***Case Study 1: An Evidence-Based Practice Review Report***

***Theme: School Based Interventions for Learning***

# *How effective are computer-based interventions in schools for improving mathematical skills in children with dyscalculia?*

## Summary

This systematic literature review examined computer-based interventions that have been implemented in schools to evaluate how effective they are for improving the mathematical skills of children with dyscalculia and similar specific mathematical learning difficulties.

The review found that there are a number of computer-based interventions that have been shown to be effective for children with dyscalculia and that Educational Psychologists (EPs) can use and support the use of such interventions in school as part of their strategy to help such children improve their mathematical skills. Computer-based tasks and computer-based games designed to improve mathematical skills in children in school were reviewed. Computer games were identified as more effective than computer-based tasks, which may be due to features that make them more engaging and motivating.

## Introduction

Mathematical skills are important for children and adults both in school and in everyday life (Parsons & Bynner, 2005). Some children and young people struggle with developing their mathematical skills and knowledge. There can be many reasons for this, such as limited educational opportunities, learning difficulties or social and communication difficulties. In order to assess and support a child who is

having difficulty learning or attaining in maths, an EP, teacher or other professional needs to investigate the key factors.

Developmental dyscalculia (here called dyscalculia) is the name given to a specific learning difficulty that affects the development of mathematical skills and knowledge. International diagnostic criteria for developmental dyscalculia define it as a domain-specific learning disorder that emerges at an early stage of development and cannot be explained by inappropriate schooling or deficient learning opportunities (Kucian & von Aster, 2015; Soares & Patel, 2015) and it is a neurodevelopmental condition (Szűcs & Goswami, 2013). The estimated prevalence rate of dyscalculia is between 3% and 6% (Kaufmann & von Aster, 2012; Kucian & von Aster, 2015). There is some debate about the utility of the concept of dyscalculia in Educational Psychology as there are concerns about the effect of labelling (or not labelling) a person and the possibility of missing children with mathematical difficulties because they do not meet diagnostic criteria (e.g. Gross, 2007). However, increasing understanding of the needs of people with dyscalculia can inform knowledge and practice. This can help assessment and intervention planning for children and young people identified as having mathematical difficulties that are not the result of comorbid difficulties such as dyslexia or social and communication needs.

Research into mathematical difficulties and interventions has increased in recent years, but is still a relatively young field compared to the fields of reading, writing and language skills. For example, despite having similar serious negative implications to its literacy counterpart, dyslexia (Beddington et al., 2008), dyscalculia has been researched far less (Bishop, 2010; Murphy, Mazzocco, Hanich, & Early, 2007). Reviews have evaluated interventions for mathematics from different perspectives and using different techniques such as meta-analyses, focusing on particular age

ranges and focusing on children with special educational needs or other difficulties such as emotional and behavioural disorders (Chodura, Kuhn, & Holling, 2015; Kroesbergen & Van Luit, 2003; Kunsch, Jitendra, & Sood, 2007; Maccini, Mulcahy, & Wilson, 2007; Myers, Wang, Brownell, & Gagnon, 2015; Templeton, Neel, & Blood, 2008). Other reviews were not peer-reviewed and have had time pass since their writing during which further interventions have been developed (e.g. Dowker, 2009).

The area of computer-based educational tools and interventions is also a growing field. Technology such as computers and tablets and apps and games are a fact of modern life and there are ways that they can be used effectively to learn (Bavelier, Green, & Dye, 2010). Computer-based training has been shown to be effective for areas such as language skills, auditory attention, working memory and reading skills (Loosli, Buschkuehl, Perrig, & Jaeggi, 2012; Stevens, Fanning, Coch, Sanders, & Neville, 2008). The use of computer technology has been shown to be not only effective in education in general, but in particular effective in mathematics, along with being effective for motivating students to engage in learning (Hasselbring, 1986; Li & Ma, 2010). An emerging area of psychological research is the impact of computer games on learning and cognitive processes, with research indicating that computer games of varying forms have a positive effective on cognitive processes and learning (Eichenbaum, Bavelier, & Green, 2014; Green & Bavelier, 2015; Kühn, Gleich, Lorenz, Lindenberger, & Gallinat, 2014), including, for example, helping children with dyslexia (Bavelier, Green, & Seidenberg, 2013).

Our understanding of how to use technology to develop skills can be combined with our psychological and neuroscientific understanding of conditions such as dyscalculia (e.g. there is a core deficit in numerosity processing) to develop effective pedagogical and educational interventions (Butterworth & Laurillard, 2010).

Computer-based methods may be particularly effective for mathematical learning because concepts can be demonstrated through this medium effectively, such as interactive physical motion, they provide the opportunity for lots of practice, can be adapted and can be more motivating (Butterworth & Laurillard, 2010; Kadosh, Dowker, Heine, Kaufmann, & Kucian, 2013). Computer games can motivate children to participate and learn, including in mathematical learning (Bottino, Ferlino, Ott, & Tavella, 2007; Ke, 2008; Papastergiou, 2009), which may help address the anxiety that children with difficulties such as dyscalculia can develop (Rubinsten & Tannock, 2010). Focusing on one area of difficulty, such as dyscalculia, may be advantageous because research has shown that in evaluating the effectiveness of computerised training interventions the factor of comorbidity of other conditions is important for the outcomes (Söderqvist, Nutley, Ottersen, Grill, & Klingberg, 2012).

Understanding computer-based interventions is important for EPs because there are many interventions on offer to schools and professionals at a time when schools have to make decisions about how to spend limited resources. An EP working in a school may want to evaluate whether the resources a school already has would be appropriate for children that they are assessing or may be involved in the process of selecting a new intervention. Evidence such as that found in this review can inform this.

The question that this systematic review of the literature is aimed to address is:

*How effective are computer-based interventions in schools for improving mathematical skills in children with dyscalculia?*

This review evaluates the effectiveness of computer-based interventions that have been implemented in schools and are aimed at improving the mathematical ability

and attainment of children with specific mathematical learning difficulties, i.e. dyscalculia. Only evidence that has been demonstrated to work in a school setting will be evaluated. In addition, this review focuses on interventions that have been implemented with children with dyscalculia or similar specific mathematical difficulties, rather than typically developing children or those with comorbid conditions such as dyslexia or autistic spectrum conditions, in order to identify interventions that are likely to be addressing the mathematical learning needs of the children involved.

## Critical Review of the Evidence Base

### Systematic Literature Search

A systematic search of the literature was conducted. Figure 1 shows the search and exclusion process and Table 1 describes the inclusion and exclusion criteria used to identify the studies for the review. The PsycINFO and the Education Resource Information Center (ERIC) databases were searched using OVID and EBSCOHost in February 2016. Search terms were inputted and combined as shown in Figure 1. As part of the preliminary stage of the exclusion process, database tools were used to limit and filter the search results to peer reviewed journals and English language studies only. The results from the two searches were combined and duplicates removed resulting in 239 articles in total. At stage one of the exclusion process, the articles were screened by title and abstract according to the inclusion and exclusion criteria, resulting in the exclusion of 164 studies. At stage two of the exclusion process the full texts of the remaining 75 studies were examined in accordance with the inclusion and exclusion criteria. Seventy studies were excluded at this stage, with five studies remaining as the focus of this review (see Table 2). Appendix A lists the excluded studies.

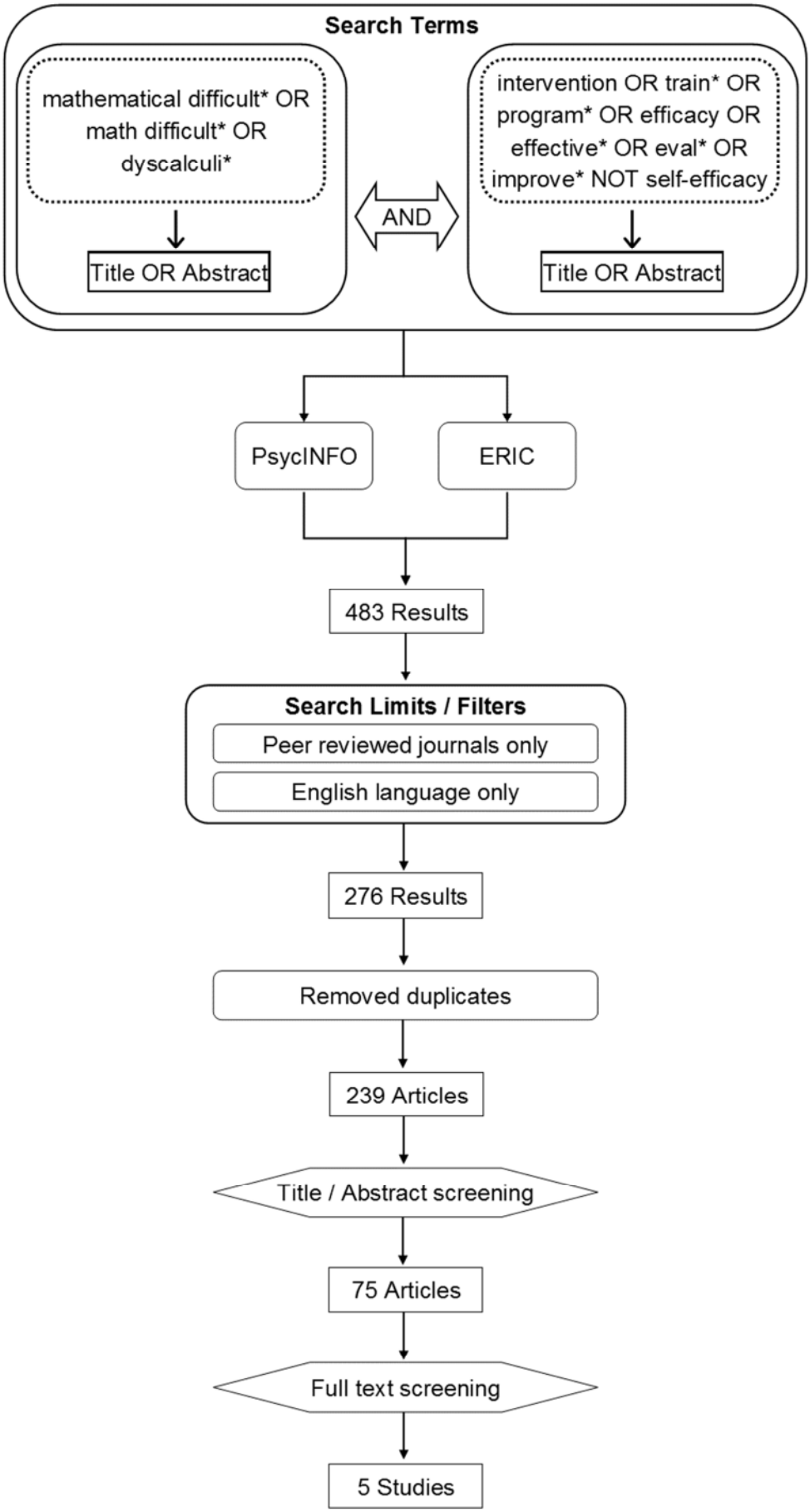


*Figure 1.* Flow diagram of the search and exclusion process

**Table 1**

*Inclusion and exclusion criteria*

| | Study feature | Inclusion criteria | Exclusion criteria | Rationale |
|---|---|---|---|---|
| 1 | Type of publication | Study published in a peer reviewed journal | Study comes from any source that is not a peer-reviewed journal | Research published in peer-reviewed journals has been evaluated by expert reviewers and has met quality standards |
| 2 | Language of study | Entire study report is available in the English language | All or part of the study report is not available in the English language | So that all of the study can be evaluated as translation services are unavailable |
| 3 | Participants / population | a) Study includes children aged between 4 – 16 years as participants | a) All participants are adults or children aged below 4 years or over 16 years, or a combination of these | a) This review is examining interventions for school-aged children |
| | | b) Participants have specific mathematical difficulties in line with dyscalculia and are not identified as having other comorbid difficulties | b) Participants are described as having conditions or difficulties other than or in addition to mathematical difficulties | b) This review is examining interventions for children with dyscalculia |
| 4 | Intervention | The study includes an intervention that:<br>a) is being used with the aim of improving mathematical outcomes | The study does not include an intervention that:<br>a) is being used with the aim of improving mathematical outcomes | This review is examining interventions that:<br>a) are designed to improve mathematical outcomes |

| | Study feature | Inclusion criteria | Exclusion criteria | Rationale |
|---|---|---|---|---|
| | | b) has a computer-based focus | b) has little or no computer-based focus (e.g. tutoring, small group work) | b) are computer-based |
| | | c) is implemented for at least 3 weeks | c) is implemented for less than 3 weeks | c) would be implemented for a moderate amount of time |
| 5 | Outcomes | The study measures a mathematical achievement, attainment or skill outcome as a dependent variable | The study does not measure any mathematical achievement, attainment or skill outcomes as a dependent variable | This review is looking at interventions that affect mathematical skills |
| 6 | Study setting | At least part of the study was conducted in a school | No part of the study was conducted in a school | This review is evaluating interventions that have been shown to be effective in schools |
| 7 | Type of study | The study contains primary empirical data | The study does not contain primary empirical data (e.g. reviews, commentaries) | This review is examining primary evidence, not evidence that has been reviewed by others or is not based on research |

**Table 2**

*The five studies included in this review*

| Full reference of study |
|---|
| Burns, M. K., Kanive, R., & DeGrande, M. (2012). Effect of a computer-delivered math fact intervention as a supplemental intervention for math in third and fourth grades. *Remedial and Special Education*, *33*(3), 184–191. |
| de Castro, M. V., Bissaco, M. A. S., Panccioni, B. M., Rodrigues, S. C. M., & Domingues, A. M. (2014). Effect of a virtual environment on the development of mathematical skills in children with dyscalculia. *PLoS ONE*, *9*(7), 1–16. |
| Leh, J. M., & Jitendra, A. K. (2013). Effects of computer-mediated versus teacher-mediated instruction on the mathematical word problem-solving performance of third-grade students with mathematical difficulties. *Learning Disability Quarterly*, *36*(2), 68–79. |
| Salminen, J., Koponen, T., Räsänen, P., & Aro, M. (2015). Preventive support for kindergarteners most at-risk for mathematics difficulties: Computer-assisted intervention. *Mathematical Thinking and Learning*, *17*(4), 273–295. |
| Wilson, A. J., Revkin, S. K., Cohen, D., Cohen, L., & Dehaene, S. (2006). An open trial assessment of 'The Number Race', an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions*, *2*(20). |

## Mapping the Field

The five studies that were identified through the systematic literature search described computer-based interventions that had been implemented in schools with children who had mathematical difficulties. Table 3 shows the key features of each study.

**Table 3**
*Mapping the field*

| | Country | Age (yrs) | Identification of mathematical difficulties | Intervention name | Intervention description | Comparison condition | Intervention intensity and duration | Outcome measures |
|---|---|---|---|---|---|---|---|---|
| Burns, Kanive & DeGrande (2012) | USA | 8–10 | Low score on assessment | Math Facts in a Flash (Renaissance Learning) | Computer-based mathematical fluency intervention | Children who used the intervention for less than once per week for 8–15 weeks | 5–15 minutes, three times per week for 8–15 weeks | Star Math assessment (Renaissance Learning; a computer-adapted assessment system) |
| de Castro, Bissaco, Panccioni, Rodrigues & Domingues (2014) | Brazil | 7-10 | Met criteria for dyscalculia | Tom's Rescue | Virtual environment incorporating 18 educational computer games | Reinforcement using traditional teaching techniques covering the same skills as the intervention | 60 mins, 2 times per week for 5 weeks | Arithmetic test within the Scholastic Performance Test (SPT), a standardised test used in Brazilian schools |
| Leh & Jitendra (2013) | USA | 8–9 | Low score on standardised school mathematics test | GO Solve Word Problems | Computer-mediated instruction | Teacher-mediated instruction that was similar to the intervention for instructional practice, problem types and | 50 mins, 2-3 times per week for 6 weeks (15 sessions total) | Researcher-developed word problem-solving test and state-level administered school assessment of mathematics |

| | Country | Age (yrs) | Identification of mathematical difficulties | Intervention name | Intervention description | Comparison condition | Intervention intensity and duration | Outcome measures |
|---|---|---|---|---|---|---|---|---|
| | | | | | | practice opportunities. | | |
| Salminen, Koponen, Räsänen & Aro (2015) | Finland | 6–7 | Scored below the tenth percentile for verbal counting | GraphoGame Math; Number Race | Educational computer games | N / a | 10–15 minute sessions, 12-15 occasions in a 3 week period | Cognitive skills measures (corsi block task, nonword repetition task) and early number skills measures (verbal counting, object counting, basic arithmetic) |
| Wilson, Revkin, Cohen, Cohen & Dehaene (2006) | France | 7–9 | Teacher report and WISC-III assessment | The Number Race | Adaptive computer game for remediation of dyscalculia | N / a | 30 minutes, 4 days per week for 4 weeks | Computerised testing battery (enumeration, symbolic and non-symbolic numerical comparison, addition, subtraction) and three subtests from the TEDI-MATH battery (counting, transcoding, base-10 comprehension) |

## Critical Evaluation

The evidence that was identified through the systematic literature review was evaluated and compared with regard to multiple factors using a weight of evidence approach (Gough, 2007).

The studies were assigned ratings that were calculated using sets of criteria that were weighted with regard to their relevance to the review question. Three sets of ratings were generated: weight of evidence A (WoE A), weight of evidence B (WoE B) and weight of evidence C (WoE C). These were combined to create the superordinate evaluation rating of weight of evidence D (WoE D).

WoE A evaluated the methodological quality of the studies. This was judged using published coding protocols for research. Four studies were evaluated using the Gersten et al. (2005) coding protocol because they had group experimental or quasi-experimental designs, and one study was evaluated using the Horner et al. (2005) coding protocol because the research design was single-group. Appendix B specifies how the coding protocol criteria were converted into WoE A ratings and Appendix C contains examples of the two coding protocols used.

WoE B evaluated how appropriate the forms of evidence from the studies were for answering the research question in this review, for example by considering the research design. To evaluate and quantify how well-suited the type of evidence was for this, a typology of evidence criteria was applied (Petticrew & Roberts, 2003; details in Appendix B).

WoE C examined how relevant the focus of the studies were for answering the question of the review (criteria details are in Appendix B). All the weightings ranged

from 1-3. For the purposes of this review, ratings of 1-1.6 are considered “low”, 1.7-2.3 “medium” and ratings of 2.4-3 are considered “high”.

The three weight of evidence ratings were combined with equal weighting to create the superordinate rating of weight of evidence D (WoE D). Table 4 contains these ratings.

**Table 4**

*Weight of evidence ratings for the studies evaluated in this review*

| | WoE A | WoE B | WoE C | WoE D |
|---|---|---|---|---|
| Burns, Kanive & DeGrande (2012) | 1 (low) | 1 (low) | 2.3 (medium) | 1.4 (low) |
| de Castro, Bissaco, Panccioni, Rodrigues & Domingues (2014) | 3 (high) | 2 (medium) | 2.5 (high) | 2.5 (high) |
| Leh & Jitendra (2013) | 3 (high) | 2 (medium) | 2 (medium) | 2.3 (medium) |
| Salminen, Koponen, Räsänen & Aro (2015) | 3 (high) | 2 (medium) | 2.5 (high) | 2.5 (high) |
| Wilson, Revkin, Cohen, Cohen & Dehaene (2006) | 2 (medium) | 2 (medium) | 2.5 (high) | 2.2 (medium) |

*Note* Ratings between 1 – 1.6 are “low”, 1.7 – 2.3 are “medium” and 2.4 – 3 are “high”

**Table 5**

*Overview of research design and comparison groups with reference to the research question of this review*

| Study | | Comparison relevant to this review | | Allocation to groups | Design[1] |
|---|---|---|---|---|---|
| | | Comparison group 1 | Comparison group 2 | | |
| Burns, Kanive & DeGrande (2012) | | Intervention group<br>Used intervention more than once per week | Control group<br>Used intervention less than once per week | Non-random | NR $O_1$ X $O_2$<br>NR $O_1$ $O_2$ |
| de Castro, Bissaco, Panccioni, Rodrigues & Domingues (2014) | | Intervention group<br>Virtual environment | Comparison group<br>Traditional teaching of the same skills | Random | R $O_1$ X $O_2$<br>R $O_1$ Y $O_2$ |
| Leh & Jitendra (2013) | | Intervention group<br>Computer-mediated intervention | Comparison group<br>Teacher-mediated intervention teaching the same skills | Random | R $O_1$ X $O_2$<br>R $O_1$ Y $O_2$ |
| Salminen, Koponen, Räsänen & Aro (2015) | 1 | GraphoGame Math Intervention (pre intervention score) | GraphoGame Math Intervention (post intervention score) | Random | $O_1$ X $O_2$ |
| | 2 | Number Race Intervention (pre intervention score) | Number Race Intervention (post intervention score) | | $O_1$ X $O_2$ |
| Wilson, Revkin, Cohen, Cohen & Dehaene (2006) | | Number Race Intervention (pre intervention score) | Number Race Intervention (post intervention score) | - | $O_1$ X $O_2$ |

[1]Based on research designs as describe by Barker, Pistrang and Elliot (2002)

Effect sizes were calculated for the findings of the five studies that were relevant to the review question (Table 6). For the three studies that used group comparison of means (Burns, Kanive, & DeGrande, 2012; de Castro, Bissaco, Panccioni, Rodrigues, & Domingues, 2014; Leh & Jitendra, 2013), Hedge's *g* was calculated (Hedges, 1981). This is because all of these studies demonstrated that the pre-intervention tests showed similar scores on the dependent variable between intervention and comparison groups. Hedge's *g* was calculated using the following formula:

$$\text{Hedge's } g = \frac{\text{mean}_{\text{post}} - \text{mean}_{\text{pre}}}{\text{SD}_{\text{pooled}}}$$

$$\text{SD}_{\text{pooled}} = \sqrt{\frac{(\text{N}_\text{A} - 1) \times \text{SD}_\text{A}^2 + (\text{N}_\text{B} - 1) \times \text{SD}_\text{B}^2}{\text{N}_\text{A} + \text{N}_\text{B} - 2}}$$

As the Wilson et al. (2006) study used a small, one-group pre-test, post-test design, Becker's standardised mean change was calculated (Becker, 1988) using the following formula:

$$\text{SMD} = \frac{\text{mean}_{\text{post}} - \text{mean}_{\text{pre}}}{\text{SD}_{\text{pre}}}$$

This was calculated where there was sufficient information to do so. For some other effects, the Campbell Collaboration Effect Size Calculator was used to calculate Cohen's d.

Becker's standardised mean change was also calculated for the findings of the Salminen et al. (2015) study because the findings were based on pre- and post-testing of the two small groups.

Cohen's interpretation of effect sizes, where 0.2 is small, 0.5 is medium and 0.8 is large can be used to evaluate the effect sizes (Hedge's *g*, Becker's standardised mean change and Cohen's d) found here (Cohen, 1988).

The effect sizes were calculated with the means ordered so that in Table 6 a positive effect size indicates an improvement due to the intervention and a negative effect size indicates change in the other direction except for in the case of timed tasks, where a reduction in time is associated with improvement and therefore indicated by a negative number.

Table 7 shows the findings, effect size range and WoE D for each of the five studies included in this review.

**Table 6**

*Effect sizes of the intervention effects for maths outcomes in the five studies in this review*

| | Sample size | | Measure | Hedge's *g* | Becker's SMD | Cohen's d | Confidence interval |
|---|---|---|---|---|---|---|---|
| Burns, Kanive & DeGrande (2012) | 442 | | Star Math assessment score (3rd grade children) | 0.36 | | | |
| | | | Star Math assessment score (4th grade children) | 0.49 | | | |
| de Castro, Bissaco, Panccioni, Rodrigues & Domingues (2014) | 26 | | SPT arithmetic test | 1.45 | | | |
| Leh & Jitendra (2013) | 25 | | Word problem solving | -0.36 | | | |
| | | | PSSA math assessment score | -0.35 | | | |
| Salminen, Koponen, Räsänen & Aro (2015) | 17 | GraphoGame Math | Verbal counting | | 1.00 | | |
| | | | Object counting subitizing (seconds) | | -0.61 | | |
| | | | Object counting dot counting (seconds) | | -1.61 | | |
| | | | Basic arithmetic | | 0.17 | | |
| | | Number Race | Verbal counting | | 1.04 | | |

| | Sample size | Measure | Hedge's *g* | Becker's SMD | Cohen's d | Confidence interval |
|---|---|---|---|---|---|---|
| | | Object counting subitizing (seconds) | | -0.48 | | |
| | | Object counting dot counting (seconds) | | -0.27 | | |
| | | Basic arithmetic | | 0.61 | | |
| Wilson, Revkin, Cohen, Cohen & Dehaene (2006) | 9 | Addition accuracy (tie) | | 0.8 | | |
| | | Addition accuracy (small) | | -0.5 | | |
| | | Addition accuracy (large) | | 0.1 | | |
| | | Subtraction reaction time (rule) | | -0.26 | | |
| | | Subtraction reaction time (small) | | 0.45 | | |
| | | Subtraction reaction time (large) | | 0.23 | | |
| | | TEDImath counting | | | 1.49 | 0.02-2.97 |
| | | TEDImath transcoding | | | 1.61 | 0.11-3.12 |

**Table 7**

*Study findings, effect size ranges and evidence weighting*

| Study | Study findings | Effect size range[1] | WoE D[2] |
|---|---|---|---|
| Burns, Kanive & DeGrande (2012) | Intervention group scored significantly higher on post test than comparison group | 0.36 – 0.49 | 1.4 |
| de Castro, Bissaco, Panccioni, Rodrigues & Domingues (2014) | Intervention group scored significantly higher on post test than comparison group | 1.45 | 2.5 |
| Leh & Jitendra (2013) | No significant difference between the post test scores of the experimental and comparison groups | -0.35 – -0.36 | 2.3 |
| Salminen, Koponen, Räsänen & Aro (2015) | Verbal counting and dot counting fluency improved with GraphoGame Math and basic arithmetic improved with Number Race | 0.17 – 1.04 | 2.5 |
| Wilson, Revkin, Cohen, Cohen & Dehaene (2006) | Improvement on a number of tasks testing mathematical skills | 0.1 – 1.61 | 2.2 |

[1] 0.2 = small, 0.5 = medium, 0.8 = large (Cohen, 1988)
[2] For WoE D, 1 - 1.6 = “low”, 1.7 - 2.3 = “medium”, 2.4 - 3 = “high”

**Interventions**

Three of the studies had interventions that consisted of or had many elements that consisted of computer games (de Castro et al., 2014; Salminen et al., 2015; Wilson,

Revkin, et al., 2006), while the other two interventions involved computer-based tasks (Burns et al., 2012; Leh & Jitendra, 2013). The computer-based task interventions involved working through mathematical problems and tasks on a computer while the computer-based game interventions included activities that were designed to be fun, engaging and entertaining with elements of competition, user choice and increased interactivity. The same game, Number Race, appeared in all three of the studies that involved computer games. This suggests that Number Race can be an effective computer game intervention for children with dyscalculia (Wilson, Revkin, et al., 2006; Wilson, Dehaene, et al., 2006) as all three studies found a positive effect of this intervention on mathematical skill of the participants.

Of the two interventions that involved computer-based tasks, one found no effect as compared to having teacher-mediated instruction (Leh & Jitendra, 2013), suggesting that possibly an important factor in the effectiveness and additional value of computer-based interventions as opposed to teacher-mediated interventions may be whether it is motivating and engaging for the child, which is in line with the concept of games being effective at least partly because they are engaging (Eichenbaum et al., 2014).

**Intervention focus**

There was a difference in the skills targeted by the interventions of the studies evaluated here, with the two computer-based task interventions targeting higher order skills such as word problem-solving and mathematical fact knowledge (Burns et al., 2012; Leh & Jitendra, 2013), and the three computer-based game interventions being aimed at more foundational skills such as counting and understanding numerosity (de Castro et al., 2014; Salminen et al., 2015; Wilson,

Revkin, et al., 2006). These factors could interact with the finding of one study that the intervention was not effective as compared to the comparison group (Leh & Jitendra, 2013) and the methodological weakness of the evidence of the other study (Burns et al., 2012) which had a very low WoE A rating. This makes is difficult to assess whether intervention focus was a possible determining factor in effectiveness of the intervention, but this is a possibility that must be considered.

**Sample**

The age range of the participants in the studies reviewed here is limited in that it ranges from 6 to 10 years. This means that the findings are not immediately generalizable to children outside of this age range.

The participants all had some mathematical difficulties, but some studies specified the nature of the participants' difficulties and assessed whether they had other needs in more detail than other studies. For example, de Castro et al. (2014) used dyscalculia criteria, assessment scores, teacher ratings, school records and interviews to identify children that had mathematical learning difficulties and did not have comorbid conditions such as dyslexia or attention deficit hyperactivity disorder (ADHD) or frequent absences. This contributed to the high WoE C rating for this study. In contrast, two studies identified participants only as those who scored below a particular cut-off point in a mathematics assessment (Burns et al., 2012; Leh & Jitendra, 2013). Occupying the middle ground for participants' needs identification are the studies that used some form of dyscalculia-related screening (Wilson, Revkin, et al., 2006) and psychological theory (verbal counting; Salminen et al., 2015) to identify the participants.

The two studies that demonstrated weaker evidence of intervention efficacy were conducted with slightly older children than the other interventions. It could be that computer-based interventions may be better suited to younger children. However, these interventions were also task- rather than game-focused, which brings about further confounding factors such as the possibility that game-focused interventions may be more engaging and motivating than task-focused interventions.

**Setting**

None of the interventions were evaluated in a UK school setting, however all five of the studies implemented the interventions in school settings. Arguably, the findings of the studies conducted in the USA, Finland and France (Burns et al., 2012; de Castro et al., 2014; Salminen et al., 2015; Wilson, Revkin, et al., 2006) are most generalizable to UK school settings due to the similarities between the respective education systems and countries. The UK, USA, Finland and France are all members of the Organisation for Economic Co-operation and Development (OECD), meaning that they have democratic and economic features in common as compared to Brazil, which is not an OECD country.

Four of the studies described intervention implementation in enough detail to ascertain that the interventions took place in the school setting in a way that could be replicable by schools who wish to use the intervention in the future without the requirement of excessive additional resources. Burns et al. (2012) were unable to provide much detail about how the interventions were implemented in schools as the researchers were not able to observe the children and teachers in the school settings, but the study did provide some data about school information and

intervention use time, suggesting that the interventions were implemented in the schools in a typical way.

**Study design**

Table 5 gives an overview of the research designs used in the five studies. Two studies used an experimental design involving a control group and random allocation (de Castro et al., 2014; Leh & Jitendra, 2013). Interestingly, Leh and Jitendra (2013) did not find an effect of their intervention as compared to the comparison group that has been characterised as the control group for the purposes of this review. Of the three studies that specified random allocation of participants to groups, none of them detailed how this was carried out, making it difficult to evaluate how much the research design adhered to an experimental design. In addition, other features were not controlled for that could have impacted the findings of the studies such as adults being aware of intervention conditions and therefore having expectancy effects.

One study in particular has significant issues in its research design. Burns et al. (2012) consistently characterise their research design in terms that suggest it is a quasi-experimental design. However, it could be argued that the research was more correlational in nature because their control group were children that had used the intervention computer program for less than once per week over the intervention period. It seems that they did not allocate the children to groups (intervention and control) but rather assigned group designations to the children that had already either accessed the intervention or had not. This means that there could be a wide range of reasons that the mathematical skills of the children in the control group did

not improve as much as those of the children in the intervention group such as poor school attendance or behavioural problems. This is why this study received a low WoE B rating.

All of the studies used dependent variable measures that are relevant to evaluating whether it seems likely that the intervention will affect mathematical skills outcomes that are of importance to children and educators in schools. Some studies used a wide battery of measures such as Wilson et al. (2006), which is partially explained by the fact that the study was an open trial of a small sample, while other studies limited the dependent variable to school assessment outcomes (e.g. de Castro et al., 2014). Leh and Jitendra (2013) used a researcher-developed measure of word problem-solving ability, which could be considered to be focused on skills too similar to those being targeted by the intervention, however they balanced this with a school-based assessment measure, which supports the methodological rigour and relevance to this review question of the study design.

According to the guidance set out by Cohen (1992), four of the five studies in this review (de Castro et al., 2014; Leh & Jitendra, 2013; Salminen et al., 2015; Wilson et al., 2006) were underpowered to find effects that exist because the sample size was too small. Cohen's (1992) guidance suggests group sizes of at least 26 to identify a large effect, 64 for a medium effect and 393 for a small effect for designs comparing two means at the .05 significance level and with power of 0.8. This means that for the study that found no significant improvement from the intervention (Leh & Jitendra, 2013), we can conclude only that there was not enough power to find an effect that may have been there rather than confidently concluding that there is no effect to be found (Altman & Bland, 1995). The fact that three of these four underpowered studies found significant improvement with two having a small

(Salminen et al., 2015; Wilson et al., 2006) and one having a large (de Castro et al., 2014) effect is surprising given that they were underpowered. Underpowered studies such as these can lead to inconsistent findings across the literature (Maxwell, 2004). One study in the review (Burns et al., 2012) had a large enough sample to have sufficient power to find an effect.

**Overall findings**

Overall, of the computer-based interventions reviewed here, the computer-based games studies provide stronger evidence of effectiveness for the group of children and intervention setting being evaluated in this review. This may be due to methodological differences, in that, for example, the Burns et al. (2012) study had significant methodological weaknesses (resulting in it being the only study with a low WoE D rating) and the other computer-based task intervention (Leh & Jitendra, 2013) found no significant effect of the intervention (however it was likely underpowered). The studies were able to provide evidence regarding interventions that can be implemented in schools and for children with dyscalculia or similar specific mathematical learning difficulties.

## Conclusion and Recommendations

The findings of this review are that there are computer-based interventions that have been designed with the aim of improving mathematical skills in children with dyscalculia and specific mathematical learning difficulties. These interventions have been implemented in school settings using research designs that vary in strength and the findings suggest that some of them are effective in improving the mathematical skills of children with dyscalculia when implemented in schools for a

moderate amount of time. The interventions that had the strongest evidence to support the positive effect that they appear to have were Number Race (de Castro et al., 2014; Salminen et al., 2015; Wilson, Revkin, et al., 2006), GraphoGame Math (Salminen et al., 2015) and the virtual environment, Tom's Rescue, that incorporated multiple games from multiple sources (de Castro et al., 2014). From the evidence evaluated in this review, computer games have a stronger evidence base for being an effective intervention for children with dyscalculia than computer-based interventions that use tasks, but this is because one study found no difference between the intervention and a similar teacher-mediated intervention (Leh & Jitendra, 2013), and the other study found evidence that is weak methodologically making it difficult to draw conclusions from it (Burns et al., 2012).

Recommendations for EPs are that there are effective interventions available for improving mathematical skills of children with dyscalculia and similar specific mathematical learning difficulties. There are a promising number of computer-based game interventions that have been developed, and EPs can advise teachers and parents that may be concerned about the negative reputation of computer games that research shows there are benefits that come from using appropriate computer games.

There was a difference in the age and focus of the interventions that were shown to be more effective with stronger evidence in this review. The interventions that were less effective and had weaker evidence also targeted more advanced skills in a slightly older age range of children than the other interventions. This suggests that it is possible that the types of interventions being evaluated in this review are more well-suited to developing the foundational skills such as counting and a sense of numerosity as targeted by the computer-based game interventions for younger

children. Therefore in evaluating the interventions here, age and intervention skill focus are potential confounding variables that could be delineated in future research.

Some limitations of this review are that only a small subset of computer-based interventions for mathematics were evaluated because there was a focus on evidence of efficacy in children with dyscalculia. It would be worthwhile to conduct a similar review that considers a wider range of computer-based interventions in a more diverse sample of children, such as including typically developing children, to begin to evaluate whether findings from such studies could be applied to the set of children that were the focus of this review.

In addition, this review is only able to generalise to a small subset of ages based on the evidence identified. More research into the efficacy of interventions for different age ranges would be beneficial. For example, the effects of interventions may be different according to age both because the specific learning needs may be different (such as comparing children under 4 years with adolescents) and also because engagement with and motivation to participate in interventions may be different in different aged children, such as children in secondary school as compared to primary school.

As identified in the introduction of this review, more research is needed to understand mathematical difficulties and develop effective interventions, and this is particularly the case for older children such as those at secondary school. Dyscalculia is a neurodevelopmental disorder (Bishop, 2010; Butterworth & Laurillard, 2010); it will not cease to affect a person as they transition through adolescence. Yet it is more important than ever for adolescents to achieve mathematics outcomes, such as with the UK education system requirement that

young people who do not gain a grade C in their GCSE Mathematics assessments being required to continue studying the subject (Department for Education, 2011), meaning that effective interventions for older children and young people are also needed. There is much scope for further research and reviews in the field of interventions for mathematical learning.

## References and Appendices

### References


Altman, D. G., & Bland, J. M. (1995). Statistics notes: Absence of evidence is not evidence of absence. *BMJ*, *311*(7003), 485–485.

Barker, C., Pistrang, N., & Elliott, R. (2002). *Research Methods in Clinical Psychology*. Chichester, UK: John Wiley & Sons, Ltd.

Bavelier, D., Green, C. S., & Dye, M. W. G. (2010). Children, wired: For better and for worse. *Neuron*, *67*(5), 692–701.

Bavelier, D., Green, C. S., & Seidenberg, M. S. (2013). Cognitive development: Gaming your way out of dyslexia? *Current Biology*, *23*(7), R282–R283.

Becker, B. (1988). Synthesizing standardized mean change measures. *British Journal of Mathematical and Statistical Psychology*, *41*, 257–278.

Beddington, J., Cooper, C. L., Field, J., Goswami, U., Huppert, F. A, Jenkins, R., … Thomas, S. M. (2008). The mental wealth of nations. *Nature*, *455*(7216), 1057–1060.

Bishop, D. V. M. (2010). Which neurodevelopmental disorders get researched and why? *PLoS ONE*, *5*(11), e15112.

Bottino, R. M., Ferlino, L., Ott, M., & Tavella, M. (2007). Developing strategic and reasoning abilities with computer games at primary school level. *Computers & Education*, *49*(4), 1272–1286.

Burns, M. K., Kanive, R., & DeGrande, M. (2012). Effect of a computer-delivered math fact intervention as a supplemental intervention for math in third and fourth grades. *Remedial and Special Education*, *33*(3), 184–191.

Butterworth, B., & Laurillard, D. (2010). Low numeracy and dyscalculia: Identification and intervention. *ZDM Mathematics and Education*, *42*(6), 527–539.

Campbellcollaboration.org. (2016). *Effect Size Calculator: The Campbell Collaboration - Framed Page*. Retrieved 21 February 2016, from http://www.campbellcollaboration.org/resources/effect_size_input.php

Chodura, S., Kuhn, J.-T., & Holling, H. (2015). Interventions for Children With Mathematical Difficulties. *Zeitschrift Für Psychologie*, *223*(2), 129–144.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* (2nd ed.). New York: Academic Press.

Cohen, J. (1992). A Power Primer. *Psychological Bulletin*, *112*(1), 155–159.

de Castro, M. V., Bissaco, M. A. S., Panccioni, B. M., Rodrigues, S. C. M., & Domingues, A. M. (2014). Effect of a virtual environment on the development of mathematical skills in children with dyscalculia. *PLoS ONE*, *9*(7), 1–16.

Department for Education. (2011). Wolf Review of Vocational Education: Government Response. London.

Dowker, A. (2009). *What works for children with mathematical difficulties?* Department for Children, Schools and Families.

Eichenbaum, A., Bavelier, D., & Green, C. (2014). Play That can do serious good. *American Journal of Play*, *7*(1), 50–72.

Gersten, R., Fuchs, L. S., Compton, D., Coyne, M., Greenwood, C., & Innocenti, M. S. (2005). Quality indicators for group experimental and quasi-experimental research in special education. *Exceptional Children*, *71*(2), 149–164.

Gough, D. (2007). Weight of Evidence: A framework for the appraisal of the quality and relevance of evidence. *Research Papers in Education*, *22*(2), 213–228.

Green, C. S., & Bavelier, D. (2015). Action video game training for cognitive enhancement. *Current Opinion in Behavioral Sciences*, *4*, 103–108.

Gross, J. (2007). Supporting children with gaps in their mathematical understanding: The impact of the National Numeracy Strategy (NNS) on children who find mathematics difficult. *Educational and Child Psychology*, *24*(2), 146–156.

Hasselbring, T. S. (1986). Research on the effectiveness of computer-based instruction: A review. *International Review of Education*, *32*(3), 313–324.

Hedges, L. V. (1981). Distribution theory for glass's estimator of effect size and related estimators. *Journal of Educational and Behavioral Statistics*, *6*(2), 107–128.

Horner, R. H., Carr, E. G., Halle, J., McGee, G., Odom, S., & Wolery, M. (2005). The use of single-subject research to identify evidence-based practice in special education. *Exceptional Children*, *71*(2), 165–179.

Kadosh, R. C., Dowker, A., Heine, A., Kaufmann, L., & Kucian, K. (2013). Interventions for improving numerical abilities: Present and future. *Trends in Neuroscience and Education*, *2*(2), 85–93.

Kaufmann, L., & von Aster, M. (2012). The diagnosis and management of dyscalculia. *Deutsches Arzteblatt International*. *109*(45), 767-778.

Ke, F. (2008). Computer games application within alternative classroom goal structures: cognitive, metacognitive, and affective evaluation. *Educational Technology Research and Development*, *56*(5-6), 539–556.

Kroesbergen, E. H., & Van Luit, J. E. H. (2003). Mathematics interventions for children with special educational needs: A meta-analysis. *Remedial and Special Education*, *24*(2), 97–114.

Kucian, K., & von Aster, M. (2015). Developmental dyscalculia. *European Journal of Pediatrics*, *174*(1), 1–13.

Kühn, S., Gleich, T., Lorenz, R. C., Lindenberger, U., & Gallinat, J. (2014). Playing Super Mario induces structural brain plasticity: Gray matter changes resulting from training with a commercial video game. *Molecular Psychiatry*, *19*(2), 265–271.

Kunsch, C. A., Jitendra, A. K., & Sood, S. (2007). The effects of peer-mediated instruction in mathematics for students with learning problems: A research synthesis. *Learning Disabilities Research & Practice*, *22*(1), 1–12.

Leh, J. M., & Jitendra, A. K. (2013). Effects of computer-mediated versus teacher-mediated instruction on the mathematical word problem-solving performance of third-grade students with mathematical difficulties. *Learning Disability Quarterly*, *36*(2), 68–79.

Li, Q., & Ma, X. (2010). A meta-analysis of the effects of computer technology on school students' mathematics learning. *Educational Psychology Review*, *22*(3), 215–243.

Loosli, S. V, Buschkuehl, M., Perrig, W. J., & Jaeggi, S. M. (2012). Working memory

training improves reading processes in typically developing children. *Child Neuropsychology*, *18*(1), 62–78.

Maccini, P., Mulcahy, C. A., & Wilson, M. G. (2007). A follow-up of mathematics interventions for secondary students with learning disabilities. *Learning Disabilities Research & Practice*, *22*(1), 58–74.

Maxwell, S. E. (2004). The persistence of underpowered studies in psychological research: Causes, consequences, and remedies. *Psychological Methods*, *9*(2), 147–163.

Murphy, M. M., Mazzocco, M. M. M., Hanich, L. B., & Early, M. C. (2007). Cognitive characteristics of children with mathematics learning disability (MLD) vary as a function of the cutoff crierion used to define MLD. *Journal of Learning Disabilities*, *40*(5), 458–478.

Myers, J. A., Wang, J., Brownell, M. T., & Gagnon, C. J. (2015). Mathematics interventions for students with learning disabilities (LD) in secondary school: A review of the literature. *Learning Disabilities: A Contemporary Journal*, *13*(2), 207–235.

Papastergiou, M. (2009). Digital game-based learning in high school computer science education: Impact on educational effectiveness and student motivation. *Computers & Education*, *52*(1), 1–12.

Parsons, S., & Bynner, J. (2005). Does numeracy matter more? *National Research and Development Centre for Adult Literacy and Numeracy*. London: Institute of Education.

Petticrew, M., & Roberts, H. (2003). Evidence, hierarchies, and typologies: Horses for courses. *Journal of Epidemiology and Community Health*, *57*(7), 527–529.

Rubinsten, O., & Tannock, R. (2010). Mathematics anxiety in children with developmental dyscalculia. *Behavioral and Brain Functions*, *6*(1), 46.

Salminen, J., Koponen, T., Räsänen, P., & Aro, M. (2015). Preventive support for kindergarteners most at-risk for mathematics difficulties: Computer-assisted intervention. *Mathematical Thinking and Learning*, *17*(4), 273–295.

Soares, N., & Patel, D. R. (2015). Dyscalculia. *International Journal of Child and*

*Adolescent Health*, *8*(1), 15–26.

Söderqvist, S., Nutley, S. B., Ottersen, J., Grill, K. M., & Klingberg, T. (2012). Computerized training of non-verbal reasoning and working memory in children with intellectual disability. *Frontiers in Human Neuroscience*, *6*(October), 1–8.

Stevens, C., Fanning, J., Coch, D., Sanders, L., & Neville, H. (2008). Neural mechanisms of selective auditory attention are enhanced by computerized training: Electrophysiological evidence from language-impaired and typically developing children. *Brain Research*, *1205*, 55–69.

Szűcs, D., & Goswami, U. (2013). Developmental dyscalculia: Fresh perspectives. *Trends in Neuroscience and Education*, *2*(2), 33–37.

Templeton, T. N., Neel, R. S., & Blood, E. (2008). Meta-analysis of math interventions for students with emotional and behavioral disorders. *Journal of Emotional and Behavioral Disorders*, *16*(4), 226–239.

Wilson, A. J., Dehaene, S., Pinel, P., Revkin, S. K., Cohen, L., & Cohen, D. (2006). Principles underlying the design of 'The Number Race', an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions*, *2*(19).

Wilson, A. J., Revkin, S. K., Cohen, D., Cohen, L., & Dehaene, S. (2006). An open trial assessment of 'The Number Race', an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions*, *2*(20).

## Appendix A

**Table A1**

*Articles excluded at full text screening stage (stage 2) with criteria reasons*

| Article | Exclusion criteria number(s)[a] |
|---|---|
| Al-Makahleh, A. A. (2011). The Effect of direct instruction strategy on math achievement of primary 4th and 5th grade students with learning difficulties. *International Education Studies*, 4(4), 199-205. | 4 |
| Anca, M., & Hategan, C. (2009). Psycho-pedagogical interventions in the prevention and the therapy of learning difficulties in the field of mathematics. *Acta Didactica Napocensia*, 2(3), 101-106. | 7 |
| Arroyo, I., Royer, J. M., & Woolf, B. P. (2011). Using an intelligent tutor and math fluency training to improve math performance. *International Journal Of Artificial Intelligence In Education*, 21(1-2), 135-152. | 3 |
| Attridge, N., & Inglis, M. (2015). Increasing cognitive inhibition with a difficult prior task: Implications for mathematical thinking. *ZDM: The International Journal On Mathematics Education*, 47(5), 723-734. | 3 |
| Avant, M. T., & Heller, K. W. (2011). Examining the effectiveness of touchmath with students with physical disabilities. *Remedial And Special Education*, 32(4), 309-321. | 3 |
| Barak, M., & Asad, K. (2012). Teaching image-processing concepts in junior high school: boys' and girls' achievements and attitudes towards technology. *Research In Science & Technological Education*, 30(1), 81-105. | 4, 5 |
| Barrett, D. C., & Fish, W. W. (2011). Our move: Using chess to improve math achievement for students who receive special education services. *International Journal Of Special Education*, 26(3), 181-193. | 4 |
| Becker, A., McLaughlin, T., Weber, K. P., & Gower, J. (2009). The effects of copy, cover, and compare with and without additional error drill on multiplication fact fluency and accuracy. *Electronic Journal Of Research In Educational Psychology*, 7(2), 747-760. | 3 |
| Beygi, A., Padakannaya, P. & Gowramma, I. P. (2009). A remedial teaching programme for children with mathematical disability. *Journal of Psychosocial Research*, 4(1), 189-202. | * |
| Beygi, A., Padakannaya, P. & Gowramma, I. P. (2010). A remedial intervention for addition and subtraction in children with dyscalculia. *Journal of the Indian Academy of Applied Psychology*, 36(1), 9-17. | 3 |
| Bolt, S. E. & Thurlow, M. L. (2007). Item-level effects of the read-aloud accommodation for students with reading disabilities. *Assessment for Effective Intervention*, 33, 15-28. | 4, 7 |

| | |
|---|---|
| Bottge, B. A., & Cho, S. (2013). Effects of enhanced anchored instruction on skills aligned to common core math standards. *Learning Disabilities: A Multidisciplinary Journal*, 19(2), 73-83. | 3, 4 |
| Burns, M. K. (2002). Comprehensive system of assessment to intervention using curriculum-based assessments. *Intervention In School And Clinic*, 38(1), 8-13. | 3, 4 |
| Burns, M. K. (2011). Matching math interventions to students' skill deficits: A preliminary investigation of a conceptual and procedural heuristic. *Assessment for Effective Intervention*, 36, 210-218. | 3 |
| Cohen, S. A., & Stover, G. (1981). Effects of teaching sixth-grade students to modify format variables of math word problems. *Reading Research Quarterly*, 16(2), 175-200. | 3 |
| Cooper, E. E., Ness, M. & Smith, M. (2004). A case study of a child with dyslexia and spatial-temporal gifts. *Gifted Child Quarterly*, 48, 83-94. | 4, 7 |
| Cotic, M., & Zuljan, M. V. (2009). Problem-based instruction in mathematics and its impact on the cognitive results of the students and on affective-motivational aspects. *Educational Studies*, 35(3), 297-310. | 3 |
| Doabler, C. T., & Fien, H. (2013). Explicit mathematics instruction: What teachers can do for teaching students with mathematics difficulties. *Intervention In School And Clinic*, 48(5), 276-285. | 7 |
| Doabler, C. T., Fien, H., Nelson-Walker, N. J., & Baker, S. K. (2012). Evaluating three elementary mathematics programs for presence of eight research-based instructional design principles. *Learning Disability Quarterly*, 35(4), 200-211. | 3, 4, 7 |
| Dobbins, A., Gagnon, J. C., & Ulrich, T. (2014). Teaching geometry to students with math difficulties using graduated and peer-mediated instruction in a response-to-intervention model. *Preventing School Failure*, 58(1), 17-25. | 7 |
| Fischer, B., Kongeter, A. & Hartnegg, K. (2008). Effects of daily practice on subitizing, visual counting, and basic arithmetic skills. *Optometry and Vision Development*, 39(1), 30-34. | 4, 6 |
| Fuchs, L. S., Seethaler, P. M., Powell, S. R., Hamlett, C. L., & Fletcher, J. M. (2008). Effects of preventative tutoring on the mathematical problem solving of third-grade students with math and reading difficulties. *Exceptional Children*, 74(2), 155-173. | 3 |
| Fuchs, L. S., Compton, D. L., Fuchs, D., Paulsen, K., Bryant, J. D. & Hamlett, C. L. (2005). The prevention, identification, and cognitive determinants of math difficulty. *Journal of Educational Psychology*, 97, 493-513. | 4 |
| Fuchs, L. S., Fuchs, D., Craddock, C., Hollenbeck, K. N., Hamlett, C. L. & Schatschneider, C. (2008). Effects of small-group tutoring with and without validated classroom instruction on at-risk students' math problem solving: Are two tiers of prevention better than one? *Journal of Educational Psychology*, 100, 491-509. | 4 |

| | |
|---|---|
| Fuchs, L. S., Powell, S. R., Seethaler, P. M., Cirino, P. T., Fletcher, J. M., Fuchs, D., et al. (2009). Remediating number combination and word problem deficits among students with mathematics difficulties: A randomized control trial. *Journal of Educational Psychology*, 101, 561-576. | 3 |
| Galloway, J., & Sheridan, S. M. (1994). Implementing scientific practices through case studies: Examples using home-school interventions and consultation. *Journal Of School Psychology*, 32(4), 385-413. | 3 |
| Gross, J. (2007). Supporting children with gaps in their mathematical understanding: The impact of the National Numeracy Strategy (NNS) on children who find mathematics difficult. *Educational and Child Psychology*, 24(2), 146-156. | 7 |
| Hopkins, S., & Egeberg, H. (2009). Retrieval of simple addition facts: Complexities involved in addressing a commonly identified mathematical learning difficulty. *Journal Of Learning Disabilities*, 42(3), 215-229. | 3 |
| Jolivette, K., Lingo, A. S., Houchins, D. E., Barton-Arwood, S. M., & Shippen, M. E. (2006). Building math fluency for students with developmental disabilities and attentional difficulties using "Great Leaps Math". *Education And Training In Developmental Disabilities*, 41(4), 392-400. | 3 |
| Käser, T., Busetto, A. G., Solenthaler, B., Baschera, G., Kohn, J., Kucian, K., & ... Gross, M. (2013). Modelling and optimizing mathematics learning in children. *International Journal Of Artificial Intelligence In Education*, 23(1-4), 115-135. | 6 |
| Kaser, T., Baschera, G-M., Kohn, J., Kucian, K., Richtmann, V., Grond, U., et al. (2013). Design and evaluation of the computer-based training program Calcularis for enhancing numerical cognition. *Frontiers in Psychology*, 4, | 3 |
| Kaufmann, L., Handl, P. & Thony, B. (2003). Evaluation of a numeracy intervention program focusing on basic numerical knowledge and conceptual knowledge: A pilot study. *Journal of Learning Disabilities*, 36, 564-573. | 4 |
| Kesler, S. R., Sheau, K., Koovakkattu, D. & Reiss, A. L. (2011). Changes in frontal-parietal activation and math skills performance following adaptive number sense training: Preliminary results from a pilot study. *Neuropsychological Rehabilitation*, 21, 433-454. | 3 |
| Kirby, K. C., & And, O. (1991). Reactivity in self-recording: Obtrusiveness of recording procedure and peer comments. *Journal Of Applied Behavior Analysis*, 24(3), 487-98. | 3, 4 |
| Krisztian, A., Bernath, L., Gombos, H. & Vereczkei, L. (2015). Developing numerical ability in children with mathematical difficulties using origami. *Perceptual and Motor Skills*, 121, 233-243. | 4 |
| Kucian, K., Grond, U., Rotzer, S., Henzi, B., Schonmann, C., Plangger, F., et al. (2011). Mental number line training in children with developmental dyscalculia. *NeuroImage*, 57, 782-795. | 6 |
| Lee, H. (1980). The effects of review questions and review passages on transfer skills. *Journal Of Educational Research*, 73(6), 330-35. | 3, 4 |

| | |
|---|---|
| Luo, W., Paris, S. G., Hogan, D., & Luo, Z. (2011). Do performance goals promote learning? A pattern analysis of singapore students' achievement goals. *Contemporary Educational Psychology*, 36(2), 165-176. | 4 |
| Montague, M., Warger, C., & Morgan, T. H. (2000). Solve It! Strategy instruction to improve mathematical problem solving. *Learning Disabilities Research & Practice*, 15(2), 110-16. | 7 |
| Moscardini, L. (2010). "I like it instead of maths": How pupils with moderate learning difficulties in scottish primary special schools intuitively solved mathematical word problems. *British Journal Of Special Education*, 37(3), 130-138. | 3 |
| Nelson, P. M., Burns, M. K., Kanive, R. & Ysseldyke, J. E. (2013). Comparison of a math fact rehearsal and a mnemonic strategy approach for improving math fact fluency. *Journal of School Psychology*, 51, 659-667. | 4 |
| Orosco, M. J. (2014). Word problem strategy for latino english language learners at risk for math disabilities. *Learning Disability Quarterly*, 37(1), 45-53. | 3 |
| Parsons, S., Law, J., & Gascoigne, M. (2005). Teaching receptive vocabulary to children with specific language impairment: a curriculum-based approach. *Child Language Teaching And Therapy*, 21(1), 39-59. | 4 |
| Petrovici, C., & Havârneanu, G. (2015). An educational program of mathematical creativity. *Acta Didactica Napocensia*, 8(1), 13-18. | 5 |
| Pool, J. L., Carter, G. M., Johnson, E. S., & Carter, D. R. (2013). The use and effectiveness of a targeted math intervention for third graders. *Intervention In School And Clinic*, 48(4), 210-217. | 3, 4 |
| Powell, S. R., Fuchs, L. S., Fuchs, D., Cirino, P. T. & Fletcher, J. M. (2009). Effects of fact retrieval tutoring on third-grade students with math difficulties with and without reading difficulties. *Learning Disabilities Research & Practice*, 24, 1-11. | 4 |
| Re, A. M., Pedron, M., Tressoldi, P. E., & Lucangeli, D. (2014). Response to specific training for students with different levels of mathematical difficulties. *Exceptional Children*, 80(3), 337-352. | 6 |
| Santi, G., & Baccaglini-Frank, A. (2015). Forms of generalization in students experiencing mathematical learning difficulties. *Pna*, 9(3), 217-243. | 3 |
| Schunk, D. H., & And, O. (1987). Peer-model attributes and children's achievement behaviors. *Journal Of Educational Psychology*, 79(1), 54-61. | 4 |
| Sedig, K. (2008). From play to thoughtful learning: A design strategy to engage children with mathematical representations. *Journal Of Computers In Mathematics And Science Teaching*, 27(1), 65-101. | 3 |
| Sharma, G. (1995). Development of an educational remedial programme for specific learning disabilities in Telugu language. *Psycho-Lingua*, 25(1-2), 115-119. | * |

| | |
|---|---|
| Sharma, G. (1995). Educational remediation for children with learning disabilities. *Journal of Indian Psychology*, 13(1), 40-46. | * |
| Slade, P. D. & Russell, G. F. (1971). Developmental dyscalculia: A brief report on four cases. *Psychological Medicine*, 1, 292-298. | 6 |
| Sood, S., & Jitendra, A. K. (2013). An exploratory study of a number sense program to develop kindergarten students' number proficiency. *Journal Of Learning Disabilities*, 46(4), 328-346. | 4 |
| Stroizer, S., Hinton, V., Flores, M. & Terry, L. (2015). An investigation of the effects of CRA instruction and students with Autism Spectrum Disorder. *Education and Training in Autism and Developmental Disabilities*, 50(2), 225-236. | 4 |
| Sullivan, K. S., Macaruso, P. & Sokol, S. M. (1996). Remediation of Arabic numeral processing in a case of developmental dyscalculia. *Neuropsychological Rehabilitation*, 6, 27-53. | 6 |
| Swanson, H. L., Lussier, C. M., & Orosco, M. J. (2015). Cognitive strategies, working memory, and growth in word problem solving in children with math difficulties. *Journal Of Learning Disabilities*, 48(4), 339-358. | 4 |
| Swanson, H. L., Lussier, C., & Orosco, M. (2013). Effects of cognitive strategy interventions and cognitive moderators on word problem solving in children at risk for problem solving difficulties. *Learning Disabilities Research & Practice*, 28(4), 170-183. | 4 |
| Swanson, H. L., Orosco, M. J., & Lussier, C. M. (2014). The effects of mathematics strategy instruction for children with serious problem-solving difficulties. *Exceptional Children*, 80(2), 149-168. | 4 |
| Swanson, H. L., Moran, A. S., Bocian, K., Lussier, C. & Zheng, X. (2013). Generative strategies, working memory, and word problem solving accuracy in children at risk for math disabilities. *Learning Disability Quarterly*, 36, 203-214. | 4 |
| Swanson, H. L., Moran, A., Lussier, C. & Fung, W. (2014). The effect of explicit and direct generative strategy training and working memory on word problem-solving accuracy in children at risk for math difficulties. *Learning Disability Quarterly*, 37, 111-122. | 4 |
| Swanson, H. L. (2014). Does cognitive strategy training on word problems compensate for working memory capacity in children with math difficulties? *Journal of Educational Psychology*, 106, 831-848. | 4 |
| Vitale, J. M., Black, J. B., & Swart, M. I. (2014). Applying grounded coordination challenges to concrete learning materials: a study of number line estimation. *Journal Of Educational Psychology*, 106(2), 403-418. | 3 |
| Waugh, M., & Harrison, G. L. (2014). WWW.com: A brief intervention to bolster a 5th grader's regrouping skills in math. *Exceptionality Education International*, 24(2), 1-16. | * |
| Williams, L. K., Mendiburo, M., Hasselbring, T., & Society for Research on Educational Effectiveness. (2013). Half of one, 6/12 of another: Understanding relative item difficulties in a fractions assessment under development. *Society For Research On Educational Effectiveness*. | 7 |

| | |
|---|---|
| Wilson, A. J., Dehaene, S., Pinel, P., Revkin, S. K., Cohen L. & Cohen, D. (2006). Principles underlying the design of "The Number Race", an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions*, 2 | 4 |
| Wu, Z., An, S., King, J., Ramirez, M., & Evans, S. (2009). Second-grade "professors". *Teaching Children Mathematics*, 16(1), 34-41. | 7 |
| Xin, Y. P., Si, L., Hord, C., Zhang, D., Cetinas, S., & Park, J. Y. (2012). Conceptual model-based problem solving that facilitates algebra readiness: An exploratory study with computer-assisted instruction. *Learning Disabilities: A Multidisciplinary Journal*, 18(2), 71-85. | 3 |
| Zhang, D., Xin, Y. P. & Si, L. (2013). Transition from intuitive to advanced strategies in multiplicative reasoning for students with math difficulties. *The Journal of Special Education*, 47(1), 50-64. | 4 |
| Zhang, D., Xin, Y. P., Harris, K. & Ding, Y. (2014). Improving multiplication strategic development in children with math difficulties. *Learning Disability Quarterly*, 37, 15-30. | 4 |

[a] *indicates that the report was inaccessible

**Table A2**

*Articles excluded at title / abstract screening stage (stage 1) with criteria reason*

| Article | Exclusion criteria number(s) |
|---|---|
| Abedalaziz, N., & Leng, C. H. (2013). The relationship between ctt and irt approaches in analyzing item characteristics. *Malaysian Online Journal Of Educational Sciences*, 1(1), 64-70. | 4, 5 |
| Adams, John W. (2007). Individual differences in mathematical ability: Genetic, cognitive and behavioural factors. *Journal of Research in Special Educational Needs*, 7, 97-103. | 7 |
| Al-Hroub, A. (2009). Charting self-concept, beliefs and attitudes towards mathematics among mathematically gifted pupils with learning difficulties. *Gifted And Talented International*, 23(2-241), 93-106. | 4 |
| Anobile, G., Cicchini, G. M. & Burr, D. C. (2012). Linear mapping of numbers onto space requires attention. *Cognition*, 122, 454-459. | 3, 4, 5 |
| Ardary, D. A. (2007). Increasing school nurse awareness of turner syndrome. *Journal Of School Nursing*, 23(1), 28-33. | 4, 5 |
| Ashkenazi, S. & Henik, A. (2012). Does attentional training improve numerical processing in developmental dyscalculia? *Neuropsychology*, 26, 45-56. | 3, 6 |

| | |
|---|---|
| Auerbach, J. G., Gross-Tsur, V., Manor, O., & Shalev, R. S. (2008). Emotional and behavioral characteristics over a six-year period in youths with persistent and nonpersistent dyscalculia. *Journal Of Learning Disabilities*, 41(3), 263-273. | 4, 5, 6 |
| Basso, A.& Beschin, N. (2000). Number transcoding and number word spelling in a left-brain-damaged non-aphasic acalculic patient. *Neurocase*, 6, 129-139. | 3, 4, 5, 6 |
| Bateman, D. F. (2008). Due process hearing case study. *Teaching Exceptional Children*, 40(6), 60-62. | 4, 5, 7 |
| Benedetto, E. & Sacerdote, L. (2013). On dependency properties of the ISIs generated by a two-compartmental neuronal model. *Biological Cybernetics*, 107, 95-106. | 3, 4, 5, 6 |
| Berry, J., Graham, T., & Smith, A. (2005). Classifying students' graphics calculator strategies. *International Journal For Technology In Mathematics Education*, 12(1), 15-32. | 3, 4, 5, 6 |
| Boets, B., De Smedt, B. & Ghesquiere, P. (2011). Coherent motion sensitivity predicts individual differences in subtraction. *Research in Developmental Disabilities*, 32, 1075-1080. | 4 |
| Booth, J. L., Barbieri, C., Eyer, F., & Paré-Blagoev, E. J. (2014). Persistent and pernicious errors in algebraic problem solving. *Journal Of Problem Solving*, 7(1), | 4 |
| Bosma, T. & Resing, W. C. M. (2010). Teacher's appraisal of dynamic assessment outcomes: Recommendations for weak mathematics-performers. *Journal of Cognitive Education and Psychology*, 9, 91-115. | 5 |
| Bowers, L. (2006). On conflict, containment and the relationship between them. *Nursing Inquiry*, 13, 172-180. | 3, 4, 5, 6, 7 |
| Boyd, D., Grossman, P., Hammerness, K., Lankford, H., Loeb, S., Ronfeldt, M., & Wyckoff, J. (2012). Recruiting effective math teachers: Evidence from New York City. *American Educational Research Journal*, 49(6), 1008-1047. | 3, 4, 5, 6, 7 |
| Braga, L. W., Souza, Ligia N., Najjar, Y. J. & Dellatolas, G. (2007). Magnetic resonance imaging (MRI) findings and neuropsychological sequelae in children after severe traumatic brain injury: The role of cerebellar lesion. *Journal of Child Neurology*, 22, 1084-1089. | 4, 5, 6 |
| Branum-Martin, L., Fletcher, J. M. & Stuebing, K. K. (2013). Classification and identification of reading and math disabilities: The special case of comorbidity. *Journal of Learning Disabilities*, 46(6), 490-499. | 3, 4, 5, 6 |
| Busch, J., Schmidt, C. & Grube, D. (2015). Arithmetic fact retrieval: Are there differences between children with developmental dyscalculia and those with mathematical difficulties? *Zeitschrift fur Psychologie*, 223, 110-119. | 4 |
| Butterworth, B., Varm, S. & Laurillard, D. (2011). Dyscalculia: From brain to education. *Science*, 332, 1049-1053. | 7 |
| Butterworth, B. (2005). The development of arithmetical abilities. *Journal of Child Psychology and Psychiatry,* 46, 3-18. | 4, 5 |
| Butterworth, B. (2010). Foundational numerical capacities and the origins of dyscalculia. *Trends in Cognitive Sciences*, 14, 534-541. | 3, 4, 5, 6, 7 |

| | |
|---|---|
| Calia, G. (2013). "The diagnosis and management of dyscalculia": Comment. *Deutsches Arzteblatt International*, 110(9), 146. | 3, 4, 5, 6, 7 |
| Canavese, C., Rigardetto, R., Viano, V., Vittorini, R., Bassi, B., Pieri, I., et al. (2007). Are dyslexia and dyscalculia associated with Rolandic epilepsy? A short report on ten Italian patients. *Epileptic Disorders*, 9(4), 432-436. | 4, 5, 6 |
| Canizares, D. C., Crespo, V. R. & Alemany, E. G. (2012). Symbolic and non-symbolic number magnitude processing in children with developmental dyscalculia. *The Spanish Journal of Psychology*, 15, 952-966. | 4, 6 |
| Carlton, K., Nicholls, M., & Ponsonby, D. (2004). Using spreadsheets to teach aspects of biology involving mathematical models. *Journal Of Biological Education*, 38(4), 183-186. | 3, 4, 5, 6 |
| Carmen, D., Dobrean, A. & Van Luit, J. E. H. (2015). Psychometric properties of Early Numeracy Test in Romanian language preliminary data. *Erdelyi Pszichologiai Szemle*, 16(1), 57-69. | 4, 5 |
| Causier, H. (2008). Review of The dyscalculia toolkit: Supporting learning difficulties in maths. *Support for Learning,* 23, 214. | 7 |
| Chen, P., & Zimmerman, B. (2007). A cross-national comparison study on the accuracy of self-efficacy beliefs of middle-school mathematics students. *Journal Of Experimental Education*, 75(3), 221-244. | 4, 5 |
| Chodura, S., Kuhn, J. & Holling, H. (2015). Interventions for children with mathematical difficulties: A meta-analysis. *Zeitschrift fur Psychologie*, 223, 129-144. | 7 |
| Cirino, P. T. & Berch, D. B. (2010). Introduction: Perspectives on math difficulty and disability in children. *Learning and Individual Differences*, 20, 61-62. | 3, 4, 4, 5, 6 |
| Cirino, P. T., Fletcher, J. M., Ewing-Cobbs, L., Barnes, M. A. & Fuchs, L. S. (2007). Cognitive arithmetic differences in learning difficulty groups and the role of behavioral inattention. *Learning Disabilities Research & Practice*, 22, 25-35. | 4, 6 |
| Clark, M., McConnell, S., Constantine, J., Chiang, H., & National Center for Education Evaluation and Regional Assistance, (. (2013). Addressing teacher shortages in disadvantaged schools: Lessons from two institute of education sciences studies. NCEE Evaluation Brief. NCEE 2013-4018. National Center For Education Evaluation And Regional Assistance, | 3, 4, 5, 6 |
| Connor, J., Moss, L., & Grover, B. (2007). Student evaluation of mathematical statements using dynamic geometry software. *International Journal Of Mathematical Education In Science & Technology*, 38(1), 55-63. | 3, 4, 5, 6 |
| Cooper, S. A., Joshi, A. C. Seenan, P. J., Hadley, D. M, Muir, K. W., Leigh, R. J., et al. (2012). Akinetopsia: Acute presentation and evidence for persisting defects in motion vision. *Journal of Neurology, Neurosurgery & Psychiatry*, 83, 229-230. | 3, 4, 5, 6, 7 |
| Corlu, M. A., & Corlu, M. S. (2012). Scientific inquiry based professional development models in teacher education. *Educational Sciences: Theory And Practice*, 12(1), 514-521. | 3, 4, 5, 6 |

| | |
|---|---|
| Daniel, David. B., Fischer, K., Williams, K. & LaGattuta, D. (2013). Award: Transforming education through neuroscience. *Mind, Brain, and Education*, 7, 151. | 3, 4, 5, 6, 7 |
| Das, J. P & Janzen, Chris. (2004). Learning Math: Basic concepts, math difficulties, and suggestions for intervention. *Developmental Disabilities Bulletin*, 32(2), 191-205. | 7 |
| Davis, H., Bryson, S. & Hoy, C. (1992). Case study of language and numerical disability: A sequential processing deficit? *Annals of Dyslexia*, 42, 69-89. | 3, 4, 5, 6 |
| Dawkins, K. R., Dickerson, D. L., McKinney, S. E., & Butler, S. (2008). Teaching density to middle school students: preservice science teachers' content knowledge and pedagogical practices. *Clearing House: A Journal Of Educational Strategies, Issues And Ideas*, 82(1), 21-26. | 3, 4, 5, 6 |
| De Smedt, B. & Gilmore, C. K. (2011). Defective number module or impaired access? Numerical magnitude processing in first graders with mathematical difficulties. *Journal of Experimental Child Psychology*, 108, 278-292. | 4 |
| de Souza, R. Krause M., da Rocha, S. F. B., Cordellini, M. F., Vosgerau, R. P. & Kowacs, P. A. (2013). Primary progressive apraxia: A syndrome difficult to categorize. *Arquivos de Neuro-Psiquiatria*, 71, 267-268. | 3, 4, 5, 6 |
| De Visscher, A. & Noel, M.-P. (2013). A case study of arithmetic facts dyscalculia caused by a hypersensitivity-to-interference in memory. Cort*ex: A Journal Devoted to the Study of the Nervous System and Behavior*, 49, 50-70. | 3, 4, 6 |
| Dehaene, S., Molko, N., Cohen, L. & Wilson, A. J. (2004). Arithmetic and the brain. *Current Opinion in Neurobiology*, 14, 218-224. | 3, 4, 5, 6, 7 |
| Dennis, M., Berch, D. B., & Mazzocco, M. M. (2009). Mathematical learning disabilities in special populations: Phenotypic variation and cross-disorder comparisons. *Developmental Disabilities Research Reviews*, 15(1), 80-89. | 7 |
| Devine, A., Soltesz, F., Nobes, A., Goswami, U. & Szucs, D. (2013). Gender differences in developmental dyscalculia depend on diagnostic criteria. *Learning and Instruction*, 27, 31-39. | 4 |
| Dinkel, P. J., Willmes, K., Krinzinger, H., Konrad, K. & Koten, J. W. Jr.. (2013). Diagnosing developmental dyscalculia on the basis of reliable single case fMRI methods: Promises and limitations. *PLoS ONE*, 8(12) | 4, 6 |
| Dowker, Ann. (2005). Early identification and intervention for students with mathematics difficulties. *Journal of Learning Disabilities*, 38, 324-332. | 7 |
| Dumontheil, I. & Klingberg, T. (2012). Brain activity during a visuospatial working memory task predicts arithmetical performance 2 years later. *Cerebral Cortex*, 22, 1078-1085. | 4, 6 |
| English, L. H., Barnes, M. A., Taylor, H. B., & Landry, S. H. (2009). Mathematical Development in Spina Bifida. *Developmental Disabilities Research Reviews*, 15(1), 28-34. | 4 |

| | |
|---|---|
| Eraslan, A. (2012). Prospective elementary mathematics teachers' thought processes on a model eliciting activity. *Educational Sciences: Theory And Practice*, 12(4), 2964-2968. | 3, 4, 5, 6 |
| Erktin, E., & Akyel, A. (2005). The role of l1 and l2 reading comprehension in solving mathematical word problems: A case in a delayed partial immersion program. *Australian Review Of Applied Linguistics*, 28(1), 52-66. | 4 |
| Even, R. (2005). Using assessment to inform instructional decisions: How hard can it be? *Mathematics Education Research Journal*, 17(3), 45-61. | 3, 4, 6 |
| Finn, B., & Miele, D. B. (2016). Hitting a high note on math tests: Remembered success influences test preferences. *Journal Of Experimental Psychology: Learning, Memory, And Cognition*, 42(1), 17-38. | 3, 4, 5, 6 |
| Fuchs, L. S., Compton, D. L., Fuchs, D., Hollenbeck, K. N., Hamlett, C. L., & Seethaler, P. M. (2011). Two-Stage Screening for math problem-solving difficulty using dynamic assessment of algebraic learning. *Journal Of Learning Disabilities*, 44(4), 372-380. | 4 |
| Gilbertson, D., Duhon, G., Witt, J. C., & Dufrene, B. (2008). Effects of academic response rates on time-on-task in the classroom for students at academic and behavioral risk. *Education And Treatment Of Children*, 31(2), 153-165. | 4, 5 |
| Gold, A. B., Ewing-Cobbs, L., Cirino, P., Fuchs, L. S., Stuebing, K. K. & Fletcher, J. M. (2013). Cognitive and behavioral attention in children with math difficulties. *Child Neuropsychology*, 19, 420-437. | 4, 5 |
| Gordon, S., & Nicholas, J. (2013). Students' conceptions of mathematics bridging courses. *Journal Of Further And Higher Education*, 37(1), 109-125. | 3, 4, 5, 6 |
| Gross-Tsur, V., Manor, O. & Shalev, R. S. (1996). Developmental dyscalculia: Prevalence and demographic features. *Developmental Medicine & Child Neurology*, 38, 25-33. | 3, 4 |
| Guberman, R., & Leikin, R. (2013). Interesting and difficult mathematical problems: Changing teachers' views by employing multiple-solution tasks. *Journal Of Mathematics Teacher Education*, 16(1), 33-56. | 3, 4, 5, 6 |
| Haag, N., Heppt, B., Roppelt, A., & Stanat, P. (2015). Linguistic simplification of mathematics items: Effects for language minority students in Germany. *European Journal Of Psychology Of Education*, 30(2), 145-167. | 4 |
| Hall, J. (2005). Review of teaching mathematics to deaf children. *Deafness & Education International*, 7, 173-174. | 7 |
| Han, X., & Paine, L. (2010). Teaching mathematics as deliberate practice through public lessons. *Elementary School Journal*, 110(4), 519-541. | 3, 4, 5 |
| Hashemi, N., Abu, M. S., Kashefi, H., Mokhtar, M., & Rahimi, K. (2015). Designing learning strategy to improve undergraduate students' problem solving in derivatives and integrals: A conceptual framework. *EURASIA Journal Of Mathematics, Science & Technology Education*, 11(2), 227-238. | 3, 4, 5, 6 |

| | |
|---|---|
| Hauser, T. U., Rotzer, S., Grabner, R. H., Merillat, S. & Jancke, L.. (2013). Enhancing performance in numerical magnitude processing and mental arithmetic using transcranial Direct Current Stimulation (tDCS). *Frontiers in Human Neuroscience*, 7 | 3, 4 |
| Hecht, S. A., & Vagi, K. J. (2010). Sources of group and individual differences in emerging fraction skills. *Journal Of Educational Psychology*, 102(4), 843-859. | 4 |
| Hora, J., & Pech, P. (2005). On one unusual method of computation of limits of rational functions in the program mathematica[R]. *International Journal For Technology In Mathematics Education*, 12(4), 161-164. | 5 |
| Hord, C., & Xin, Y. P. (2013). Intervention research for helping elementary school students with math learning difficulties understand and solve word problems: 1996-2010. *Learning Disabilities: A Multidisciplinary Journal*, 19(1), 3-17. | 7 |
| Huber, S., Sury, D., Moeller, K, Rubinsten, O. & Nuerk, H.-C. (2015). A general number-to-space mapping deficit in developmental dyscalculia. *Research in Developmental Disabilities*, 43-44, 32-42. | 3, 4, 5, 6 |
| Ishizuka, M., Okazaki, S. & Maekawa, H. (2010). Automaticity of number processing in children with mathematical difficulties: Distance effect on a number comparison task. *Japanese Journal of Special Education*, 47(6), 443-455. | 4 |
| Iuculano, T. & Kadosh, R. C. (2014). Preliminary evidence for performance enhancement following parietal lobe stimulation in Developmental Dyscalculia. *Frontiers in Human Neuroscience*, 8 | 3, 5, 6 |
| Janssen, J. C, Schott, J. M, Cipolotti, L, Fox, N. C, Scahill, R. I, Josephs, K. A, et al. (2005). Mapping the onset and progression of atrophy in familial frontotemporal lobar degeneration. *Journal of Neurology, Neurosurgery & Psychiatry*, 76, 162-168. | 3, 4, 5, 6 |
| Jovanovic, G., Jovanovic, Z., Bankovic -Gajic, J., Nikolic, A., Svetozarevic, S. & Ignjatovic-Ristic, D. (2013). The frequency of dyscalculia among primary school children. *Psychiatria Danubina*, 25(2), 170-174. | 4 |
| Jovic, N. J., Milovanovic, V. & Knezevic, L. (1996). Neuropsychologic analysis of children with tics. *Psihijatrija Danas*, 28(4), 397-410. | 4, 5, 6 |
| Kaemingk, K. L., Carey, M. E., Moore, I. M., Herzer, M. & Hutter, J. J. (2004). Math weaknesses in survivors of acute lymphoblastic leukemia compared to healthy children. *Child Neuropsychology*, 10, 14-23. | 4, 6 |
| Karagiannakis, G., Baccaglini-Frank, A. & Papadatos, Y. (2014). Mathematical learning difficulties subtypes classification. *Frontiers in Human Neuroscience*, 8 | 4, 5, 6, 7 |
| Kaufmann, L. (2008). Dyscalculia: Neuroscience and education. *Educational Research*, 50(2), 163-175. | 4, 7 |
| Kaufmann, L. & Nuerk, H-C. (2005). Numerical development: Current issues and future perspectives. *Psychology Science*, 47(1), 142-170. | 4, 7 |
| Kaufmann, L. & Nuerk, H-C. (2008). Basic number processing deficits in ADHD: A broad examination of elementary and complex number processing skills in 9- to 12-year-old children with ADHD-C. *Developmental Scienc*e, 11, 692-699. | 4 |

| | |
|---|---|
| Kaufmann, L. & von Aster, M. (2012). The diagnosis and management of dyscalculia. *Deutsches Arzteblatt International*, 109(45), 767-778. | 4, 7 |
| Kelly, R. R. (2003). Using technology to meet the developmental needs of deaf students to improve their mathematical word problem solving skills. *Mathematics And Computer Education*, 37(1), 8-15. | 3, 4 |
| Khoshaim, H. B., & Rashid, S. (2016). Assessment of the assessment tool: Analysis of items in a non-mcq mathematics exam. *International Journal Of Instruction*, 9(1), 119-132. | 3, 4, 5, 6 |
| Ko, Y., & Knuth, E. (2009). Undergraduate Mathematics majors' writing performance producing proofs and counterexamples about continuous functions. *Journal Of Mathematical Behavior*, 28(1), 68-77. | 3, 4, 5, 6 |
| Kosc, L. (1979). To the problems of diagnosing disorders of mathematical functions in children. *Studia Psychologica*, 21(1), 62-67. | 4, 5 |
| Kucian, K., Ashkenazi, S., Schwizer, H., J., Rotzer, S., J., Lutz, M., E., et al. (2014). Developmental dyscalculia: A dysconnection syndrome? *Brain Structure & Function*, 219(5), 1721-1733. | 4, 5, 6 |
| Kuhn, J-T. (2015). Developmental dyscalculia: Neurobiological, cognitive, and developmental perspectives. *Zeitschrift fur Psychologie*, 223, 69-82. | 4, 5, 6, 7 |
| Landerl, Karin. & Kolle, C. (2009). Typical and atypical development of basic numerical skills in elementary school. *Journal of Experimental Child Psychology*, 103, 546-565. | 4 |
| Lang, F. K. (1999). What is a "good guess" anyway? teaching quantity and measurement estimation. *Young Children*, 54(4), 78-81. | 3, 4, 5, 6 |
| Lannie, A. L., & Martens, B. K. (2004). Effects of task difficulty and type of contingency on students' allocation of responding to math worksheets. *Journal Of Applied Behavior Analysis*, 37(1), 53. | 4, 5 |
| Liang, H., & Sedig, K. (2010). Can interactive visualization tools engage and support pre-university students in exploring non-trivial mathematical concepts? *Computers & Education*, 54(4), 972-991. | 3, 4, 5, 6 |
| Lloyd, C. B., & Abbey, A. (2009). Teaching elementary accounting to non-accounting majors. *American Journal Of Business Education*, 2(2), 23-30. | 3, 4, 5, 6, 7 |
| Lopes-Silva, J. B., Moura, R., J-C., Annelise, Haase, V. G. & Wood, G. (2014). Phonemic awareness as a pathway to number transcoding. *Frontiers in Psychology*, 5 | 4 |
| Lowrie, T., & Diezmann, C. M. (2007). Solving graphics problems: Student performance in junior grades. journal of educational research, 100(6), 369-378. | 4, 5 |
| Marchetti, C., Foster, S., Long, G., & Stinson, M. (2012). Crossing the communication barrier: Facilitating communication in mixed groups of deaf and hearing students. *Journal Of Postsecondary Education And Disability*, 25(1), 51-63. | 3, 4, 5, 6 |

| | |
|---|---|
| Martin, R. B., Cirino, P. T., Barnes, M. A., Ewing-Cobbs, L., Fuchs, L. S., Stuebing, K. K., et al. (2013). Prediction and stability of mathematics skill and difficulty. *Journal of Learning Disabilities*, 46, 428-443. | 4 |
| Maskan, A. K. (2007). Preservice Science and math teachers' difficulties in disruptive behavior and class management. *International Journal Of Educational Reform*, 16(4), 336-349. | 3, 4, 5, 6 |
| Mazzocco, M. M. M., Myers, G. F., Lewis, K. E., Hanich, L. B. & Murphy, M.M. (2013). Limited knowledge of fraction representations differentiates middle school students with mathematics learning disability (dyscalculia) versus low mathematics achievement. *Journal of Experimental Child Psychology*, 115, 371-387. | 4, 5 |
| Mazzocco, M. M. M. (2005). Challenges in identifying target skills for math disability screening and intervention. *Journal of Learning Disabilities*, 38, 318-323. | 7 |
| Mendiburo, M., Williams, L., Henson, R., Hasselbring, T., & Society for Research on Educational Effectiveness, (2013). Designing and Redesigning a Framework for Assessing Students' Understanding of Foundational Fractions Concepts. Society For Research On Educational Effectiveness, | 4, 5 |
| Moomaw, S., Carr, V., Boat, M., & Barnett, D. (2010). Preschoolers' number sense. *Teaching Children Mathematics*, 16(6), 332-340. | 4 |
| Mundia, L. (2012). The assessment of math learning difficulties in a primary grade-4 child with high support needs: Mixed methods approach. *International Electronic Journal Of Elementary Education*, 4(2), 347-366. | 4 |
| Munn, P. & Reason, R. (2007). Arithmetical difficulties: Developmental and instructional perspectives. *Educational and Child Psychology*, 24(2), 5-15. | 7 |
| Naude, H & Pretorius, E. (2002). The quest for an instructional delivery framework for children with Gerstmann's syndrome. *Early Child Development and Care*, 172, 643-650. | 4, 5 |
| Neumarker, K.-J. (2000). Mathematics and the brain: Uncharted territory? *European Child & Adolescent Psychiatry*, 9, S2-S10. | 4, 7 |
| Niklas, F. & Schneider, W. (2014). Casting the die before the die is cast: The importance of the home numeracy environment for preschool children. *European Journal of Psychology of Education*, 29, 327-345. | 4 |
| Nishimoto, Y., Shibata, M., Onodera, O. & Suzuki, N. (2011). Neuroaxonal integrity evaluated by MR spectroscopy in a case of CARASIL. *Journal of Neurology, Neurosurgery & Psychiatry*, 82, 860-861. | 3, 4, 5, 6 |
| Olsen, A., LeMire, S., & Baker, M. (2011). The impact of self-efficacy and peer support on student participation with interactive white boards in the middle school mathematics class. *Journal Of Computers In Mathematics And Science Teaching*, 30(2), 163-178. | 4, 5 |
| Olson, J. (1991). Function recognition and computerized graphing. *Physics Teacher*, 29(5), 293-95. | 4, 5 |

| | |
|---|---|
| Orraca-Castillo, M., Estevez-Perez, N. & Reigosa-Crespo, V. (2014). Neurocognitive profiles of learning disabled children with neurofibromatosis type 1. *Frontiers in Human Neuroscience*, 8. | 4, 5, 6 |
| Osmon, D. C., Smerz, J. M., Braun, M. M. & Plambeck, E. (2006). Processing abilities associated with math skills in adult learning disability. *Journal of Clinical and Experimental Neuropsychology*, 28, 84-95. | 3, 4, 5, 6 |
| Ostad, S. A. (2015). Private speech use in arithmetical calculation: Relationship with phonological memory skills in children with and without mathematical difficulties. *Annals Of Dyslexia*, 65(2), 103-119. | 4, 5 |
| Ostad, S. A. & Sorensen, P. M. (2007). Private speech and strategy-use patterns: Bidirectional comparisons of children with and without mathematical difficulties in a developmental perspective. *Journal of Learning Disabilities*, 40, 2-14. | 4, 5, 6 |
| Palha, S., Dekker, R., & Gravemeijer, K. (2015). The effect of shift-problem lessons in the mathematics classroom. *International Journal Of Science And Mathematics Education*, 13(6), 1589-1623. | 3, 6 |
| Parker, M., & Leinhardt, G. (1995). Percent: A privileged proportion. *Review Of Educational Research*, 65(4), 421-81. | 4, 5, 6, 7 |
| Pavuluri, M. N., O'Connor, M. M., Harral, E. M., Moss, M. & Sweeney, J. A. (2006). Impact of neurocognitive function on academic difficulties in pediatric bipolar disorder: A clinical translation. *Biological Psychiatry*, 60, 951-956. | 4, 5, 6 |
| Perkins, F. F. Jr., Breier, J., McManis, M. H., Castillo, E., Wheless, J., McGregor, A. L., et al. (2008). Benign rolandic epilepsy--Perhaps not so benign: Use of magnetic source imaging as a predictor of outcome. *Journal of Child Neurology*, 23, 389-393. | 4, 5, 6 |
| Piazza, M., Facoetti, A., Trussardi, A. N., Berteletti, I., Conte, S., Lucangeli, D., et al. (2010). Developmental trajectory of number acuity reveals a severe impairment in developmental dyscalculia. *Cognition*, 116, 33-41. | 4, 5 |
| Pitsolantis, N., & Osana, H. P. (2013). Fractions instruction: Linking concepts and procedures. *Teaching Children Mathematics*, 20(1), 18-26. | 7 |
| Polat, E., Adiguzel, T., & Akgun, O. E. (2012). Adaptive web-assisted learning system for students with specific learning disabilities: A needs analysis study. *Educational Sciences: Theory And Practice*, 12(4), 3243-3258. | 4, 5 |
| Powers, R. A., Craviotto, C., & Grassl, R. M. (2010). Impact of proof validation on proof writing in abstract algebra. *International Journal Of Mathematical Education In Science And Technolog*y, 41(4), 501-514. | 3, 4, 5, 6 |
| Prevatt, F., Proctor, B., Swartz, S. L., & Canto, A. I. (2003). Profiles of academic achievement and cognitive processing in college students with foreign language difficulties. *Journal Of Postsecondary Education And Disability*, 16(2), 63-77. | 3, 4, 5, 6, 7 |
| Price, G. R. & Ansari, D. (2014). Developmental dyscalculia: Characteristics, causes and treatments. *Paedagogisk Psykologisk Tidsskrift*, 51(5-6), 41-54. | 7 |
| Raches, D. & Mazzocco, M. M. M. (2012). Emergence and nature of mathematical difficulties in young children with Barth syndrome. *Journal* | 3, 4, 5, 6 |

| | |
|---|---|
| *of Developmental and Behavioral Pediatrics*, 33, 328-335. | |
| Raghubar, K. P., Barnes, M. A. & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences*, 20, 110-122. | 7 |
| Rankin, J. L., & Reid, R. (1995). The SM rap--or, here's the rap on self-monitoring. *Intervention In School And Clinic*, 30(3), 181-88. | 4, 5 |
| Reed, D. D., & Martens, B. K. (2008). Sensitivity and bias under conditions of equal and unequal academic task difficulty. *Journal Of Applied Behavior Analysis*, 41(1), 39-52. | 4, 5 |
| Reilly, C., & Stedman, L. (2013). Supporting Children with genetic syndromes in the classroom: The example of 22q deletion syndrome. *Support For Learning*, 28(3), 115-121. | 7 |
| Ricci, D. & Tinelli, F. (2013). Compromised approximate number system acuity in school-aged children born extremely preterm. *Developmental Medicine & Child Neurology*, 55, 1070-1071. | 7 |
| Ricks, K. G., Richardson, J. A., Stern, H. P., Taylor, R. P., & Taylor, R. A. (2014). An engineering learning community to promote retention and graduation of at-risk engineering students. *American Journal Of Engineering Education*, 5(2), 73-90. | 3, 4, 5, 6 |
| Roessler, K., Sommer, B., Grummich, P., Coras, R., Kasper, B. S., Hamer, H. M., et al. (2014). Improved resection in lesional temporal lobe epilepsy surgery using neuronavigation and intraoperative MR imaging: Favourable long term surgical and seizure outcome in 88 consecutive cases. *Seizure*, 23, 201-207. | 3, 4, 5, 6 |
| Rosenberg-Lee, M., Ashkenazi, S., Chen, T., Young, C. B., Geary, D. C. & Menon, V. (2015). Brain hyper-connectivity and operation-specific deficits during arithmetic problem solving in children with developmental dyscalculia. *Developmental Science*, 18, 351-372. | 4 |
| Rosselli, M., Matute, E., Pinto, N. & Ardila, A. (2006). Memory abilities in children with subtypes of dyscalculia. *Developmental Neuropsychology*, 30, 801-818. | 4 |
| Rubinsten, O., Bedard, A-C. & Tannock, R. (2008). Methylphenidate has differential effects on numerical abilities in ADHD children with and without co-morbid mathematical difficulties. *The Open Psychology Journal*, 1, | 6 |
| Rubinsten, Orly. (2015). Link between cognitive neuroscience and education: The case of clinical assessment of developmental dyscalculia. *Frontiers in Human Neuroscience*, 9 | 4, 5, 6 |
| Scheer, J. K., & Henniger, M. T. (1982). Math Clinic: An Ideal Setting for Parental Involvement. Arithmetic Teacher, 30(2), 48-51. | 6 |
| Scherer, M. (2010). Getting a grip on the gaps. *Educational Leadership*, 68(3), 7. | 4, 5, 6 |
| Schwab, J. R., Tucci, S., & Jolivette, K. (2013). Integrating schema-based instruction and response cards for students with learning disabilities and challenging behaviors. *Beyond Behavior*, 22(3), 24-30. | 7 |

| | |
|---|---|
| Sella, F., Berteletti, I., Martina, B., Lucangeli, D., & Zorzi, M. (2013). Number line estimation in children with developmental dyscalculia. *Learning Disabilities: A Contemporary Journal*, 11(2), 41-49. | 4 |
| Sella, F., Lanfranchi, S. & Zorzi, M. (2013). Enumeration skills in Down syndrome. *Research in Developmental Disabilities*, 34, 3798-3806. | 4 |
| Shalev, R. S, Auerbach, J, Manor, O & Gross-Tsur, V. (2000). Developmental dyscalculia: Prevalence and prognosis. *European Child & Adolescent Psychiatry*, 9, S58-S64. | 4, 7 |
| Shalev, R. S. & Gross-Tsur, V. (1993). Developmental dyscalculia and medical assessment. *Journal of Learning Disabilities*, 26, 134-137. | 4, 5 |
| Shalev, R. S., Auerbach, J. & Gross-Tsur, V. (1995). Developmental dyscalculia behavioral and attentional aspects: A research note. *Child Psychology & Psychiatry & Allied Disciplines*, 36, 1261-1268. | 4, 5 |
| Shalev, R. S., Manor, O., Amir, N., Wertman-Elad, R. & et al. (1995). Developmental dyscalculia and brain laterality. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, 31(2), 357-365. | 4, 5, 6 |
| Shalev, R. S., Weirtman, R. & Amir, N. (1988). Developmental dyscalculia. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, 24(4), 555-561. | 4, 5, 6 |
| Shamir, A., & Baruch, D. (2012). Educational e-books: A support for vocabulary and early math for children at risk for learning disabilities. *Educational Media International*, 49(1), 33-47. | 3 |
| Sizoo, S., Jozkowskia, R., Malhotra, N., & Shapero, M. (2008). The effects of anxiety and self-efficacy on finance students. *Journal Of Instructional Psychology*, 35(4), 347-356. | 3, 4, 5, 6 |
| Smith, D. N. (1997). Independent mathematical modeling. *Teaching Mathematics And Its Applications*, 16(3), 101-06. | 4 |
| Smith, G. G., & Ferguson, D. (2004). Diagrams and math notation in e-learning: Growing pains of a new generation. *International Journal Of Mathematical Education In Science And Technology*, 35(5), 681-695. | 3, 4, 5, 6 |
| Soares, N. & Patel, D. R. (2015). Dyscalculia. *International Journal of Child and Adolescent Health*, 8(1), 15-26. | 7 |
| Stoianov, I., Zorzi, M. & Umilta, C. (2004). The role of semantic and symbolic representations in arithmetic processing: Insights from simulated dyscalculia in a connectionist model. *Cortex: A Journal Devoted to the Study of the Nervous System and Behavior*, 40, 194-196 | 4 |
| Svien, K. & Sherlock, D. (1979). Dyscalculia and dyslexia. *Bulletin of the Orton Society*, 29, 269-276. | 7 |
| Szalay, I. (2008). On the quasi-extended addition for exploded real numbers. *Acta Didactica Napocensia*, 1(2), 1-15. | 3, 4, 5, 6 |
| Tobias, S. (1988). Dealing with math/science blocks. *Liberal Education*, 74(2), 20-31. | 7 |
| Tropper, N., Leiss, D., & Hänze, M. (2015). Teachers' temporary support and worked-out examples as elements of scaffolding in | 3 |

| | |
|---|---|
| mathematical modeling. *ZDM: The International Journal On Mathematics Education*, 47(7), 1225-1240. | |
| Tutak, T., & Güder, Y. (2013). Opinions of secondary school mathematics teachers on mathematical modelling. *Educational Research And Reviews*, 9(19), 799-806. | 3, 4, 5, 6 |
| Villanueva, M. G., Taylor, J., Therrien, W., & Hand, B. (2012). Science education for students with special needs. *Studies In Science Education*, 48(2), 187-215. | 7 |
| Volante, L., & Earl, L. (2002). Teacher candidates' perceptions of conceptual orientations in their preservice program. *Canadian Journal Of Education*, 27(4), 419-438. | 3 |
| Wadlington, E., & Wadlington, P. L. (2008). Helping students with mathematical disabilities to succeed. *Preventing School Failure*, 53(1), 2-7. | 4 |
| Wagner, P. A. (2011). Socio-sexual education: A practical study in formal thinking and teachable moments. *Sex Education: Sexuality, Society And Learning*, 11(2), 193-211. | 4, 5 |
| Wang, L., Tasi, H., & Yang, H. (2012). Cognitive Inhibition in students with and without dyslexia and dyscalculia. *Research In Developmental Disabilities: A Multidisciplinary Journal,* 33(5), 1453-1461. | 4 |
| Wang, L-C., Tasi, H-J. & Yang, H-M. (2012). Cognitive inhibition in students with and without dyslexia and dyscalculia. *Research in Developmental Disabilities*, 33, 1453-1461. | 4 |
| Wilt, J. R. (2005). Ninth Grade Physics: A Necessity for High School Science Programs. Journal Of Curriculum And Supervision, 20(4), 342-362. | 4, 5 |
| Wischgoll, A., Pauli, C., & Reusser, K. (2015). Scaffolding--how can contingency lead to successful learning when dealing with errors? *ZDM: The International Journal On Mathematics Education*, 47(7), 1147-1159. | 4, 5 |
| Zeguers, M. T., Snellings, P., Tijms, J., Weeda, W. D., Tamboer, P., Bexkens, A., & Huizenga, H. M. (2011). Specifying theories of developmental dyslexia: A diffusion model analysis of word recognition. *Developmental Science*, 14(6), 1340-1354. | 4, 5 |

## Appendix B

**Table B1**

*Weight of evidence A criteria and rationale*

| | WoE A Score | Criteria | Rationale |
|---|---|---|---|
| Gersten et al. (2005) Coding Protocol | 3 | Meets ≥ 9 essential criteria and ≥ 4 desirable criteria | Based on recommendations of Gersten et al. (2005) |
| | 2 | Meets ≥ 9 essential criteria and ≥ 2 desirable criteria | |
| | 1 | Meets < 9 essential criteria and < 2 desirable criteria | |
| Horner et al. (2005) Coding Protocol | 3 | Average score of 2–3 across the seven judgement areas | Possible scores range from 0–3, this criteria converts them into scores between 1–3. |
| | 2 | Average score of 1–1.9 across the seven judgement areas | |
| | 1 | Average score of 0–0.9 across the seven judgement areas | |

**Table B2**

*Weight of evidence B criteria and rationale*

| Weighting | Type of study design | Rationale |
|---|---|---|
| 1 | Qualitative research, surveys, case-control studies, non-experimental evaluations | These are the types of evidence, aside from systematic reviews, that are most suited to research questions about "effectiveness" (Petticrew & Roberts, 2003) |
| 2 | Cohort studies, quasi-experimental designs | |
| 3 | Randomised control trial studies | |

**Table B3**

*Weight of evidence C criteria and rationale*

| Criteria | | Weightings | | Rationale |
|---|---|---|---|---|
| A | Sample | 3 | Specified as only having dyscalculia or mathematical difficulties | To identify interventions that help mathematical skills because they target mathematical difficulties |
| | | 2 | Has dyscalculia or mathematical difficulties and does not specify whether has comorbid conditions | |
| | | 1 | Has or is likely to have other comorbid conditions in addition to dyscalculia or mathematical difficulties | |
| B | Intervention implementation | 3 | Intervention implemented by school staff in a school using school resources without additional costs or staff; implementation could be reproduced by school staff in a typical school | An intervention is more likely to be used and more feasible if it can be implemented using typical school resources and is not dependent on specialist personnel and equipment |
| | | 2 | Intervention implemented by specialist staff or using additional research resources, but could be implemented by school staff using school resources | |
| | | 1 | Intervention requires specialist staff and / or significant specialist resources such as specialist computing equipment or prohibitively expensive software | |
| C | Measurement of mathematical skills improvement | 3 | School testing outcomes or typical educational measures of numeracy / mathematical ability | To identify interventions that could typically be used to help children improve their mathematical skills so that they can succeed in their |
| | | 2 | Outcomes that are more relevant to research and are not typically used in school but are reflective of skills and abilities tested in education settings | |

| | | | | |
|---|---|---|---|---|
| | | 1 | Measures that are specific to the study or are not reflective of educational attainment or required skills. | education at school. |
| D | School setting | 3 | OECD educational system | To identify interventions that could be implemented in an OECD educational system such as the UK educational system |
| | | 2 | Similar to OECD educational system | |
| | | 1 | Very different to OECD educational system | |

*Note* Scores on A, B, C and D are averaged to create WoE C rating

**Table B4**

*Weight of evidence C ratings for the five studies included in the review*

| Study | Criteria score | | | | Average score |
|---|---|---|---|---|---|
| | A | B | C | D | |
| Burns, Kanive & DeGrande (2012) | 1 | 3 | 2 | 3 | 2.3 |
| de Castro, Bissaco, Panccioni, Rodrigues & Domingues (2014) | 3 | 2 | 3 | 2 | 2.5 |
| Leh & Jitendra (2013) | 1 | 2 | 2 | 3 | 2 |
| Salminen, Koponen, Räsänen & Aro (2015) | 2 | 3 | 2 | 3 | 2.5 |
| Wilson, Revkin, Cohen, Cohen & Dehaene (2006) | 3 | 2 | 2 | 3 | 2.5 |

## Appendix C
## Coding Protocol Examples

Name of Coder:

Date: February 2016

Full Study Reference:

**de Castro, M. V., Bissaco, M. A. S., Panccioni, B. M., Rodrigues, S. C. M., & Domingues, A. M. (2014). Effect of a virtual environment on the development of mathematical skills in children with dyscalculia. *PLoS ONE*, *9*(7), 1–16.**

Intervention Name (description of study): Virtual environment (Tom's Rescue)

Research design: Group Experimental

Type of Publication: Peer-reviewed journal

---

*Gersten et al., (2005). Quality Indicators for Group Experimental and Quasi-Experimental Research in Special Education*

**Essential Quality Indicators**

***Describing Participants***

Was sufficient information provided to determine/confirm whether the participants demonstrated the disability(ies) or difficulties presented?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

Were appropriate procedures used to increase the likelihood that relevant characteristics of participants in the sample were comparable across conditions?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

Was sufficient information given characterizing the interventionists or teachers provided? Did it indicate whether they were comparable across conditions?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

***Implementation of the Intervention and Description of Comparison Conditions***

Was the intervention clearly described and specified?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

Was the fidelity of implementation described and assessed?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

Was the nature of services provided in comparison conditions described?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

***Outcome Measures***

Were multiple measures used to provide an appropriate balance between measures closely aligned with the intervention and measures of generalised performance?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

Were outcomes for capturing the intervention's effect measured at the appropriate times?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

***Data Analysis***

Were the data analysis techniques appropriately linked to key research questions and hypotheses? Were they appropriately linked to the unit of analysis in the study?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

Did the research report include not only inferential statistics but also effect size calculations?
☐ Yes

☒ No
☐ N/A
☐ Unknown/Unable to Code

**Desirable Quality Indicators**

Was data available on attrition rates among intervention samples? Was severe overall attrition documented? If so, is attrition comparable across samples? Is overall attrition less than 30%?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

Did the study provide not only internal consistency reliability but also test-retest reliability and interrater reliability (when appropriate) for outcome measures? Were data collectors and/or scorers blind to study conditions and equally (un)familiar to examinees across study conditions?
☐ Yes
☒ No
☐ N/A
☐ Unknown/Unable to Code

Were outcomes for capturing the intervention's effect measured beyond an immediate posttest?
☐ Yes
☒ No
☐ N/A
☐ Unknown/Unable to Code

Was evidence of the criterion-related validity and construct validity of the measures provided?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

Did the research team assess not only surface features of fidelity implementation (e.g. number of minutes allocated to the intervention or teacher/interventionist following procedures specified), but also examine quality of implementation?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

Was any documentation of the nature of instruction or series provided in comparison conditions?

☐ Yes
☒ No
☐ N/A
☐ Unknown/Unable to Code

Did the research report include actual audio or videotape excerpts that capture the nature of the intervention?
☐ Yes
☒ No
☐ N/A
☐ Unknown/Unable to Code

Were results presented in a clear, coherent fashion?
☒ Yes
☐ No
☐ N/A
☐ Unknown/Unable to Code

**Overall Rating of Evidence: ☒ 3 ☐ 2 ☐ 1 ☐ 0**

Horner et al., (2005). The Use of Single-Subject Research to Identify Evidence-Based Practice in Special Education

**Quality Indicators Within Single-Subject Research**

**Article Reference:**

**Wilson, A. J., Revkin, S. K., Cohen, D., Cohen, L., & Dehaene, S. (2006). An open trial assessment of 'The Number Race', an adaptive computer game for remediation of dyscalculia. *Behavioral and Brain Functions*, *2*(20).**

***Description of Participants and Setting***

Participants are described with sufficient detail to allow others to select individuals with similar characteristics; (e.g., age, gender, disability, diagnosis).

☐ **Yes**
**X No**
☐ **N/A**
☐ **Unknown/Unable to Code**

The process for selecting participants is described with operational precision.

☐ **Yes**
**X No**
☐ **N/A**
☐ **Unknown/Unable to Code**

Critical features of the physical setting are described with sufficient precision to allow replication.

☐ **Yes**
**X No**
☐ **N/A**
☐ **Unknown/Unable to Code**

**Overall Rating of Evidence:** ☐ 3 ☐ 2 ☐ 1 **X** 0

***Dependent Variable***

Dependent variables are described with operational precision.

**X Yes**
☐ **No**
☐ **N/A**
☐ **Unknown/Unable to Code**

Each dependent variable is measured with a procedure that generates a quantifiable index.

**X Yes**
☐ **No**
☐ **N/A**
☐ **Unknown/Unable to Code**

Measurement of the dependent variable is valid and described with replicable precision.

**X Yes**
☐ **No**
☐ **N/A**
☐ **Unknown/Unable to Code**

Dependent variables are measured repeatedly over time.

**X Yes**
☐ **No**
☐ **N/A**
☐ **Unknown/Unable to Code**

Data are collected on the reliability or inter-observer agreement associated with each dependent variable, and IOA levels meet minimal standards

☐ **Yes**
**X No**
☐ **N/A**
☐ **Unknown/Unable to Code**

**Overall Rating of Evidence**: ☐ 3 **X** 2 ☐ 1 ☐ 0

***Independent Variable***

Independent variable is described with replicable precision.

**X Yes**
☐ **No**
☐ **N/A**
☐ **Unknown/Unable to Code**

Independent variable is systematically manipulated and under the control of the experimenter.

**X Yes**
☐ **No**
☐ **N/A**
☐ **Unknown/Unable to Code**

Overt measurement of the fidelity of implementation for the independent variable is highly desirable.

☐ **Yes**
**X No**
☐ **N/A**
☐ **Unknown/Unable to Code**

**Overall Rating of Evidence:** ☐ 3 **X** 2 ☐ 1 ☐ 0

***Baseline***

The majority of single-subject research studies will include a baseline phase that provides repealed measurement of a dependent variable and establishes a pattern of responding that can be used to predict the pattern of future performance, if introduction or manipulation of the independent variable did not occur.

☐ **Yes**
**X No**
☐ **N/A**
☐ **Unknown/Unable to Code**

Baseline conditions are described with replicable precision.

☐ **Yes**
**X No**
☐ **N/A**
☐ **Unknown/Unable to Code**

**Overall Rating of Evidence**: ☐ 3 ☐ 2 ☐ 1 **X** 0

***Experimental Control/internal Validity***

The design provides at least three demonstrations of experimental effect at three different points in time.

☐ **Yes**
**X No**
☐ **N/A**
☐ **Unknown/Unable to Code**

The design controls for common threats to internal validity (e.g., permits elimination of rival hypotheses).

**X Yes**
☐ **No**
☐ **N/A**
☐ **Unknown/Unable to Code**

The results document a pattern that demonstrates experimental control.

**X Yes**
☐ **No**
☐ **N/A**
☐ **Unknown/Unable to Code**

**Overall Rating of Evidence:** ☐ 3 **X** 2 ☐ 1 ☐ 0

***External Validity***

Experimental effects are replicated across participants, settings, or materials to establish external validity.

☐ **Yes**

**X No**
☐**N/A**
☐**Unknown/Unable to Code**

**Overall Rating of Evidence**: ☐ 3 ☐ 2 ☐ 1 **X** 0

***Social Validity***
The dependent variable is socially important.
**X Yes**
☐ **No**
☐**N/A**
☐**Unknown/Unable to Code**

The magnitude of change in the dependent variable resulting from the intervention is socially important.
**X Yes**
☐ **No**
☐**N/A**
☐**Unknown/Unable to Code**

Implementation of the independent variable is practical and cost effective
**X Yes**
☐ **No**
☐**N/A**
☐**Unknown/Unable to Code**

Social validity is enhanced by implementation of the independent variable over extended time periods, by typical intervention agents, in typical physical and social contexts.
**X Yes**
☐ **No**
☐**N/A**
☐**Unknown/Unable to Code**

**Overall Rating of Evidence**: **X** 3 ☐ 2 ☐ 1 ☐ 0

**<u>Average WoE A across the 7 judgement areas:</u>**
**Sum of X / N = 9 / 7 = 1.3**
X = individual quality rating for each judgement area
N = number of judgement areas
**Overall Rating of Evidence:** ☐ **3 X 2** ☐ **1** ☐ **0**