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TECHNOLOGY AND LEARNING FOR EARLY CHILDHOOD AND PRIMARY EDUCATION

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ABSTRACT

Educational software and apps offer a potential solution for the global learning crisis in maths and literacy. When designed, implemented, and integrated effectively, these programmes can offer accessible and personalised learning experiences for young children at school and at home. This paper synthesises current evidence evaluating the use of educational software and apps with young children aged 0-8 years in early childhood and primary education, including those from disadvantaged and marginalised groups across a range of low-, middle- and high-income countries. Based on this evidence synthesis, recommendations for system-wide conditions in the EdTech ecosystem to achieve optimal outcomes for all children are discussed, including potential avenues for effective pedagogy, implementation, and integration.

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Introduction

Over 55% of children around the world do not have the minimum proficiency levels in mathematics (383 million children) and reading (387 million children) (UNESCO, 2017). Data also suggests the Covid-19 pandemic has exacerbated longstanding inequalities that are affecting the poorest and most vulnerable children. This has limited progress towards the Education Sustainable Development Goal (SDG) 4 (United Nations, 2021).

Early childhood and primary education make a vital contribution for attaining the Education SDG4 (Saeed & Munir, 2021). Although it is not the only important period for meaningful educational investment (Howard-Jones et al., 2012), evidence suggests ensuring that young children have the foundations in basic maths and literacy skills supports later educational, economic, and social success (Barnett, 2011; Heckman, 2006). For example, research shows the mastery of early maths skills at age four predicted long-term schooling success (Davis-Kean et al., 2021). Likewise, successful reading interventions implemented before children were eight years old reduced the chance of them developing later reading difficulties, compared to when the reading interventions were implemented with children over eight years (Lovett et al., 2017). As such, evidence-based interventions are needed during early childhood and primary education to ensure young children have strong foundations in maths and literacy skills.

Educational technology (EdTech) has been identified as a potential solution for raising attainment and addressing some of the educational inequalities (Sabatini et al., 2022). EdTech offers opportunities for personalised learning and can reach disadvantaged and marginalised groups when it is "designed and implemented in an ethical, inclusive, and equitable manner" (Duraiappah et al., 2022, p. 61). This paper focuses on educational software and applications (apps) used on laptop or desktop computers, hand-held touch-screen tablets, or smartphone devices. Based on a rapid review conducted by the authors, this paper synthesises current evidence relating to the use of these forms of EdTech for young children aged 0-8 years in formal and informal settings across different countries. In doing so, this paper addresses two questions:

RQ1): What do we currently know about good practices in the use of educational software and apps for supporting access, equity, and inclusion for young children around the world?

RQ2): What recommendations can be drawn from the evidence base relating to the system-wide conditions required to promote optimal outcomes, including the pedagogy underpinning educational software and apps, and how they can be most effectively implemented and integrated in different learning environments?

Impact of educational apps on maths and literacy

2.1. Typically developing children

A recent systematic review of 35 randomised control trials (RCTs) and quasi-experimental designs (QEDs) found using interactive educational apps benefitted the maths and literacy skill development of children aged 0-6 years (Griffith et al., 2020). Furthermore, a separate meta-analysis of 36 RCTs and QEDs reported an overall effect size of +0.31 on maths and literacy outcomes following educational app use by typically developing children aged 4-9 years, compared to a range of control groups (Kim et al., 2021).

However, there is mixed evidence as to whether these benefits may be restricted to the specific number and literacy skills targeted by the educational software and apps and may not always transfer to broader measures of mathematics, reading, and language development (Jamshidifarsani et al., 2019; Outhwaite et al., 2022). This may be because educational software and apps often focus on basic aspects of maths and literacy development, such as number and letter recognition, respectively. These basic skills are often presented in isolation, and do not always embed the learning content in meaningful ways that promote generalisation to novel contexts (Jamshidifarsani et al., 2019; Outhwaite et al., 2022). In cases where generalisation to broader measures and/or secondary benefits have been observed, the educational software and apps have included a broad and detailed curriculum (e.g., see Case Study A).

Nevertheless, these educational technology results are similar to other meta-analyses synthesising the benefits of traditional one-to-one tutoring and small-group instruction, which reported overall effect sizes of +0.38 for maths and +0.35 for literacy. Greater effect sizes were also seen for younger children before (+0.45) or at the start of primary education (+0.42), compared to children over 7 years of age (+0.29) (Nickow et al., 2020).

2.1.1. Conclusion and recommendation

Evidence suggests educational software and apps have the potential to provide young children with supplementary learning opportunities that can support their acquisition of basic maths and literacy skills. Reported effect sizes are similar for maths and literacy and are broadly comparable with other forms of individual and small group intervention. This suggests this form of educational technology can provide meaningful learning opportunities, without the additional, time-consuming teaching demands associated with other intervention approaches (Hilton, 2018). However, it is important to remember that technology is not a replacement for high-quality teaching and its success is influenced by a number of factors, which are discussed in this paper.

2.2. 'Struggling learners'

There is indicative evidence that educational software and apps may also be particularly beneficial for young children identified in the literature as 'struggling learners' or learners in need of additional, individualised support across low-, middle- and high-income countries. Separate meta-analyses of 14 RCTs for maths and 20 RCTs for literacy showed digital-based interventions had an overall effect size of +0.54 on struggling learners' maths outcomes (Benavides-Varela et al., 2020) and +0.37 for literacy (Cheung & Slavin, 2013a). A collection of other RCTs of a literacy programme with a focus on a broad range of skills, including phonics, reading fluency, and comprehension, were also found to support struggling readers from poor and indigenous backgrounds across Australia, Canada, China, Hong Kong, Kenya, and the UK (Abrami et al., 2020; McNally et al., 2016).

However, these studies offer varying definitions of how ‘struggling learners’ were identified and there are often inconsistencies in the literature. For example, children may be defined as ‘struggling learners’ based on a statistical cut-off on a diagnostic assessment tool or are identified by their teacher. Sometimes, there are also research practices that pose threats to the internal validity of the study findings (Outhwaite et al., 2022). For example, a study by Hassler Hallstedt et al. (2018) (included in reviews by Benavides-Varela et al., 2020 and Outhwaite et al., 2022) identified ‘struggling learners’ based on a statistical cut-off on the maths assessment conducted before the intervention (i.e., pre-test). The same assessment tool was then used to measure the outcome of the maths app intervention. This poses a threat to the internal validity of the reported findings, as there is the possibility of regression to the mean (Barnett et al., 2004).

Regression to the mean is when extreme values, such as low pre-test maths score, may be due to measurement error and are therefore more likely to be followed by a less extreme score when measured again. This repeated measure of maths skill is more likely to be closer to the participants’ true ability. Consequently, it is very difficult to disentangle potential impact of regression to the mean effect from those of the intervention (Barnett et al., 2004; Yudkin & Stratton, 1996).

Nevertheless, a large scale RCT in early primary school with educational apps that included a broad range of early maths skills, including number, shape, space, and measure, were found to support skill development with ‘struggling learners’ from low socio-economic backgrounds in England (Nunes et al., 2019). ‘Struggling learners’ in this study were identified by teachers in the participating schools, rather than by measures used by the researchers and so was independent of the outcome measure. This means a potential regression to the mean effect is avoided and there is greater confidence in the validity of these findings.

2.2.1.Conclusion and recommendation

There is indicative evidence that educational apps and software can support children identified as ‘struggling learners’. However, some of the current research should be interpreted with caution, particularly as there are threats to the internal validity of some findings. Further research is needed that incorporates methodological best practices to understand better the specific impacts of educational apps and software for these children.

2.3.Children with special educational needs and disabilities

There is also emerging evidence in low- and high-income countries on the feasibility of educational software and apps on learning outcomes for children with specific special educational needs and disabilities (SEND). Much of this evidence follows from research with slightly older children, whose chronological age may not necessarily align with their ability levels.

In a QED, Sella et al. (2021) found children aged 5-12 years with Down syndrome in Italy made significant learning gains in specific numerical and mental calculation skills after using an adaptive computerised maths game, compared to controls. The software focused on enhancing number sense, establishing links between representations of number, conceptualising, and mastering arithmetic, and enhancing motivation for maths. This was achieved through board game style activities and is available in seven languages, including English, Finnish, French, Italian, Norwegian, Polish, and Swedish (Wilson & Dehaene, 2004).

Similarly, Pitchford et al. (2018) found 7-11year-old children with vision loss and emotional, behavioural, communication, and learning difficulties in Malawi were able to interact and learn with app-based maths instruction. However, children with hearing and/ or language difficulties made slower progress through the maths apps, compared to their peers with other SEND profiles and those children without SEND.

Further observational studies in the USA and Malaysia also found 6-9-year-old children with attention deficit hyperactivity disorder (ADHD), communication difficulties, and Down syndrome showed improvements in their maths skills after using app-based interventions. However, these children also faced challenges when accessing this form of maths instruction, such as sometimes being distracted or unfocused while using the maths apps, as well as interrupted by the schedule changes needed to use the apps in the classroom settings (Ahmad et al., 2014; Pecora et al., 2015).

Studies examining educational software and apps for literacy for children with SEND have largely focused on children with autism. For example, a systematic review of 12 studies investigating the use of computer-assisted instruction to teach literacy skills, such as phonological awareness, vocabulary, decoding, and comprehension, to primary-aged children with autism revealed largely positive effects (Ramdoss et al., 2011). However, considerable variability was noted across studies, possibly due to the range of taught skills and heterogeneity of the target population group.

Similarly, a recent QED study examined the impact of an interactive, web-based programme with activities to support the development of phonics, phonemic awareness, vocabulary, reading fluency and comprehension for 5-11-year-olds with autism in Australia. Results showed children made significant improvements in decoding skill and reading comprehension after using the web-based programme with a trained facilitator on a 1:1 basis, compared to a control group receiving business-as-usual literacy instruction (Bailey et al., 2017). However, the importance of in-person delivery supporting computer-assisted instruction for this group was apparent when considering the findings from another QED study that found no gains in reading accuracy or comprehension when the same programme was delivered by facilitators online to children with a diagnosis of autism aged 5-12, also in Australia (Bailey et al., 2022).

2.3.1. Conclusion and recommendation

There is emerging evidence that children with SEND can benefit from well-designed educational software and apps. However, special considerations are needed to ensure the EdTech is designed and implemented to meet the specific needs of these children and ensure access and equity. For example, many of these children with SEND may be chronologically older than the children the software and apps were designed for. As such, it is vital that further research and development is invested in creating and scaling EdTech interventions that represent and include children with SEND. Considerations should be given to how the software and apps are meaningfully implemented in children's learning environments, including additional one-to-one support from a trained facilitator.

2.4. Children in low- and middle-income countries

Much of the evidence on the impact of educational software and apps with young children has been conducted in high income countries in the global North with established economies. Duraiappah et al., (2022) describe these as Western, educated, industrialised, rich, and democratic (WEIRD) countries. For example, in a systematic review of 50 studies evaluating maths apps, 52% were conducted in the USA, and only eight studies have examined the same apps across different high, middle, and low-income country contexts with similar methods (Outhwaite et al., 2022). Results from Brazil, Ethiopia, Kenya, Malawi, South Africa, Tanzania, and the UK showed the educational apps at the focus of these studies supported learning for children in early primary school (Outhwaite et al., 2022; Pitchford, 2022; see Case Study A).

In particular, when looking at the role of gender on children's maths and reading outcomes with these apps in Malawi, Pitchford et al. (2019) found that girls and boys benefitted equally. Furthermore, when the maths apps were used at the start of elementary school at aged 5 and above, it was found that this form of instruction prevented the emergence of significant gender discrepancies in maths, which typically hinders girls' maths development, relative to their male peers (UNESCO, 2015).

Furthermore, a systematic review of 15 RCTs evaluating the use of educational software and apps specifically in low- and middle-income countries also found a moderate effect size of +0.18 on children's learning (Major et al., 2022). However, only four of these studies worked with children aged 8 and below in rural and urban communities in Russia, Malawi, and China (Bettinger et al., 2020; Pitchford, 2015; Pitchford et al., 2019; Yang et al., 2013). The average effect size across these studies was +0.21 on maths, reading and language skills.

While evidence suggests educational software and apps can raise maths and literacy attainment in low- and middle-income countries, further studies highlight the importance of linguistic and contextual factors in the design and implementation of these EdTech tools. For example, Drolia et al. (2022) emphasised the importance of representation of refugees' cultural features in design of educational apps, such as incorporating a right to left layout for app navigation, in line with the reading direction of Arabic for Arabic-speaking children. Similarly, Huntington et al. (in prep) conduced qualitative expert elicitation with 14 stakeholders involved in the Global Learning XPrize competition. This competition evaluated the impact of five educational apps on children's numeracy, literacy and writing skills in remote, out-of-school communities in Tanzania. Results showed cultural sensitization, contextually appropriate app content and design, facilitator involvement, and well-installed infrastructure were key to the successful implementation of educational apps in these low-income contexts.

2.4.1. Conclusion and recommendation

EdTech solutions have the potential to reach and impact children across different educational, economic, and social contexts, including those most vulnerable to educational inequalities. However, other studies have highlighted that it is vital that these solutions are localised to reflect the child's language and culture and are implemented and scaled in ways that consider the contextual factors of the communities that they aim to serve.

System-wide conditions: Pedagogy

Despite the promising evidence base on the impact of educational software and apps on children's learning, there are a range of factors within a multi-level education system that can influence their successful implementation and integration, and consequently their outcomes. For example, the success of an educational app intervention is first underpinned by its pedagogy (Outhwaite et al., 2019). Research has examined the educational content and design features of maths and literacy software and apps to assess the quality of their pedagogy and provide an understanding of how they can support children's learning.

3.1.Educational content

23 maths apps used by children in the first three years of school in eight countries were identified through a systematic review. Countries included Brazil, Canada, China, Malawi, Sweden, UAE, UK, and USA. A content analysis of these maths apps found practice-based apps were the most common. Practice-based apps are designed to support the acquisition of basic maths facts and concepts through targeted practice. Most apps targeted basic number skills, such as number representation with Arabic digits, verbal, and/or written number word recognition, one-to-one correspondence, and cardinality. More advanced maths skills, such as fractions, place value, multiplication and sequencing of events were less frequently included in the identified maths apps (Outhwaite et al., 2022).

Research studies evaluating these 23 maths apps predominately reported greater immediate and specific learning benefits, compared to a range of control conditions (Outhwaite et al., 2022). Moreover, apps that included a broader maths curriculum reported greater learning outcomes, including generalisation to other measures of mathematics and secondary outcomes, including attention, when compared to standard practice and active control groups (i.e., non-educational apps) (see Case Study A). However, it is currently unknown, whether apps that have a narrower focus (i.e., just number skills) also have wider benefits on children's learning, as additional outcome measures were not included in the associated evaluation studies (Outhwaite et al., 2022).

Similarly, a systematic review of 32 technology-based reading programmes found very few comprehensively covered literacy skill development. These programmes had been evaluated in 11 countries, including Canada, Chile, Finland, France, Germany, Netherlands, Spain, Sweden, Taiwan, UK, and USA (Jamshidifarsani et al., 2019). Furthermore, a content analysis of 30 commercially available computer-assisted software programmes for early literacy skills in North America, showed the inclusion of alphabetic knowledge, the relationship between graphemes and phonemes, and text comprehension skills followed developmental expectations across the selected programmes for children aged 4-7 years. However, other literacy skills, such as concepts of print, early phonological skills, syntactic awareness, decoding, and fluency were not taught comprehensively. Phonics content across the 30 programmes was also mixed, with the majority of programmes including onset-rime awareness but lacking embedded phonics (Grant et al., 2012).

3.1.1.Conclusion and recommendation

EdTech interventions have the potential to support learning but do not always capture the complexity of maths and literacy development, or reflect the localised national curriculum implemented in schools. Educational apps also need to be age-appropriate and informed by child development and learning, so that children can access the right educational content at the right age and ability level. Programmes that have a broad and holistic maths and literacy curriculum, with appropriate design features and have been empirically evaluated should be prioritised for further scaling.

3.2. Design features

Although many apps do not clearly state a specific learning theory in their development or associated research papers (Drolia et al., 2022), several frameworks have been developed to assess the design features included within educational apps for young children (Callaghan & Reich, 2018; Herodotou, 2021; Kolak et al 2020; Meyer et al., 2021; Papadakis et al., 2017).

Outhwaite et al. (2022) synthesised the predominant design features across these frameworks and applied them to 23 maths apps (identified through a systematic review) with mixed results. 52% of the maths apps included explanatory (i.e., explaining why a given answer is right or wrong) and motivational feedback (i.e., "Great job!"). The levelling of maths content was provided in a suggested, but not enforced sequence of activities (known as participatory, free from levelling) in 52% of the apps. 39% of the apps offered personalised learning that was adaptive to the individual child (known as programmatic levelling). 43% of the apps included an in-app character who provided task instructions, and in some cases modelled the learning activity. Only 8% of the apps included support for adult-child interactions. In 48% of the apps the task instructions could be repeated by the child, as often as required, but this was not consistent across the full sample of maths apps. 74% of apps provided the opportunity to practice basic maths skills in isolation, but only 13% offered practice in multiple basic maths skills in relation with each other. Across this sample of apps, the practice of maths skills was not embedded within a real-life context or applied to solve novel problems.

The relationship between some of these design features and the maths learning outcomes observed in the associated studies from the systematic review was also considered through a qualitative comparative analysis (Outhwaite et al., 2022). This approach enabled the combination of different design features to be examined, rather than considering their unique contribution to children's learning in isolation of one another. Results showed learning outcomes were maximised when the maths apps provided a personalised and adaptive learning journey (i.e., programmed levelling), and included explanatory and motivational feedback. This corroborates further systematic review evidence that showed significant effect sizes of children's learning gains in low- and middle-income countries were enhanced when the EdTech included personalised learning features that adapted or adjusted to individual students' current level of learning, so that they remained the zone of proximal development (Major et al., 2022).

The importance of feedback has also been highlighted in the context of literacy apps for supporting learning and enabling children to self-monitor their progress (Johnson et al., 2017). Outcome (i.e., whether a given answer is correct or incorrect) and explanatory feedback (i.e., explaining why a given answer is right or wrong) has also been shown to enhance learner outcomes in computer-based literacy games (Mayer & Johnson, 2010; Benton et al, 2018). It is important that feedback is kept simple and clear. Research with primary-aged children in England found that whilst elaborative and outcome feedback in a literacy app were both attended to equally, younger children sometimes struggled to use and apply the explanatory feedback (Vasalou et al., 2021). Likewise, beginner readers, struggling readers, and those learning English as an Additional Language, all benefitted from feedback presented visually. However, younger children did not always notice explanatory feedback presented verbally, compared to older learners. All children also struggled to fully understand and act on this form of app-based feedback (Gauthier et al., 2022). As such, this also highlights a need for further explicit explanation in educational apps, which could be provided by an adult supporting game play.

Despite the current evidence demonstrating the importance of effective pedagogy within educational software and apps, recent analyses of the commercial EdTech market found more than a quarter of commercial apps labelled as educational on the UK Google Play Store did not include any explicit learning content (Kanders et al., 2022). Likewise, six of the top 25 most popular maths apps in both the UK Apple and Google Play Stores were identified as not including any maths content (Outhwaite et al., 2022). This raises significant challenges for teaching practitioners, parents, and other stakeholders, when making informed and evidence-based decisions about which EdTech programmes to use with their children.

3.2.1. Conclusion and recommendation

Evidence suggests feedback and levelling are key design features for personalised and adaptive learning with educational software and apps. This is particularly relevant in contexts where a supervising adult may not always be able to provide these additional pedagogical supports. Nevertheless, teaching practitioners and parents need access to high-quality resources and training focused on how to identify high-quality software and apps, as well as how to support children in app-based learning environments, so that learning, implementation, and integration can be optimized.

System-wide conditions: Implementation

4.1. Age group and language skills

A systematic review of 36 studies conducted in low- and high-income countries found educational apps were most beneficial for typically developing children aged 4-5 years (preschool), compared to children aged 5-9 years (Kindergarten- Grade 3) (Kim et al., 2021). An additional systematic review of 74 studies found computer assisted instruction was more effective for enhancing maths attainment when used in elementary school from aged 5 and beyond, compared to high school (Cheung & Slavin, 2013b). Similarly, a synthesis of 20 studies focused on struggling readers, found technology-based literacy interventions were also more effective for younger children aged 6-9 years (USA Grades 1-3), compared to older children aged 9- 12 years (USA Grades 4-6) (Cheung & Slavin, 2013a). But no age differences in digital-based intervention outcomes were seen between children identified as struggling with maths aged 5-16 years (Benavides-Varela et al., 2020).

Collectively, this evidence suggests that children at the start of school and younger may benefit more from technology-enhanced learning. The evidence needs to be balanced against a further systematic review of 19 studies which found children aged under 4, did not benefit as well from educational apps, compared to children over 4 years (Herodotou, 2018). Evidence suggests children younger than 4 years may face barriers when accessing educational app software based on their language skills, particularly if the software is designed for independent use by the child (Outhwaite et al., 2022).

Experimental research found children in Brazil and Malawi with stronger language competencies made greater progress through a maths app intervention, compared to children with less developed language skills (Pitchford et al., 2018; Outhwaite et al., 2020). Further observational studies found young children in the USA who demonstrated purposeful questioning and movement while using the selected maths apps showed greater progression than those that did not (Bullock et al., 2017). Children with English as an Additional Language in England were also reported to benefit and enjoy using practice-based maths apps in their first language but were also identified as needing additional pedagogical support from their teachers, particularly around understanding the mathematical concepts included in the apps, when presented in their home language (Pitchford et al., 2021).

4.1.1.Conclusion and recommendation

Evidence suggests children who are still developing their language skills may not be able to access app-based instruction, particularly when the apps are designed to be used independently. As such, considerations should be made when deciding which type of apps and how they are implemented may be suitable for different children. In some cases, children may need additional support from an adult, or another type of app, such as a parent-based app. Parent- based apps are primarily designed to be used by parents or caregivers and are designed to encourage offline interactions and learning opportunities with children (Outhwaite et al., 2022).

4.2.Role of the adult in supporting learning with technology

A systematic review of 16 studies found literacy apps used by 0-6-year-old children, in preschool and at home can foster emergent writing and letter knowledge when delivered with scaffolding from a supportive adult, such as a parent/caregiver (Neumann & Neumann, 2017). Additional scaffolding from teaching practitioners has also been shown to be important for enhancing children's motivation and facilitating the generalisation of the maths and literacy learning beyond the technology-based context (McTigue et al., 2020; Nunes et al., 2019).

However, survey research shows only 21% of parents in the UK and South Africa co-play with their children to support their learning and development while using a tablet device (Marsh et al., 2020). Further experimental studies also showed that when parents co-play with their children, they provided their children with fewer teaching and responsiveness supports during app-based spatial play, compared to the same activity using physical 3D blocks (Lee & Wood, 2020). Analysis of parental talk during app-based play sessions found parents focused on children's engagements with features of the app and not necessarily the learning content (Griffith & Arnold, 2017). Design features, such as inbuilt narration and real-time conversation prompts can encourage parent-child dialogue and have been shown to support aspects of language learning and meaningful adult-child interactions (Booton et al., 2021).

Other types of apps, such as parent-based apps may also support the use of guided play principles in young children's learning environments. A systematic review and meta-analysis of 30 RCTs and QEDs found that guided play, which is initiated by adults, and led by children, had a greater effect on children's early maths skills, compared to direct instruction and free play. Small effects in favour of guided play were also seen for reading skills, but not vocabulary (Skene et al., 2022). RCT evidence shows parent-based apps that align with the principles of socially interactive learning and support meaningful dialogue can support 6-7-year-old children's maths skills in the USA, particularly for those children whose parents are anxious about maths (Berkowitz et al., 2015; Schaffer et al., 2018). Similarly, this type of app has also been shown to support the development of parental self-efficacy in the UK, compared to an active control group in the child's first 1,000 days (Outhwaite, 2021a). Parent self-efficacy has an established causal relationship with later child outcomes (Albanese et al., 2019), and is thus an important target of intervention during this critical early period (WHO, 2020).

However, the role of the parent or teacher may not always be crucial to maximising learning outcomes, particularly if the apps are well-designed and can be used independently by the child. For example, evidence from an implementation process evaluation found that teacher support, which was characterized by technical support, encouragement, and guidance, did not correlate with children's learning outcomes with a practice-based maths app. Instead, how the intervention was organised within the individual classroom routines and context was shown to significantly predict children's outcomes. Specifically, an established routine, which included consistent timing, a dedicated staff member and classroom space, with organised equipment and a seating plan, was shown to account for 47% of the variance in children's learning outcomes with the maths app intervention in England (Outhwaite et al., 2019).

4.2.1. Conclusion and recommendation

In some cases, children may need additional support to understand and act on the learning content presented to them in app-based environments. However, this is not always the case, and decisions on the appropriate role of the adult for supporting learning should be considered when specific EdTech interventions are scaled with specific groups of children. Likewise, consideration should also be given to the type of app implemented and the relative benefits it could support. For example, parent-based apps are able to encourage and support off-screen engagements in children's learning and play and parent-child interactions. This type of app may be particularly suited for much younger children.

4.3. Dosage

A meta-analysis of 36 experimental studies evaluating maths and literacy apps across low-, middle- and high-income countries with children aged 4-9 years found no association between the intervention dosage and mean effect sizes on immediate learning gains across studies (Kim et al., 2021). However, it is important to acknowledge that dosage (i.e., session length, occurrence, overall duration) was not frequently or reliably reported across evaluation studies, which may have hindered the accurate examination of this potential relationship (Outhwaite et al., 2022).

To further examine a potential relationship between dosage and long-term learning outcomes with maths apps, Outhwaite et al. (2022) thematically synthesised five studies that adequately reported sufficient data to calculate dosage and effect sizes on learning outcomes. Results showed that when the maths app intervention was used for a sustained period (e.g., 15-28 hours), the immediate learning gains were maintained at a 5-month to 2-year follow-up (Hassler Hallstedt et al., 2018; Outhwaite et al., 2017; Schaeffer et al., 2018). In contrast, when the maths apps were used for a shorter duration (e.g., 1.7- 5 hours), the immediate learning gains faded one to two months later (Ramani et al., 2019; Vanbecelaere et al., 2020).

A lack of consistency in fully reporting dosage in reading app or computer-assisted intervention research is also acknowledged by Jamshidifarsani et al. (2019). In their review of 32 reading programs, studies differed in their reporting of the length of each session (e.g., in minutes), how many sessions occurred per week, and the overall duration (e.g., total number of weeks). While they did not explicitly assess the effect of dosage on reading outcomes, Jamshidifarsani et al. (2019) identified that multi-component programs (i.e., those targeting a range of literacy skills) had the longest individual session lengths. They also found that interventions focused on phonological awareness had, on average, longer overall durations than interventions that targeted reading fluency. Another review of technology interventions to support struggling readers by Cheung and Slavin (2013a), which only included studies with a minimum intervention duration of 12 weeks, found larger effect sizes for high-intensity programs (classified as <75 mins per week) compared to low-intensity programs (>75 mins per week), with effect sizes of +.19 and +.08 respectively. This suggests that high intensity intervention may be more beneficial for struggling readers. Further research is, however, needed to better understand the optimal dosage for reading technology interventions.

4.3.1. Conclusion and recommendation

In many cases, educational software and apps can offer an effective supplementary teaching tool that provides children with individualised, additional practice in specific maths and literacy skills. Evidence suggests that learning gains are maximised when the EdTech is used for a sustained period, but this should also be considered alongside how they are meaningfully integrated into specific formal and informal contexts, such as in school and at home.

System-wide conditions: Integration

5.1. Role of CPD

The effectiveness of educational software and apps also hinges on the nature and quality of continued professional development (CPD) for educational professionals (Cheung & Slavin, 2013b). However, research suggests there is a lack of specific teacher training to successfully support the use of educational technologies into the classroom, which poses a significant barrier to their effective integration and adoption (Picton, 2018). Recommendations from the Education Endowment Foundation in the UK emphasises that a clear support plan considering initial training needs and ongoing CPD are essential for EdTech to have a meaningful impact on learning (Stringer et al, 2019).

CPD models should always be adapted for the specific purpose for which it will be used (Boylan et al., 2018) and it is crucial to recognise the distinct contexts, differing starting points of participants, and varied levels of prior knowledge, as well as the role of school leadership in the allocation of training and resources for CPD (Lewin et al., 2019; Weston & Clay, 2018). CPD should also be offered via experiential learning, where teachers can be provided with 'hands-on' opportunities to try out software and develop their confidence and skills (Stringer et al., 2019). Ideally, this training should be incorporated as part of ongoing support, rather than a one-off session, as this can support teachers with opportunities to plan together, implement plans in their specific settings, and enable cycles of reflective practice (Ekanayake & Wishart, 2015).

5.1.1.Conclusion and recommendation

Overall, ensuring teaching practitioners are appropriately trained to achieve the most impact from technology use is a continuous challenge (Lewin et al, 2019; Hubbard, 2019). Existing frameworks for good practice in this area, such as the UNESCO ICT competency frameworks for teachers and national education policy makers provides benchmarks for teaching standards, including an emphasis on how technologies can support curriculum development, pedagogy, and ongoing CPD (UNSECO, 2011). Furthermore, a linked hub, curated by UNESCO and partner countries, provides open access training resources, professional networking, and developing communities of practice with success across multiple adopter countries, including Guyana, Rwanda, South Africa, Tunisia, and Turkey (Moore et al., 2016; Mtebe, 2020).

5.2. Digital Divide

The 'Digital Divide' is a complex and dynamic issue (Van Dijk, 2020) and can be conceptualised on three levels: access, skills, and usage (Scheerder et al., 2017). Inequalities in these three interconnected areas, combined also with CPD difficulties, poses a significant challenge to the successful integration of EdTech in early childhood education. For example, limited internet access in schools and a lack of maintenance supports, combined with a lack of teaching CPD training were some of the reasons for the limited success of the One Laptop Per Child initiative in the USA, Peru, Rwanda, and Tanzania (Hubber et al., 2016).

To overcome these issues, inequalities in access to technological resources has been the main focus of research and policy (Van Dijk, 2020). For example, survey data shows significant differences between children's access to technology in low- and high-income countries: 94% of children in the UK were reported to own or have access to a touch-screen tablet device, compared to 34% of children in South Africa. Significant differences in access were also reported based on the child's race within the South African context, with greater access for children who identified as White and Indian or Asian, compared to Black African and Coloured. Children from higher-income households, across both countries, were also more likely to have access to a tablet device, than their peers (Marsh et al., 2020).

Further evidence suggests the impact of these inequalities were exacerbated by the Covid-19 pandemic when schools were closed, and remote learning was enforced. In the UK, estimates suggest that only 21% of children from the lowest income households had access to the technological support that they needed to access remote learning (Outhwaite, 2021b), which had a significant impact on their engagement and attainment outcomes (Sharp et al., 2020).

When attempting to address the 'Digital Divide', most OECD countries focus their digital innovation policy strategies on physical access to technology, including hardware, connectivity, and other infrastructures (Tate & Greatbatch, 2022; Van der Vlies, 2020). While this may still be the priority in low- and middle- income countries, considerations are also needed in terms of inequalities in the required skills and usage of technological resources (Van Dijk, 2020).

Evidence suggests that it is often assumed children are 'digital natives' that is, they have the innate necessary skills to use educational technologies. For example, research shows 2-year-old children have the motor skills required to operate touch-screen tablet devices (Nacher et al., 2015; Vatavu et al., 2015). However, there are also evidence gaps in the frequency and nature of their technological use (Van Dijk, 2020). Mobile learning activities are less frequently designed to have children as producers, collaborators, and creators of knowledge (Crompton et al., 2017; Outhwaite et al., 2022), and surveys show only 58% of children the UK and 49% in South Africa were able to create digital content on their devices (Marsh et al., 2020).

Parents and teachers' may also lack the confidence to support their children using technology. Only 64% of South African parents reported feeling confident helping their child play with technology and there were significant socio-economic differences, with 50% of lower-income parents and, over 75% for higher-income parents reporting feeling confident. Similar patterns were also observed for UK parents (Marsh et al., 2020). Although some governments have implemented national campaigns to signpost quality literacy app resources, such as the Hungry Little Minds Initiative in the UK (DfE, 2019), little has been done to boost parent confidence. For teachers, digital skills and new approaches to teaching and learning with technology are included in the digital education strategies of the majority of OCED countries (Tate & Greatbatch, 2022).

Further research also suggests these issues are closely intertwined. PISA data from 2018 showed that for the majority of the 21 participating European counties, family socio-economic status was shown to have a greater influence on children's access to technological resources, compared to their integration in school settings. (Gonzalez-Betancor et al., 2021). This is consistent with the first level of the 'Digital Divide'. However, the integration of technology into school settings was shown to be more influential on the frequency and quality of use of these resources at home, than the socio-economic status of the family. This evidence suggests the integration of educational technologies in schools across the curriculum, provides a compensatory measure for inequalities in the child's home environment, and thus may contribute to closing the 'Digital Divide'. It is also suggested that supporting teacher CPD and developing the skills and competencies of students are vital components for successful EdTech integration. However, further research on these topics is needed to understand country-specific issues within low- and middle-income contexts, particularly with marginalised children and where access to technology may be limited.

5.2.1. Conclusion and recommendation

Addressing the digital divide in access, skills, and usage should extend beyond providing more hardware and connectivity to communities, to also include programmes that do not require internet access to function (Drolia et al., 2022) and align with principles of best practice in design features (Outhwaite et al., 2022), as well as high-quality CPD and support for teaching practitioners and parents (Cheung & Slavin, 2013b). To support evidence-based EdTech is it vital that app developers, researchers, and educational practitioners work in collaboration (Clark-Wilson et al., 2021; Porter, 2018).

Two case studies demonstrating good practices in EdTech in Early Childhood and Primary Education

Discussed next are two case studies, which illustrate how high-quality educational software and apps have been successfully implemented and integrated in different educational, economic, and cultural contexts. In line with the scope of the current report, these case studies have been selected based on programs that have demonstrated measurable impact on improved maths and/or literacy outcomes, as well as the research team's expert opinion.

6.1.Case study A: Unlocking Talent

Established in 2013, the Unlocking Talent initiative aims to address the global learning crisis through high-quality and evidence-based maths and reading apps. This case study describes the educational apps and summarises some of the evidence and lessons learnt in implementing and scaling the initiative in Malawi and other low- and middle-income countries (see Pitchford, 2022 for further details).

6.1.1.Description of the educational apps

The educational apps within the Unlocking Talent initiative were developed by the not-for-profit organisation, onebillion, who were joint winners of the Global Learning XPRIZE in 2019. These practice-based apps include over 4,000 activity units targeting specific skills that are essential to maths and reading development, including number representation and relationships, counting, arithmetic, shape, patterns, and measurement, as well as phonological awareness, reading fluency, and comprehension. The latest version of the apps, also known as onecourse, also includes over 160 illustrated stories from around the world and a free play zone (onebillion, 2022).

The apps are available in multiple languages, including English, Swahili, Chichewa, and French. The apps are designed to support individualised and self-paced learning with minimal adult support. The apps include key design features known to support learning, including motivational and explanatory feedback, and an on-screen teacher provides task demonstrations and instructions, which can also be repeated. The apps provide a suggested, but not enforced sequence of learning activities, as well as continuous assessment of knowledge through end-of-topic quizzes. Children's progress through the apps is automatically fed back to teachers, which can facilitate additional implementation support. The latest version of the apps, onecourse, also includes an assessment of children's skill levels at the start of play to place them on their own personalised learning journey.

6.1.2.Evidence of Unlocking Talent

The educational apps within the Unlocking Talent initiative have been evaluated using a mixed methods approach in various studies across seven countries, including Brazil, Ethiopia, Kenya, Malawi, South Africa, Tanzania, and the UK, with positive results for children in early primary school (Outhwaite et al., 2022; Pitchford, 2022). For example, Pitchford (2015) established initial proof of concept of the maths apps with 283 children in the first three years of school in Malawi. Additional benefits were also observed for children's attention skills (Pitchford & Outhwaite, 2019). These learning gains were sustained as the programme scaled to over 14 schools and expanded to reading, and girls also learnt just as well as boys (Pitchford et al., 2019). Results were also comparable across studies in different educational, economic, and social contexts with, on average, a 3-month gain in maths and a 4-month gain in reading with the apps, compared to standard classroom practice (Imagine Worldwide, 2020; Outhwaite et al., 2020; Nunes et al., 2019; Pitchford et al., 2019).

6.1.3.Implementation of Unlocking Talent

Based on research evidence (Pitchford, 2015; Pitchford et al., 2019), the apps have been used in 63 schools across 10 education districts across Malawi. Children use the apps with headphones in groups of 30-60, facilitated by their teacher, for 40 minutes sessions. Children have their own personalised, in-app profile, meaning that devices can be used by multiple children throughout the day. Learning sessions are delivered in a specifically designed classroom at the school, which is solar powered and has a dedicated and trained learning centre co-ordinator. This helps to ensure a suitable and sustainable infrastructure for the programme.

Overall, the implementation of the Unlocking Talent initiative in Malawi is underpinned by an alliance of app developers (i.e., onebillion), practice partners (i.e., Voluntary Services Overseas), policy makers (i.e., Ministry of Education, Science and Technology in the Government of Malawi) and researchers (i.e., University of Nottingham and University of Malawi), as well as various funders. These core partnerships also engage with key stakeholders, including teachers, school and community leaders, parents, and children to ensure the initiative meets their specific needs at each stage of scaling.

6.1.4.Scaling of Unlocking Talent

To support the scaling of the Unlocking Talent initiative, Pitchford (2022) highlights four key areas of activity. Firstly, through collaborations with practice partners and policy makers, specific teacher training on the use of digital educational technology is now embedded within CPD and in-service teacher training courses offered at government-owned teacher training colleagues. This capacity building has and will continue to support the scaling of the Unlocking Talent initiative in formal educational settings.

Secondly, direct-to-community approaches have been adopted to increase the reach of the latest version of the educational apps to the most vulnerable and marginalised children. In doing so, onebillion have created onetab: a low-cost tablet device with the onecourse maths and reading app content pre-installed. The onetab device can be used when access to school is challenging, as it does not require an internet connection and is solar powered. As such, these adaptations extend the current implementation of the Unlocking Talent initiative to informal learning environments, including out-of-school outreach programmes and refugee camps in Malawi.

Thirdly, a series of implementation toolkits have been developed across the collaborative alliance, which are designed to provide guidance to other government and non-governmental organisations on designing, planning, launching, and evaluating tablet-based learning initiatives.

Finally, the educational apps included in the Unlocking Talent initiative are undergoing various localisation adaptations for different countries facing significant educational challenges. For example, the onecourse content has recently been localised into French for West and Central Africa (onebillion, 2021). This process involves extensive collaborations with local language and pedagogy experts, as well as native voice artists.

6.1.5. Recommendations for similar initiatives

Overall, Pitchford (2022) details some of the key operational lessons learnt from the Unlocking Talent initiative, which has involved genuine co-operation and collaboration between many different stakeholders across the global education challenges ecosystem. In particular, Pitchford (2022) highlights how these relationships were curated and maintained over a sustained period with a focused and overarching goal. These cross-sector collaborations also often required an agile approach to working, particularly in the rapidly changing EdTech sector. Effective communication was also emphasised, particularly when terminology may be specific or hold different meanings to different groups.

6.2. Case Study B: Navigo

The Navigo literacy game was developed to support young children learning to read. The Navigo literacy app was developed as part of the iRead, EU-funded Innovation Action project (2017-2021), which was co-ordinated by researchers at UCL, in collaboration with 15 EU partners across six countries, including Germany, Greece, Romania, Spain, Sweden, and the UK. This case study describes the key features of the Navigo literacy app and summarises the preliminary research that has focused on the design and scalability of Navigo. Recommendations for the development and adoption of reading technologies are also identified.

6.2.1. Description of Navigo

The Navigo literacy app was co-designed by partners in education and industry. It is an adaptive literacy game with a focus on supporting novice readers, struggling readers and children learning English as a Foreign Language (EFL). Navigo was developed and trialled in schools in Germany, Greece, Romania, Spain, Sweden, and the UK. Following the design phase (2017-2020), it has been used in 144 schools by over 4,500 children.

Navigo contains over 900 mini game activities covering a range of literacy skills, such as phonics, morphology, word recognition, reading fluency, syntax, and comprehension. It has 15 different game mechanics, including matching words, splitting words, multiple choice, sequencing, hit-the-target, and fill-in-the-gaps. Variety in game mechanisms are crucial for maintaining children’s interest, as well as enabling practice of the same learning objective through different activities and fostering transferability of learning.

The development of app content (learning activities) was informed by theories and research on reading development. Language features, including their coding of difficulty and pre-requisite knowledge, were developed in a domain model created by language experts. This domain model was based on the research literature and content was designed to align with primary school literacy curriculums and existing reading schemes. Within Navigo, a structured and systematic learning journey starts with children (i) applying the correct linguistic rule, (ii) moving towards using and combining different linguistic rules to build a correct word or meaningful sentences and (iii) finishes with automatising this knowledge.

Navigo is based on a mastery learning approach that ensures the technology updates and adapts to each child's existing skills based on their game performance and pre-existing knowledge. As such, it is a personalised learning game and removes the planning requirement for teachers. A teacher tool enables teachers to control features that a child may access according to their learning needs and to override the game's automation. This allows flexibility to tailor games to classroom activities. Navigo was designed to be used either in the adaptive mode or as a teacher-led tool. Digital reports are available for teachers to assess progress and to identify where further support may be needed. Users of Navigo – children and teachers – were involved in the design and evaluation phases of the app.

Navigo was awarded a 'high quality' mark by the Department for Education in England in their Hungry Little Minds 2019 campaign, as well as being awarded the Serious Games Society GaLA 2018 Award for the Academy category.

6.2.2.Research evidence on Navigo and recommendations

Studies using Navigo have, to date, focused on three areas: (i) understanding instructional features in literacy games, (ii) the role of adaptivity and (iii) scalability.

First, observations and analysis of Navigo gameplay revealed that for English novice readers (aged 5-6 years), struggling readers (aged 8-11 years), and Swedish children learning EFL (aged 9-10 years) visual, outcome feedback (e.g., correct/incorrect) fostered children's understanding of an error, but children struggled to understand elaborative feedback within the game (e.g., 'look for a noun') (Gauthier et al., 2022; Vasalou et al., 2021). Younger children and those with reading difficulties or less experience with a language may lack the meta-linguistic knowledge to apply elaborative feedback independently. These findings are particularly interesting given that recommendations are often made to include auditory/verbal elaborative feedback within educational games to avoid placing too many demands on the visual processing system (Mayer & Moreno, 2003). The key recommendation for designing effective feedback in literacy learning games for children would be to consider the learning level and characteristics of the target age group. Here, conversations between developers and users are crucial. Pedagogically, the findings point towards the importance of the presence of an adult to further support children's game play.

Second, a preliminary QED study comparing Spanish EFL primary children who played Navigo for one hour per week over six months, either in the adaptive mode or following a teacher-led sequence, reported improvements in measures of reading accuracy and fluency at post-intervention, regardless of mode (Serra & Gilabert, 2021). Conclusions about the specific impact of Navigo are limited due to the lack of a control group. Further research is needed to better understand the efficacy of Navigo. The findings do, however, support the development of adaptive literacy games mapped to the curriculum which may be employed when teacher time is limited.

Finally, a key component of the iRead project was to understand how reading technologies, such as Navigo, can be deployed successfully into the classroom. Teaching staff in England that took part in learning design workshops appropriated Navigo as a way of practising reading and perceived the literacy game as an individual learning task

(Vasalou et al., 2022). Care should be taken to ensure that learning games can be collaborative to check understanding. Interviews with 21 teachers across nine schools in Germany with a range of socioeconomic status, identified common challenges of Navigo adoption, such as frequency of use and lack of time within a busy curriculum, access and confidence in handling tablets, and low digital literacy (Pflaumer et al., 2021). Similarly, observations and interviews with teaching staff in England highlighted that for adoption to be successful, a match was needed between the school ethos and available resources to incorporate technology in the classroom (Ibrahim et al., 2022). Indeed, it was recognised that technology use in the classroom creates other logistical tasks that encroach on teacher time (e.g., charging devices, supporting logins for young children, setting up activities on devices). The automation offered in Navigo was therefore considered advantageous, as it allowed time for teachers to attend to these new tasks.

A key recommendation for similar initiatives is to ensure that, through ongoing mentorship or development of 'technology champions' in schools, teachers are supported to develop digital readiness and able to plan ways to overcome some of the lower level set up to reduce workload and foster sustained use of technology.

Conclusion

Educational software and apps have the potential to raise attainment and reduce inequalities in maths and literacy. Although current evidence is primarily focused on high-income, Western populations, there is promising evidence in low- and middle-income countries demonstrating that children, regardless of educational, social, or economic context, can learn with these technology-based forms of instruction.

However, it is also important that these EdTech programmes are not implemented in isolation. Rather they should be used as supplementary tools to complement and enhance current teaching. As part of this, it is vital that they are underpinned and integrated in effective pedagogy and good practices.

Educational software and apps that have shown significant impact at scale across low-, middle- and high-income countries are characterized by high-quality and age-appropriate maths and literacy content, which is localised, both linguistically and culturally, to the child's specific context. They also include effective design features, particularly feedback and levelling, presented in multisensory ways that children can access and understand.

That said, high-quality software and apps alone will not equal success. To ensure learning, access, equality, and inclusion, it is vital that they are implemented and integrated as part of a holistic and meaningful support structure. This includes access to hardware devices, and when needed internet connectivity, as well as high-quality CPD and ongoing support for teaching practitioners and parents to ensure knowledge and confidence with technology.

Overall, good practices may evolve over time within this rapidly changing EdTech ecosystem. As such, collaborations across multiple stakeholders are essential for ensuring optimal outcomes for all children.

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