räsänen et al., 2009; Shin et al., 2006; Pitchford, in prep.) This is the first study to empirically evaluate hand-held technology in a classroom setting with UK foundation pupils. Therefore, it can provide a unique insight into the use of technology based educational games. More specifically, in relation to the within-subject level effect size analysis (tables 1 and 3), this study shows a much larger effect size for curriculum knowledge learning gains compared to children's math ability improvements in Räsänen et al. (2009) and Shin et al. (2006). Although, the concept knowledge effect sizes were not as large, this can be attributed to two reasons.

Firstly, the curriculum knowledge assessment was based on the apps content, including the quizzes. Whereas, the conceptual knowledge assessment was a format children were not regularly accustomed to, which may suggest a lack of transfer. Secondly, and more likely, it may be due to the reduced sensitivity of the concept knowledge assessment. For example, some of the tasks required children to identify all the numbers in a grid of letter and symbol distractors (see table 5). This task aimed to assess children's Arabic numeral awareness. However, based on the nature of the task, it may have relied too heavily on visual attention abilities. If a child missed one number in the grid, they got a score of zero, the same as if they had misidentified letters or symbols as numbers. Therefore, the measure of concept knowledge needs to be further refined to ensure greater accuracy. Nevertheless, overall the intervention findings suggest the EuroTalk© maths apps are very effective for younger students and can be used to support early maths skills development, which is vital for later achievement (see Duncan et al., 2007).

Future research could take two directions. Firstly, based on the significant learning gains made by foundation pupils, the EuroTalk© maths apps could be used to support children struggling with maths, similar to Räsänen et al. (2009). 'Struggling' children could be identified statically with pre-test maths scores. For example, two standard deviations (SD) below the group mean. This was not possible in this study, because two SD below this group mean was a negative score. Alternatively, teacher based assessments could be used, similar to Räsänen et al. (2009). Secondly, an age matched control group should be included to directly compare the effectiveness of EuroTalk© maths apps to normal pedagogical practise. While this was initially incorporated in the studies design (see section 2.1.), uncontrollable factors prevented this from occurring. Although the typical maths development trajectory provides some comparison to normal pedagogical practise, the age matched controls would provide a more detailed and empirical evaluation, which is often lacking in learning technology research (Leemkuil, 2005).

4.2. Validity and reliability of the Unlocking Talent assessment app

Test re-test reliability analysis with graded measures, showed, IQ, STM, curriculum and concept maths knowledge showed positive and significant correlations across time. WM was also positively correlated but non-significant. Split-half reliability analysis across multiple pre-test trails with timed measures identified high reliability for MCO and VA measures and moderate reliability for MPS. These results were as expected and demonstrate the Unlocking Talent assessment app has good internal reliability. Therefore, it is a reliable tool for assessing maths and cognitive abilities in young children.

Validity assessments showed the standardised WPPSI-III Block Design and Symbol Search tasks positively correlated with graded measures and negatively correlated with timed measures as predicted. The positive correlations between graded measures and Symbol Search were all significant. In particular, the Symbol Search task is a well-established measure of STM (Sattler, 2001). Moreover, the correlations between WM and IQ and the Block Design task were significant. The IQ results were expected as the iPad based IQ assessment is a two dimensional version of the three dimensional standardised task. Overall, these results suggest the Unlocking Talent assessment app is a valid measure of IQ, WM and STM.

However, the timed measures negative correlations with both standardised tasks were mostly non-significant. MCO and Block Design approached significance. As both tasks require manual dexterity, this relationship would be expected. The lack of significant correlations suggests the tasks lack external validity and further task refinement is needed. In future studies, the validation measures used to assess the refined tasks could be expanded to include other standardised assessments more closely related to the cognitive tasks. For example, VA could be validated against the visual attention subset of the NEPSY (Korkman et al., 1998) used in Aunola et al's (2004) study. The NEPSY is developed for preschool and school aged children. If further developed and validated, the assessment app offers an accessible assessment tool that can be used by researchers and other professionals, such as, teachers and educational psychologists.

4.3. Factors associated with maths development

4.3.1. General cognitive abilities

As hypothesised, pre-test maths scores positively correlated with graded measures of cognitive ability (IQ, WM and STM). The correlations were shown to be significant, indicating higher levels of IQ, WM and STM are related to better early maths ability. These findings corroborate previous longitudinal research highlighting the importance of IQ and memory in early maths skills (Passolunghi et al., 2008; Alloway & Alloway, 2010; Passolunghi & Lanfranchi, 2012; Bull et al., 2008; Geary et al., 2012).

Similarly, as predicted pre-test maths ability negative correlated with timed cognitive ability tasks (MPS, MCO and VA). This suggests children who display faster manual and attentional abilities have higher levels of maths ability, compared to children who completed the tasks more slowly. However, these correlations were non-significant, which was unexpected based on previous empirical research (Passolunghi & Lanfranchi, 2012; Geary et al., 2012; Taub et al., 2008; Mulder et al., 2010; Aunola et al., 2004; Cameron et al., 2012; Grissmer et al., 2010). These divergent findings can be attributed to two possible reasons. Firstly, some of the tasks used in this study and previous research differ. For example, previous PS research used a variety of visual, verbal and rarely manual based tasks. Conversely, this study focused on manual PS, which may account for the difference in results. Secondly and more likely, there was a lack of external validity for the timed measures as they did not significantly correlate with the standardised WPPSI-III measures (see section 4.2). This might suggest the tasks used in this study did not accurately measure MPS, MCO and VA. This can be addressed through sensitivity refinement of the assessment app, as discussed in section 4.2.

With a more sensitive form of assessment, future research could assess the contribution of the cognitive abilities underpinning early maths skills. This could be used as part of a holistic assessment, alongside the statistical and self-report measures previously discussed to identify students struggling with maths. Identifying 'at risk' pupils allows interventions such as, the EuroTalk© maths apps to be effectively targeted.

4.3.2. SES

There was a clear pattern of results regarding the impact of SES on early maths skills. As expected, there was a significant negative correlation between pre-maths curriculum scores and SES. The relationship between pre-maths concept scores and SES was also negative but non-significant. This lack of significance can be attributed to the reduced sensitivity of the concept knowledge assessment, as discussed in section 4.3.1. These findings suggest children who live in areas of higher deprivation have lower maths ability, which converges with previous studies (Anders et al., 2012; Denton & West, 2002; Strand, 1997).

Additionally, results showed the child's SES did not influence learning gains. Importantly, this suggests all children regardless of their background, benefitted from the EuroTalk© maths apps. However, the negative correlation between SES and maths curriculum knowledge observed at pre-test, remained significant following the intervention. Although this was not expected, the improvements made by all children can still be regarded as a success. Furthermore, children with low SES did not fall further behind their higher SES peers, unlike the results found by Anders et al. (2012) and Strand (1997). The SES gap in maths achievement could be addressed through the home-learning environment.

The EuroTalk© maths apps are available for home use and offer a suitable learning tool which parents can use to support their child's maths development. Based on previous research highlighting the importance of the home-learning environment on early maths skills (Siegler, 2009; Blevin-Knabe et al., 2007), the home use of the maths apps could help address the SES gap in maths achievement. Further research using a similar intervention design with appropriate controls groups would be needed to empirically evaluate the potential of the EuroTalk© maths apps in fostering a positive home learning environment. Based on this study's findings, a positive result would be expected.

4.3.3. EAL

Finally, as expected, results showed children defined as EAL scored lower on pre-maths ability assessments, compared to their non EAL peers. These results identify an EAL gap in achievement consistent with previous findings (NALDIC, 2013; Denton & West, 2002). Similar to SES, no significant differences in learning gains were observed for the two groups. This also suggests all children benefitted from the EuroTalk© maths apps intervention. However, unlike the SES findings, results showed the EAL gap in achievement at pre-test was not maintained following the intervention. As predicted, these findings suggest the EuroTalk© maths apps helped reduce EAL differences in maths achievement. However, it is important to recognise children's language abilities may have improved over the intervention period, which may have also contributed to the reduced EAL gap in achievement. Nevertheless, the pre and post-intervention differences in curriculum knowledge particularly were significant and thus the contribution of the EuroTalk© maths apps cannot be discounted. These findings can be attributed to the apps interactive and engaging presentations and clear instructions, which do not necessarily rely on language.

4.4. Conclusion

Overall, this study shows clear benefits of the EuroTalk© maths apps in supporting foundation pupils' maths development, regardless of their background. The children's learning gains, especially in curriculum knowledge, were beyond what would be expected based on normal pedagogical practise and has given all children a stronger foundation in maths skills. This strong foundation will support later maths achievement in an increasingly demanding national curriculum and can support a smoother transition from EYFS to KS1. Moreover, the findings support previous technology based educational game research and justify the use of learner centred hand-held technology in the classroom for young children.

Furthermore, this study identifies key cognitive abilities underlying maths development and offers ways in which interventions can be targeted to 'at risk' pupils. Further research adopting similar or improved designs with adequate control groups is needed to examine the effectiveness of the EuroTalk© maths apps for 'at risk' students and for fostering a quality home learning environment that supports children's maths development. Additionally, this study offers a platform to further develop and refine the Unlocking Talent assessment app. This will offer a more accessible form of assessment.

Word count: 7, 972 (excluding abstract, tables, figures, reference list and appendices)

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Appendix A

See table A1.

Table A1: Significant Kolmogorov- Smirnov tests indicating non- normal data distribution

Measure	Kolmogorov- Smirnov test
Pre Curriculum	x
Pre Concept	x
Post Curriculum	
Post Curriculum	
Difference in Curriculum	
Difference in Concept	
WM	x
IQ	
STM	
MPS	
MCO	
VA	x
Block Design	x
Symbol Search	
EAL	x
SES	x
Time on task	x
Parts completed	

Appendix B

See table A2.

Table A2: Number of outliers excluded from timed task measures

Measure	Outliers excluded
VS	2
MPS	2
MCO	3