

Interventions to improve mathematics achievement in primary school-aged children: a systematic review

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Date Submitted: 22 September 2016

Date Revision Submitted: 16 December 2016

Approval Date: 29 January 2017

Publication Date: 6 February 2017

TITLE OF THE REVIEW

Interventions to improve mathematics achievement in primary school-aged children: a systematic review

BACKGROUND

Mathematics achievement is predictive of academic success, future employment, economic productivity (Williams, Clements, Oleinikova & Tarvin, 2003) and health outcomes (Rowlands, 2014). Global comparison studies such as PISA (Organisation of Economic Co-operation and Development, OECD, 2014) have emphasised the impact of the mathematical skills of a country on economic growth and wellbeing (OECD, 2010). The recently published 2015 TIMSS report (The Trends in International Mathematics and Science Study, 2016) highlights some improvements across countries such as Russia, Kazakhstan and Northern Ireland. However there still remains a significant gap between the US or UK and Singapore, the highest performer in the world. In contrast, despite spending more than most other countries per student, the United States continue to perform poorly in mathematical achievement; with 12% of children performing below the basic-proficiency level in mathematics (OECD, 2012). Similarly, within the United Kingdom, a large proportion of children (13% in England) do not meet the expected levels in mathematics by the end of primary school (DE, 2015). The cost of poor numeracy to the UK economy is estimated at £20.2 billion per year (National Numeracy Organisation, 2014).

The negative consequences of low achievement in mathematics are not restricted to a small proportion of individuals with identified mathematical learning difficulties (Dyscalculia) but extend beyond this to include a larger proportion of children who fail to achieve numeracy levels needed for everyday life (Dowker, 2009). These poor early numeracy skills have been acknowledged as contributing to a “viscous cycle of disadvantage and a poverty of opportunity” (Northern Ireland Audit Office, 2013). The Social Exclusion Unit reported approximately 25% of young people in custody and 65% of adult prisoners lack basic numeracy skills (Social Exclusion Unit, 2002), poor mathematics is linked to higher levels of truancy and exclusion from schools (Brookes, Goodall & Heady, 2007) as well social and behavioural problems in later life (Every Child a Chance Trust, 2009). Every Child a Chance Trust report concluded the lifetime cost of very poor numeracy for an annual cohort of approximately 36,000 children exceeds £2,000 million. In comparison, the cost of providing additional support to raise numeracy skills was £89 million (Every Child a Chance Trust, 2009).

Recently, increasing investment, both in terms of time and finances, has been dedicated to developing effective interventions to improve mathematical achievement. Key to this has been the identification of a number of general cognitive and mathematics-specific skills that are predictive of mathematical achievement in primary school aged children such as working memory (Raghubar, Barnes & Hecht, 2010), inhibitory control (Cragg & Gilmore, 2014),

counting skills (Cowan et al., 2011) and flexible strategy use (Geary & Brown, 1991). Attitudes and anxious thoughts directed towards mathematics have also been linked to mathematical performance (Maloney, Schaffer & Beilock, 2013). Although the literature in this field has grown substantially, there continues to be a lack of studies designed to test interventions based on these associations.

To date, mathematics interventions have taken a variety of approaches, from one-to-one computerised training to whole-class pedagogy approaches. Individually-administered training has been developed to improve specific mathematical skills such as number sense (Wilson, Dehaene, Dubois & Fayol, 2009) and basic addition skills (Siegler & Ramani, 2008). It has also been proposed that computerised training of working memory may lead to gains in mathematical achievement, although evidence for this is mixed (Melby-Lervag & Hulme, 2013). Classroom-based educational interventions such as explicit delivery of heuristics, encouraging children to reflect and verbalise their strategy use and explicit instruction have been established to be effective in improving mathematical outcomes (Gersten et al., 2009). Expressive writing interventions that aim to reframe anxious thoughts about mathematics have been observed to improve mathematical performance on a classroom level (Ramirez & Beilock, 2011). In addition, peer-tutoring, in which children guide one-another's learning and provide feedback, has also been observed to assist in mathematical outcomes (Thurston, Tymms, Merrell & Conlin, 2014). Tentatively, the use of concrete manipulatives, such as cuisenaire rods or Numicon™ have been associated with improvements in mathematical achievement, however, as a whole, these studies have not been systematic and have included very small sample sizes (Dowker, 2009).

There is no doubt that mathematics is a complex and expansive area to systematically review and currently there are few up-to-date comprehensive syntheses of the literature, usually in the form of a meta-analysis (e.g. Carbonneau, Marley & Selig, 2012; Cheng & Slavin, 2013). In addition, to the authors' knowledge, there are no systematic reviews exploring specifically the outcomes of randomised controlled trials on mathematics achievement. The use of randomised controlled trials (RCT) in schools has been debated many times (Oakley, Toroyan, Wiggins, Roberts & Stephenson, 2003). However, in recent years there has been a call for education to follow other fields such as medicine, which strongly advocate the application of randomised experiments and using these findings to guide policy and practice (Goldacre, 2013). This has led to a gradual increase towards the inclusion of randomised controlled trials as a means to gain high quality evidence to help inform decision-making within education (Tranfield, Denyer & Smart, 2003) as well as a range of global educational initiatives. The introduction of national centres such as the What Works Clearinghouse (U.S.A.) and Evidence for Policy and Practice Information and Coordinating Centre (EPPI-Centre, U.K.) aims to support the use of practices centred on scientifically based research, most importantly, the implementation of randomised controlled trials.

OBJECTIVES

This systematic review will aim to answer the following questions:

- (1) What types of classroom-based interventions or programmes are used with primary school-aged children who do not meet the criteria for mathematical learning difficulties?
- (2) What are the most effective classroom based interventions for improving mathematical achievement in primary school-aged children?
- (3) What are the resource requirements of the most effective interventions for improving mathematical achievement primary-school aged children?

EXISTING REVIEWS

It is important to acknowledge poor mathematical achievement affects a large proportion of individuals who do not meet the criteria for diagnosed mathematical learning disability, yet previously published research have largely focused on interventions with populations of children with, for example, MLD or Dyscalculia (Gersten et al., 2009; Kroesbergen & Van Luit, 2003; Xin & Jintendra, 1999). In addition, there is one ongoing registered Cochrane review focusing on mathematical interventions to improve mathematical achievement specifically in children with Dyscalculia (Furlong et al., 2016), the protocol of which has been recently published. Current theories suggest that children with Dyscalculia or mathematical learning difficulties struggle with mathematics due to specific cognitive deficits not shared by individuals with general low achievement in mathematics. Accordingly, there is a need to systematically review interventions targeted at this broader population.

Currently there are only a few mathematical systematic reviews/meta-analyses on interventions for improving mathematical achievement and they focus on specific types of interventions. Cheung and Slavin (2013) carried out a meta-analysis investigating the use of educational technology application for enhancing mathematic achievement. This review identified 74 studies and found overall a positive but small effect when technology-based programs or applications are used to support the learning of mathematics. Carbonneau, Marley and Selig (2012) undertook a meta-analysis assessing 55 studies in the use of concrete manipulatives in mathematics. The findings also suggest that the use of concrete manipulatives supports the development of mathematic achievement. However, both meta-analyses contain complicated methodology by including a wide range of experimental designs, duration of interventions, sample ages and year of publication; ultimately increasing the likelihood of several methodological biases and reducing the quality of findings.

All previous reviews of mathematical interventions have also focused on wide age-ranges of populations. However, across a variety of health and education outcomes it has been suggested that early interventions are the most cost effective and efficient approach to improving children's outcomes (Easton & Gee, 2012). Therefore, discrepancies between

studies concerning the impact of interventions on achievement may be attributed to comparing studies that intervene on young children to those that focus on adolescents. Although a more targeted approach was taken in an unpublished doctoral thesis which conducted a meta-analysis of effective instructional practices for 3-6 year-old children, this body of work is now outdated as only papers published between 1977 and 2003 were included (Malofeeva, 2005). This further emphasises the need for a systematic review that provides a clearly focused criterion (i.e. on primary school sample; implemented in school settings) to allow interpretation and application by the relevant practitioners and policy makers.

INTERVENTION

The proposed review will include:

- Randomised control trials.
- Interventions directed towards students in classroom settings.
- Interventions may vary in terms of delivery method; those delivered by teachers, teaching/classroom assistants or other trained professionals as well as through other mediums, e.g. peer tutoring or digital/computerised administration.
- Studies that have been published since 2000, in order to identify timely and relevant research studies; ensuring that the materials included are relevant in terms of curriculum context.

The proposed review will exclude:

- Interventions delivered within special schools, in the home or community setting.
- Studies based on solely on teacher training programs, professional development, school policy or curriculum reforms.

An initial pilot search on PsycINFO identified 33 appropriate studies meeting our criteria.

Table 1. PsycINFO Search terms

Abstract	math* OR mathematic* OR numerical OR numeracy OR arithmetic*
Abstract	intervention* OR program* OR instruct* OR learn* OR teach* OR educat* OR train* OR assign*
Abstract	Trial OR RCT OR random* OR 'control group*'
Full text	counting OR addition OR subtraction OR multiplication OR division OR procedural OR conceptual OR adding OR sum* OR "math attainment" OR "math achievement" OR geometry OR fractions OR algebra OR "place value" OR arithmetic

Full text	class* OR school* OR lesson* OR education OR primary OR element* OR child* OR pupil* OR reception OR kindergart* OR grade* OR year* OR age*
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Some examples of studies that subsequently met our inclusion criteria are summarised below:

Some examples of studies that met our inclusion criteria are summarised below:

1. Barner and colleagues (2016) conducted a randomised controlled trial to assess the impact of a mental abacus technique on students' mathematical abilities within a low socioeconomic status school in India. Children aged 5 to 7 years old were randomly assigned to an intervention group to use the mental abacus technique or control group of standard curriculum maths. The mathematics outcome measured four mathematical tasks; using the Math Fluency subset of the Wechsler Individual Achievement Test (WIAT-III); the Calculation subtest of the Wood-cock Johnston Tests of Achievement (WJ-III); and two specifically designed tests to target arithmetic and place value knowledge. The study also assessed cognitive, academic and attitudinal outcomes however these did not demonstrate consistent improvement or significance. However, the mental abacus technique led to gains in the Calculation subtest, arithmetic and place value knowledge suggesting use of a mental abacus as an effective tool for improving math outcomes.
2. Presser and Clements (2015) also conducted a large cluster-randomised controlled trial into Big Math for Little Kids (BMLK), a play-based early mathematics program for 4-5 year-old children. The experimental group completed the BMLK program whereas the comparison group was a 'business-as-usual' control group, children were selected on the basis of low socioeconomic status and general mathematics ability was assessed as a baseline. The study found BMLK had a small but positive impact on young children's mathematic knowledge as measured by the primary outcome measure, ECLS-B Direct Mathematics Assessment (Najarian et al., 2010).
3. McNeil, Fyfe and Dunwiddie (2015) conducted a randomised controlled trial on the effectiveness of a modified presentation of traditional arithmetic practice workbooks. Children aged 7-8 years old were recruited from three schools, two serving children from low socioeconomic backgrounds. In order to assess understanding of math equivalence a modified workbook (e.g. $_ = 4+3$) or a control workbook with a traditional layout (e.g. $4+3=_$) was presented to children. In addition, the study assessed 'computational fluency' using the Math Computation section of the Level 8 of the Iowa Test of Basic skills along with a timed paper and pencil addition test designed by Geary et al. (1996) (e.g. number of single digit addition facts answered correctly in one minute). No significant changes in computational fluency were noted but the intervention group showed better understanding of mathematical equivalence compared to the control group, suggesting that even minor

modifications to the presentation of math problems can lead to a greater understanding of mathematical concepts.

4. Obersteiner, Reiss and Ufer (2013) tested a modified version of the 'Number Race' game (to emphasise either approximate or exact numerical representations) using a randomised controlled trial. Children 6-7 years old, were randomly allocated into one of four groups; approximate version, exact version, both versions or the control group (using literacy software). Overall, there was a general improvement of basic number processing and arithmetic achievement; as the difficulty, speed and complexity of training increased, reaction times decreased and mean scores of arithmetic achievement increased. However significant improvements were restricted to individual approaches; 'approximate' training version led to improvements in estimating number processing tasks (e.g. magnitude comparison, number comparison and approximate calculation) and 'exact' training led to improvements in exact number processing tasks (e.g. subitizing and conceptual subitizing).

POPULATION

Participants will be children aged 4-11 years' old who attend mainstream primary-level schools. Studies that selected participants on the basis of suspected or diagnosed mathematical difficulties, i.e. mathematics achievement below the 25th percentile or less on standardized mathematical tests, will be excluded.

OUTCOMES

Primary outcomes will be achievement in mathematics from the following assessment methods: targeted mathematics assessment such as curriculum-based outcome measures (e.g. Key Stage assessments); standardised tests (e.g. Wechsler Individual Achievement Test Numerical Operations or Mathematical Reasoning); or cognitive experimental measures of specific mathematics skills, for example, speeded recall of arithmetic facts, flexible strategy use. Secondary outcomes that will be included are psychological measures such as attitudinal measures towards mathematics, mathematical anxiety levels, mathematical self-efficacy, and confidence in mathematics skills or enjoyment of the subject.

STUDY DESIGNS

All studies included in the review will be randomised controlled trials (including cluster randomised controlled trials) that compare a mathematics intervention to a control condition. Suitable control conditions include no intervention, practice-as-usual, waiting list, or active control group. Quasi-randomised, matched, cross-over design, single-subject or correlational designs will be excluded.

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ROLES AND RESPONSIBILITIES

Victoria Simms (Principal investigator) will be responsible for the overall conduct of the review, supervising the work of a full-time post-doctoral researcher. Dr Camilla Gilmore (Co-investigator) is a content expert and will contribute to all aspects of the review. Dr Seaneen Sloan (Co-investigator) will provide guidance on systematic review methods and will contribute to all aspects of the review. The post-doctoral researcher (Miss Clare McKeaveney) has attended training on systematic reviews. In addition, we have an expert advisory group with substantial content and methodological expertise (Dr Nuala Livingstone and Dr Sarah Miller).

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FUNDING

Yes, we have received funding from the Nuffield Foundation.

POTENTIAL CONFLICTS OF INTEREST

No, there are no conflicts of interest.

PRELIMINARY TIMEFRAME

Note, if the protocol or review are not submitted within 6 months and 18 months of title registration, respectively, the review area is opened up for other authors.

- Date you plan to submit a draft protocol: January 2017

- Date you plan to submit a draft review: September 2017

AUTHOR DECLARATION

Authors' responsibilities

By completing this form, you accept responsibility for preparing, maintaining, and updating the review in accordance with Campbell Collaboration policy. The Coordinating Group will provide as much support as possible to assist with the preparation of the review.

A draft protocol must be submitted to the Coordinating Group within one year of title acceptance. If drafts are not submitted before the agreed deadlines, or if we are unable to contact you for an extended period, the Coordinating Group has the right to de-register the title or transfer the title to alternative authors. The Coordinating Group also has the right to de-register or transfer the title if it does not meet the standards of the Coordinating Group and/or the Campbell Collaboration.

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