Government Office for Science

COUNCIL FOR SCIENCE AND TECHNOLOGY

Current Understanding, Support Systems, and Technology-led Interventions for Specific Learning Difficulties

Evidence reviews commissioned for work by the Council for Science and Technology

Review 1: Julia Carroll

Review 2: Helen Ross

Review 3: Rosemary Luckin, Canan Blake, Carmel Kent, and Alison Clark-Wilson

Review 4: Diana Laurillard and Brian Butterworth

July 2020

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Executive summary

1. Introduction

The Government Office for Science has commissioned a series of four rapid evidence reviews to help inform a project carried out by the Prime Minister's Council for Science and Technology (CST) which explores how technology and research can help improve educational outcomes for learners with specific learning difficulties (SpLDs). The evidence reviews form part of a wide range of evidence that CST members consulted in formulating their advice.

In compiling their evidence reviews, the commissioned authors have focused on developments in the past decade, examining progress since the Foresight Report on Mental Capital and Wellbeing[1] (Goswami, 2008) and the Independent Review of the Primary Curriculum[2] (Rose, 2009). The overarching purpose of the reviews was to help CST understand how developments in science and technology have advanced our understanding of SpLDs, to present and examine the evidence available on effective strategies to support learners, and to identify areas where policy, practice and research funding strategies could benefit from taking into account new developments in science and technology. The work should also be of value to the Department for Education-(DfE) led SEND Review.[3]

The evidence reviews focus on the following:

Review 1: Current understanding of the causes and identification of SpLDs

Review 2: The support system for learners with SpLDs

Review 3: Technology-based interventions for SpLDs

Review 4: A case study approach focusing on dyscalculia to explore all three themes above

The research questions used to guide the evidence reviews were developed through engagement with academics with expertise in SpLDs, as well as government officials working on special educational needs policy. Evidence reviews were commissioned to academic experts and practitioners by competitive tender, and were peer reviewed before being finalised.

The views expressed are those of the authors and do not represent those of any government or organisation. This document is not a statement of government policy.

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[1] www.cne.psychol.cam.ac.uk/pdfs/publication-pdfs/Learning_difficulties.pdf/at_download/file
[2] https://dera.ioe.ac.uk/30098/2/2009-IRPC-final-report_Redacted.pdf
[3] www.gov.uk/government/news/major-review-into-support-for-children-with-special-educational-needs

2. Summary of key findings and recommendations

Authors identified the following key conclusions and recommendations.

Review 1: Current understanding of the causes and identification of SpLDs (Carroll)

- There is a disconnect between the needs-based identification used in schools and the formal diagnosis required by universities and employers, and also the 'identification pathways' used by health services. It would be useful to align these systems more.
- As most children show difficulties in school as some of the early warning signs for SpLDs, teachers and Special Educational Needs and Disabilities Coordinators (SENDcos) need to be much better equipped to identify and support SpLDs. In particular, all teachers should be aware that SpLDs are very common, there are no clear dividing lines between typical and atypical learners with respect to SpLDs, co-occurrence of SpLDs is high, and all children should be supported according to their needs, which will change over time.
- No single method of identification of SpLDs is ideal. Identification needs to be an ongoing process, gaining information from multiple sources (parents, teacher, standardised measures) over a period of time.
- Further research is needed on the role of identification in the progress of SpLDs over time. This requires longitudinal approaches.
- Focus on a single area of processing for identification and diagnosis is not helpful, because of the interactions between different risk factors and the high levels of co-occurrence of different disorders.
- Early identification is useful but should be accompanied by regular updates and reassessments to understand how needs change over time.
- Recent research findings indicate that studies including multiple methodologies (e.g. combining genetic, neuroimaging and behavioural measures) and levels of explanation are a fruitful future research area in SpLDs.
- The National Pupil Database is a precious resource that should be used for large-scale longitudinal data analysis of SpLDs. It also provides an opportunity to understand the divisions between research and practice in more detail.
- With respect to learners with SpLDs, more studies are needed to understand how and why response to intervention varies across learners, and it may be that genetic and neurobiological factors play an important role in this. One approach may be to combine intervention studies with longitudinal cohort studies to allow these types of analyses.

Review 2: The support system for learners with SpLDs (Ross)

- Central government and local policy should clearly define expectations on parents in devising support programmes/interventions for their children. For example, alternative formats (e.g. video) for parents' and children's contributions should be supported.
- Need for procedural consistency in identification and support for young people with SpLDs across Local Authorities in England: it was impossible to outline procedures in England, due to regional/local operational, policy and accessibility differences.
- Support parents/teachers through workshops to provide training on interventions used to support learners with SpLD.
- For parents of children with SpLD, ensure interaction with schools is accessible.
- Initial Teacher Training (ITT) frameworks should include instruction about Special Educational Needs and Disabilities (SEND), which specifically addresses the needs of learners with SpLD. This should be developed through liaison between the DfE, professionals and third sector bodies such as the British Dyslexia Association and the Dyspraxia Foundation, amongst others.
- PG (level 7) standard professional development for teachers relating to areas of need within the SEND Code of Practice, linked to SENCo training routes. SENCos locally could develop skills networks; this needs further research and development. This should be developed through liaison and appropriate research with third sector organisations, professionals and DfE, as well as education and training providers.
- Investment in accredited training for teaching assistants/working with students with SpLD to facilitate schools' access to highly trained individuals to support students with SpLD.
- Training for professionals/parents/carers on accessibility features of information and communications technology already available in school such as MS Office, Adobe, inbuilt features of Apple devices, etc.
- Research into efficacy of intervention programmes, both technological and staff-led, to form a high-quality evidence base.
- Research into the efficacy of diverse technologies, with consistent language and methodology for comparability of results.
- High-quality research into experiences/views of parents/carers whose children have SpLD.
- Exploration with the Joint Council for Qualifications (JCQ) of development of regulations and hardware apps to facilitate use of students' own technology in public examinations, such that the examination is not compromised (i.e. internet access blocked), but so that students 'reasonably adjust' materials congruent with their normal way of working. This will also support the efficient deployment of staff.
- Research on the use of mobile technology in the classroom whilst maintaining online safety but allowing for 'reasonable adjustments' to curricular materials by students.
- Encourage use of e-readers/eBooks through text-to-speech features already available e.g. Office 365, or mobile technology.

Review 3: Technology-based interventions for SpLDs (Luckin et al.)

- The challenging teacher recruitment situation in the UK can be ameliorated for learners with SpLDs through the leveraging of technology to support both early diagnosis and effective learning support.
- The evidence about the way that technology can be used to support education for people with SpLDs summarised in this review is still relatively embryonic, patchy and lacks consistency and scale. Unless this paucity of evidence is addressed, there is a risk that the potential benefits of technology will not be effectively expedited for people with SpLDs. More evidence needs to be generated and a set of widely accepted methodologies agreed.
- If developments in AI technology and in our understanding about how people with SpLDs learn continue to progress as they have in the last decade, and we leverage them effectively, the potential for increasing educational achievements for people with SpLDs is great.
- A clear SpLD educational technology ontology, as described in section 5 of this review, will enable the application of data science and help the government to leverage technology effectively for the education of people with SpLDs.
- If academic researchers were required to make their findings accessible both to educators and to technology developers, there would be an improved prospect for technology suitable for learners with SpLDs to be developed and effectively applied in education.
- The generation and accessibility of large datasets about people with a SpLD is a challenge, but as more people are diagnosed earlier in their lives, datasets should be collated and made available to those developing machine-learning AI techniques for both screening and support of those with SpLDs.
- The potential and increased use of AI presents ethical obstacles to the widespread data collection and algorithm design involved in using machine learning AI. These obstacles must be addressed in order to ensure that the education of learners with SpLDs benefits from advances in science and technology.
- Early intervention and support for reading and writing difficulties should be given priority.

Review 4: A case study approach focusing on dyscalculia to explore all three themes (Laurillard and Butterworth)

- Re-establish official recognition for Developmental Dyscalculia (DD). Official government recognition would help policymakers, parents, and schools act. It cannot be left to non-governmental bodies. The US and Italy have laws requiring intervention for dyscalculia.
- Promote the use of reliable screening tools that focus on the efficiency of numerosity processing tasks in order to ensure the validity of interventions for dyscalculia.
- Increase funding for DD research to match that for dyslexia, which has a similar prevalence and impact on education and employment.
- Encourage cross-professional collaborative research between teachers, specialists in schools, and parents to establish what types of intervention work for DD.
- Train teachers, other education professionals, and parents in what DD is and what it is not, and how to support it, especially using concrete manipulables, a focus on foundational concepts, and the procedural skills using formal representations of arithmetic.
- Ensure that all training courses for teachers embed modules for all teachers that enable them to recognise and respond appropriately to every learner, as well as provision for specialisms in SpLDs.
- Direct funding towards technology-based interventions that focus on the most challenging concepts for the most challenging learners, as these will also be of value to all early learners.
- Provide specifications around the design of interventions to ensure reliable and comparable data that is based on learner performance in the classroom.
- Require research and development projects to maintain good practice on screening for the specific diagnosis for each SpLD considered, and its related milder conditions, such as dyscalculia and Mathematics Learning Difficulties (MLDs).
- Use research on technology-based interventions, with standardised, trackable, and measurable data on learners' interaction analytics that enable properly controlled trials of which work best.
- Use Massive Open Online Courses (MOOC) platforms for open online collaborations, to engage teachers in the Research and Development (R&D) process by guiding the large-scale empirical testing of digital interventions with their help.
- Government should endorse and require the certification supplied by MOOC platforms to motivate teachers and other education professionals to collaborate on effective innovation for SpLDs.
- Develop online courses, webinars, and support sites to provide collaborative professional development on all SpLDs, which are often not covered adequately in training courses. Access should be extended to parents, other education professionals and policymakers.

Review 1: Current understanding of causes and identification of SpLDs

Professor Julia Carroll, University of Coventry

1. Executive summary and key recommendations

This review summarises evidence and makes recommendations on the question:

> *How has our understanding developed around the causes and identification of Specific Learning Difficulties over the past decade?*

According to national education data, specific learning difficulties (SpLDs) are amongst the most common special educational needs affecting students. Based on the available evidence, steps must be taken to provide improved identification and support of SpLDs within schools to effectively meet learner needs. Increased use of methodologically sound longitudinal studies to understand these issues would be highly beneficial.

The following recommendations for policy and research arise from this review:

- There is a disconnect between the needs-based identification used in schools and the formal diagnosis required by universities and employers, and also the ‘identification pathways’ used by health services. It would be useful to align these systems more.
- As most children show difficulties in school as some of the early warning signs for SpLDs, teachers and SENDcos need to be much better equipped to identify and support SpLDs. In particular, all teachers should be aware that SpLDs are very common, there are no clear dividing lines between typical and atypical learners with respect to SpLDs, co-occurrence of SpLDs is high, and all children should be supported according to their needs, which will change over time.
- Further research is needed on the role of identification in the progress of SpLDs over time. This requires longitudinal approaches.
- No single method of identification of SpLDs is ideal. Identification needs to be an ongoing process gaining information from multiple sources (parents, teacher, standardised measures) over a period of time.
- Focus on a single area of processing for identification and diagnosis is not helpful, because of the interactions between different risk factors and the high levels of co-occurrence of different disorders.
- Early identification is useful but should be accompanied by regular updates and reassessments to understand how needs change over time.
- Recent research findings indicate that studies including multiple methodologies (e.g. combining genetic, neuroimaging and behavioural measures) and levels of explanation are a fruitful future research area in SpLDs.
- The National Pupil Database is a precious resource that should be used for large-scale longitudinal data analysis of SpLDs. It also provides an opportunity to understand the divisions between research and practice in more detail.
- With respect to learners with SpLDs, more studies are needed to understand how and why response to intervention varies across learners, and it may be that genetic and neurobiological factors play an important role in this. One approach may be to combine intervention studies with longitudinal cohort studies to allow these types of analyses.

2. Methodology

The guidance received was that I should use my existing knowledge of the area to guide my search strategy, rather than relying only on systematic searches. Hence, I planned the sections based on the specification given, my own knowledge of the area, and recent searches carried out for reviews on dyslexia and developmental language disorder (DLD) (Hayiou-Thomas, Carroll, & Snowling, 2018; Carroll & Critten, 2019).

I supplemented this knowledge using various methods:

- I carried out general searches using PsycInfo[4]. I carried out searches for different SpLDs using the pre-set search terms and limiting searches to literature reviews, systematic reviews and meta-analyses published in the last 10 years. I then read titles and abstracts and selected papers that would be useful to read in more detail. Pre-set search terms were as follows:
    - Dyslexia OR dyslexic OR reading disability OR learning disability
    - Dyscalculia OR math difficulty OR math disability OR mathematics disability OR mathematics difficulty
    - Dyspraxia OR developmental co-ordination disorder OR DCD OR motor co-ordination
    - Language disorders OR language impairment OR specific language impairment
    - I also carried out a search for dysgraphia but concluded that the evidence was not strong enough to include it as a separate disorder
- I also carried out searches for specific topics that I had planned to include within the review, so for example ‘working memory’, ‘brain’ or ‘genetics’ alongside the pre-set disorder search terms (limited to the previous 10 years again). Again, the titles and abstracts of returned papers were used to select useful references.
- I used Scopus to carry out author searches to find recent work by well-established leaders in the field: for example, Bruce Pennington, Robert Plomin, Margaret Snowling, Brian Butterworth, Dorothy Bishop. I also searched for recent work from some less high-profile authors who I knew had done some particularly interesting or novel work: Courtenay Norbury, Duncan Astle and Elsje van Bergen.
- Throughout the process, I also employed informal search strategies – for example, following up references in reviews, recent papers I had read, and papers highlighted by researchers I follow on Twitter.
- With respect to assessing the quality of the evidence, it is perhaps worth saying that I have not included any studies which I consider to be low-quality research. There are some areas in which the research is quite novel (e.g. with respect to the neurological research) which I think requires replication. I have made an effort to highlight where I think research needs further replication.

[4] PsycInfo is a comprehensive international database of psychology and relevant materials from medicine, education, psychiatry and social science. The benefits of PsycInfo are that one can limit searches to types of paper – e.g. systematic reviews and meta-analyses. It also has some pre-set search terms. For example, if you type ‘dyslexia’ it suggests ‘dyslexia OR dyslexic OR reading disability OR learning disability’. This is an efficient way of finding papers using varied terminology.

3. Background: What are Specific Learning Difficulties?

Specific learning difficulties (SpLDs) are some of the most common special educational needs affecting learners. The underlying logic behind the term ‘specific learning difficulty’ is that these individuals have a weakness in one specific area of cognition, and that other areas are unimpaired. This is likely to be a significant over-simplification, as discussed later.

3.1 Dyslexia

This is the most well understood and commonly diagnosed SpLD. A widely accepted definition occurs in a 2009 government report (Rose, 2009):

> *Dyslexia is a learning difficulty that primarily affects the skills involved in accurate and fluent word reading and spelling. Characteristic features of dyslexia are difficulties in phonological awareness, verbal memory and verbal processing speed. Dyslexia occurs across the range of intellectual abilities. It is best thought of as a continuum, not a distinct category, and there are no clear cut-off points. Co-occurring difficulties may be seen in aspects of language, motor co-ordination, mental calculation, concentration and personal organisation, but these are not, by themselves, markers of dyslexia.*

Dyslexia occurs in 5-10% of the population. It runs in families and has a significant heritable component, discussed in more detail below (Snowling & Melby-Lervåg, 2016). Individuals with dyslexia are likely to have long term difficulties in adulthood (Maughan et al., 2009). It is likely that the consequences of dyslexia are particularly acute for those learning to read and write in English, because English is a complex language with a large vocabulary and many irregular spellings (Seymour, Aro, & Erskine, 2003).

There is a large body of evidence demonstrating that phonological awareness and processing (that is, awareness and processing of speech sounds) plays an important causal role in dyslexia and that providing teaching which includes phonological awareness improves literacy skills in this group (Bus & Ijzendoorn, 1999; Melby-Lervåg, Lyster, & Hulme, 2012). Indeed, phonological awareness training is useful for almost all children (Ehri et al., 2001). Nonetheless, phonological awareness deficits are neither necessary nor sufficient for explaining literacy difficulties (Carroll & Breadmore, 2018; Carroll, Solity, & Shapiro, 2016), and recent evidence indicates dyslexia occurs as a consequence of multiple risk factors (Pennington et al., 2012), with phonological awareness likely to be the most important risk factor.

3.2 Developmental Language Disorder

Developmental Language Disorder (DLD) has been described as “the most common developmental disorder that you have never heard of”. Over the past 10 years, there has been a sustained campaign to raise awareness of DLD and to standardise the terminology used to describe and define the disorder (Bishop, Snowling, Thompson, & Greenhalgh, 2017). The CATALISE consortium agreed that DLD should be diagnosed in children who “have language difficulties that create obstacles to communication or learning in everyday life and the problems have not resolved by five years of age, and are not associated with a known biomedical condition such as hearing loss or autism.”

They also agreed to use the term DLD in preference to the wide range of terminology previously used to describe the disorder, including specific language impairment (SLI), language impairment, language learning difficulties and verbal dyspraxia.

Recent prevalence estimates put the rate of DLD at approximately 7% in UK five-year-old children (Norbury et al., 2016). Age is an important factor in this disorder: many children show transient language difficulties which resolve by age 5. Children who show difficulties at age 5 tend to show persistent difficulties (Norbury et al., 2017), and are at increased risk of a range of negative long-term outcomes, including poor educational qualifications, emotional and behavioural difficulties (Conti-Ramsden, Durkin, Toseeb, Botting, & Pickles, 2018; Snowling, Bishop, Stothard, Chipchase, & Kaplan, 2006).

It is generally agreed that there are multiple causes of DLD, and, like dyslexia, it runs in families and there is a significant genetic component to the disorder (Bishop & Hayiou-Thomas, 2007; Rudolph, 2017). Children with DLD respond well to high-quality language intervention delivered individually or in small groups (Fricke et al., 2017).

3.3 Dyscalculia

Dyscalculia (or mathematics disorder) is defined as a significant difficulty in numerical processing despite otherwise normal intellectual abilities and educational experiences (Landerl, Bevan, & Butterworth, 2004; Schwenk et al., 2017). Prevalence rates seem similar to those for dyslexia at around 6% (Gross-Tur, Manor, & Shalev, 1996). Dyscalculia often co-occurs with other SpLDs, as will be discussed below, but can also occur in isolation (Landerl & Moll, 2010).

Many researchers argue that the underlying deficit in dyscalculia is a specific weakness in numerical processing, demonstrated by slow and error-prone responses to basic tasks such as saying which number or quantity is larger (Butterworth, 2010). Others argue that working memory deficits, particularly in visuo-spatial working memory, are core to the disorder (David, 2012), or highlight deficits in information processing speed (Willburger, Fussenegger, Moll, Wood, & Landerl, 2008) . It is likely that multiple underlying deficits may be relevant.

As with other SpLDs, there is evidence for a significant heritable component in dyscalculia (Kovas et al., 2007), and evidence of significant co-occurrence with other SpLDs (Willcutt et al., 2013). There is also evidence for the long-term negative effects of dyscalculia (Aro et al., 2019).

3.4 Developmental Co-ordination Disorder

Developmental Co-ordination Disorder (DCD) is the internationally recognised term for developmental dyspraxia. It is characterised by significant difficulties in both gross motor and fine motor co-ordination, which can cause widespread difficulties in daily life – for example in handwriting. It has an estimated prevalence of 1.7% of the UK population of seven-year-olds (Lingam et al., 2009). Individuals with DCD often show additional problems in literacy, attention and social communication, and on average tend to show poorer educational outcomes (Harrowell et al., 2018). In other words, it is likely to co-occur with other SpLDs.

Individuals with DCD are on average less active than their typically developing peers, and are at increased risk of obesity (Cairney & Veldhuizen, 2013). This is likely to be an example of a gene-environment correlation, as described in the section on genetics below.

Causal theories of DCD have focused on neurological and cognitive underpinnings of the condition, but the causes are not yet well established (Wade & Kazeck, 2018; Wilson, Caeyenberghs, Dewey, Smits-Engelsman, & Steenbergen, 2018).

3.5 Other related developmental disorders

There are several other SpLDs that have been proposed, including dysgraphia, non-verbal learning difficulties and others. However, the existing evidence does not clearly establish the value of these labels as separate diagnostic categories. For example, dysgraphia seems to co-occur with dyslexia at an extremely high rate, and might be better considered a form of dyslexia (Döhla, Willmes, & Heim, 2018).

Attention difficulties and attention deficit hyperactivity disorder (ADHD) commonly co-occurs with all SpLDs. ADHD would normally be diagnosed by a medical professional, because medical treatment can be useful in managing the condition. However, ADHD often causes extensive difficulties in learning, and many children present with both ADHD and one or more SpLDs, suggesting some shared underlying causes.

4. Issues around definitions of SpLDs

4.1 Differences in research and practice definitions of SpLDs

Differences between ways of defining SpLDs for research studies and for practical support in education have been under-recognised by researchers as well as educators. For example, Quinn and Wagner (2015) reported that only around 20% of children identified as having reading difficulties by research criteria were also identified by the school, and vice versa. While this study is carried out in the USA with a relatively young sample (second graders, or seven-year-olds), and therefore cannot be automatically generalised to the UK education system, it certainly implies a lack of agreement in diagnosis.

In part, this discrepancy is likely to be because the role of definition in each case is quite different: researchers are trying to understand similarities and characteristics of a group of learners at a single point in time. In contrast, educational professionals are trying to understand how best to support an individual over time. As such, SpLDs are often defined in research studies by performance on a few short measures (for example, dyslexia would be defined by showing a below average score on word reading, or dyscalculia by a below average score on an arithmetic measure), rather than trying to gather a range of information from multiple informants (Lopes, Gomes, Oliveira, & Elliott, 2020). This implies that not all individuals with an SpLD as defined by researchers would meet criteria for diagnosis by education professionals, and vice versa (Castles, 2014).

There are multiple commonly used approaches to identification and diagnosis of SpLDs, which are described in the 'identification' section below. Each has their own strengths and weaknesses and will identify slightly different groups of children.

4.2 Changes to diagnostic criteria for SpLDs

In 2013, the most recent version of the Diagnostic and Statistical Manual was published (DSM-5). This included several changes to the way that developmental disorders were classified. Rather than listing reading, writing and mathematical disorders separately, an umbrella term, 'Specific Learning Disorder', was introduced. This reflects the finding that there are high levels of co-occurrence between different learning disorders. Similarly, the two disorders 'expressive language disorder' and 'mixed expressive-receptive disorder' were combined into a single 'language disorder'.

The DSM-5 also changed the terminology around the role of intelligence in diagnosis of SpLDs. DSM-IV had indicated that a discrepancy between 'measured intelligence' and academic achievement should be demonstrated for diagnosis, whereas DSM-5 instead states that the difficulties in academic achievement are not explained by 'intellectual disability'. In other words, a discrepancy between intelligence scores and attainment scores is not required for diagnosis. This reflects a recent widespread change to our understanding of the role of intelligence testing in diagnosis of SpLDs.

One major and consistent change to identification of SpLDs and DLD is in the role of underlying intelligence as a factor. Classically, SpLDs were diagnosed in terms of a discrepancy between ability in a specific area and overall intelligence level. However, researchers have been arguing for many years that this is not ideal, for various theoretical, pedagogical and practical reasons. Fundamentally, there is not clear evidence for differences in the underlying causes or characteristics of SpLDs or DLD according to intelligence level (Norbury et al., 2017; Stanovich, & Siegel, 1994; Tanaka et al., 2011). Therefore, overall intelligence should not have a role in identification unless individuals show severe general learning difficulties. However, it can be useful in understanding overall strengths and weaknesses and predicting prognosis, and therefore can be useful to include in assessment. This view is now widely accepted. It is perhaps worth highlighting that broadening the definition of SpLDs in this way will lead to the inclusion of individuals with more complex patterns of difficulties (Snowling, Hulme, & Nation, 2020).

5. What are the causes of SpLDs

5.1 Classical causal models of SpLD

Classically, causal models of SpLD have sought specific causes, with the implicit idea that there is a single cognitive impairment that underlies each disorder: for example, dyslexia is caused by a phonological impairment; ADHD is caused by an impairment in executive function, and so on. There are two problems with this approach: first, that single deficits don't seem to coincide with disorders consistently (Carroll et al., 2016), and second, that co-occurrence of different developmental disorders (especially SpLDs) is the norm rather than the exception. Around 50% of children with a diagnosis of dyslexia also meet criteria for DLD, and vice versa (McArthur, Hogben, Edwards, Heath, & Mengler, 2000). Furthermore, children with SpLD show increased risk of a wide range of emotional and behavioural difficulties (Carroll, Maughan, Goodman, & Meltzer, 2005).

5.2 Describing causes: Levels of explanation and proximal and distal causes

When considering causes in SpLDs, it is useful to consider that causes can often be described at different levels of explanation (Morton & Frith, 1995).

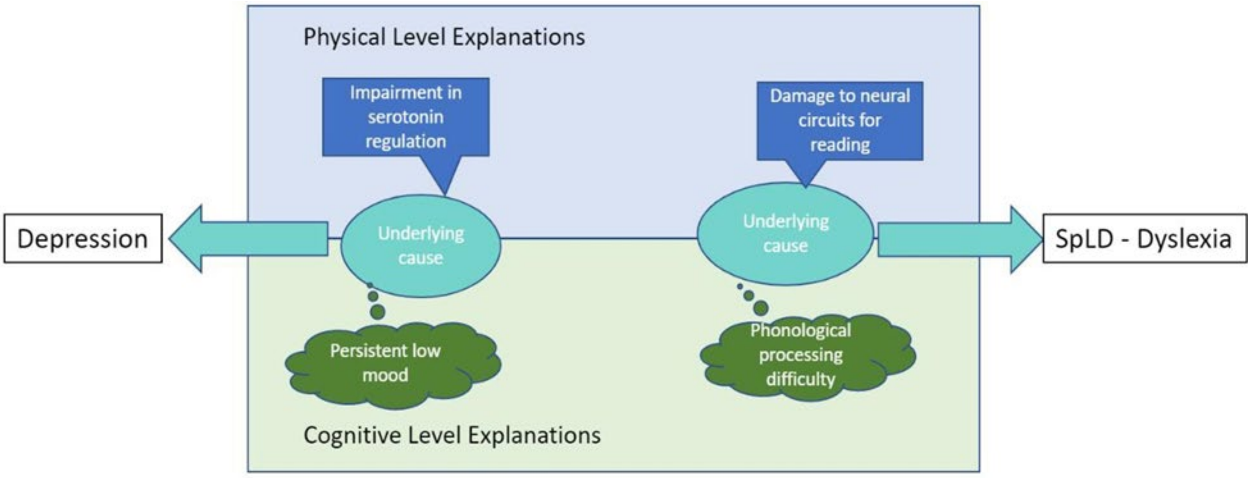

Figure 1: different levels of explanation of underlying causes

The biological level involves the neurological brain processes that occur. Every mental (cognitive) event is also a physical (biological) event, and therefore all brain processes can be described at both cognitive and biological levels. Figure 1 demonstrates some potential underlying causes that can be defined at both the physical and cognitive levels. Note that these are examples rather than verified explanations for each disorder. Sometimes both levels of explanation are relevant. For example, depression can be improved both by biological means (e.g. anti-depressants) and cognitive means (e.g. counselling). Sometimes it is more useful to focus on one level of explanation rather than another. It is often useful to focus on cognitive, rather than biological, explanations for the causes of SpLDs. These explanations rely on non-invasive methods of investigation which are accessible to education professionals, and currently provide much more reliable and predictive links to behaviour than neurological explanations. This is not to say that neurological explanations will not prove useful in the future.

It can also be useful to distinguish proximal and distal causes. Proximal causes are the immediate cause of an outcome, while distal causes have more long-term and indirect effects. Genetic effects would generally be distal causes, because the genes code for proteins which influence brain biology at various stages of development. Broad environmental factors such as socio-economic disadvantage or parental education would also be distal causes, rather than proximal causes. In the case of both proximal and distal causes, it may be better to classify these elements as 'risk factors' rather than causes: their effects are probabilistic, rather than deterministic.

5.3 The developmental nature of SpLD

Classical models drew parallels between SpLDs and patterns of adult brain damage in which specific functions are impaired. However, we now know that these models are inadequate (Karmiloff-Smith, 1998). The developing brain is much more plastic than an adult brain, and will respond to areas of damage or weakness by functional reorganisation (Blakemore & Frith, 2005). Children are constantly changing in terms of their cognitive abilities. It is unsurprising therefore that the nature of an individual's cognitive strengths and weaknesses will vary over time and according to the demands placed on them by their environment.

In the past, research has focused on children early in development, in order to find possible underlying causes and effective intervention strategies. This means that we know relatively little about how disorders change and develop over time, particularly into adolescence and adulthood. However, we do know that individuals with a history of SpLD are at increased risk of lower educational qualifications, more unstable employment and lower psychological wellbeing (Aro et al., 2009; Maughan, 1995).

5.4 Co-occurrence between different disorders

As mentioned above, SpLDs co-occur more often than would be expected by chance. They also co-occur with other developmental disorders, such as ADHD and autism, as well as emotional and behavioural difficulties (Carroll et al., 2006). There are several possible reasons for this, which are not mutually exclusive (Angold, Costello, & Erkanli, 1999). Disorders often share underlying risk factors, whether these are environment risk factors such as socioeconomic disadvantage, or genetic risk factors. An alternative view is that the existing divisions between SpLDs do not adequately characterise the patterns of impairments. For example, Moll, Landerl, Snowling, & Schulte-Korne (2015) argue that a similar behavioural difficulty (mathematical difficulty) can be caused by different underlying causes, suggesting that two children could be classified as having similar difficulties despite different underlying causes. A third view, based on the multiple deficit model (MDM), is that disorders share some underlying cognitive deficits and have some additional specific deficits. This third view seems to be a promising way to characterise developmental disorders and SpLDs in particular and is discussed in more detail below.

5.5 Multiple cause models of disorders

Pennington (2006) proposed a multiple deficit model (MDM) of developmental disorders. Rather than a single underlying deficit matching up to a specific disorder, he argued that developmental disorders occur when there is a combination of different risk factors. This account helps us to understand why developmental disorders co-occur so often, and why we see children with ostensibly the same developmental disorder showing different underlying impairments. In Pennington's example, children with dyslexia tend to have difficulties in processing speed as well as phonological impairments. Children with a single deficit in either domain would be likely to overcome their difficulties and not show a developmental disorder (though they might show, for example, transient spelling difficulties). On the other hand, some deficits are shared across disorders: processing speed difficulties occurring in both dyslexia and ADHD, for example, while phonological difficulties occur in both dyslexia and developmental language disorder.

There is growing convergent evidence in favour of the MDM (McGrath, Peterson & Pennington, 2020). Multiple studies have shown that co-occurring SpLDs can be explained by common underlying cognitive factors (Moll, Göbel, Gooch, Landerl, & Snowling, 2016). There is also evidence that most individuals with SpLDs show multiple, rather than single, underlying cognitive deficits (Carroll et al., 2016).

5.5.1 How has our understanding of 'causes' changed?

- Using the MDM as a framework has changed our understanding of the causes of SpLDs in quite fundamental ways. Most importantly, it leads us to consider co-occurring deficits as an integral part of a disorder, rather than an unnecessary complication. Historically, researchers have tried to select 'pure' examples of a disorder, with no co-occurring difficulties. We now understand that this artificially limits the sample and distorts the patterns of impairments we see. We need to understand this complexity rather than marginalise it.
- This approach also makes us consider causes as probabilistic rather than deterministic. We used to think of genetics as highly deterministic, searching for a gene underlying a particular skill or disorder. We now understand that genes interact with one another and with the environment in extremely complex ways.
- Similarly, we must also think of underlying brain processes as probabilistic rather than deterministic. The brain changes and compensates for damage or weakness in many different ways. Different patterns of brain activation can lead to the same behavioural patterns, and vice versa.
- These factors are daunting and show that understanding of SpLDs is more complex than we supposed. In order to understand this complexity, large-scale studies which follow individuals over time are needed.

5.5.2 Potential complications of using this approach

The multiple deficit model does have some disadvantages (McGrath, Peterson, & Pennington, 2020). It is relatively difficult to falsify: a poorly fitting model could always be explained by an additional, unmeasured variable. Second, it focuses on risk factors, rather than protective and compensatory factors. McGrath et al suggest that it should be renamed the 'multiple factors model' rather than 'multiple deficit model'.

A third drawback of the MDM is that it is inherently complex. Rather than focusing in on a single specific deficit, one needs to take a global view of a child, consider all their strengths and weaknesses, and how they potentially interact.

6. Risk factors in SpLDs

6.1 Genetic effects in SpLDs

There are two types of genetics research relevant to the study of developmental disorders: behavioural and molecular genetics. Behavioural genetics studies genetic and environmental effects on behaviours, mainly through twin and family studies. Molecular genetics seeks to understand the functions of particular genes. Behavioural genetics has demonstrated that SpLDs have a substantial genetic component (Willcutt et al., 2010). There is also evidence to indicate that the genes associated with different developmental disorders tended to be similar across those disorders, as well as being associated with abilities within the average range. In other words, genetic effects tend to be quite general in nature, increasing the risk of a developmental disorder (Plomin & Yovas, 2005). In contrast, Plomin and Yovas argue that the environmental effects which each individual experiences are specific, thus one set of environmental factors might lead to a child presenting with dyslexia, whilst another set results in a child with the same genetics presenting with ADHD.

It is worth highlighting that Plomin and Yovas do not provide details of the factors in the environment that might lead to these differences, and this is a significant shortcoming. It is, at present, more a theoretical framework than a detailed model. However, if one accepts the framework, it indicates that the learning environment of a child has an important influence on the manifestation of their learning difficulties. Therefore, schools and teachers can help students to overcome learning difficulties. However, as the underlying genetic factors remain, students are likely to require ongoing support as the demands of their curriculum changes.

The multiple deficit account and the generalist gene hypotheses have a lot in common, and have been usefully combined (e.g. van Bergen, van der Leij, & De Jong, 2014). They both suggest that developmental disorders can be considered as aggregations of multiple small risk factors, which in themselves are not necessary or sufficient to cause a disorder.

6.2 Gene-environment interactions/correlations

In the past decade, there has been much research on understanding the interactions and correlations between genetics and the environment, rather than considering them as opposing forces in development. Different genetic factors can make some individuals more susceptible to ‘risky’ environments than others. For example, Viding, Frick, & Plomin (2007) demonstrate that individuals with a particular gene form are more susceptible to abusive home environments, and an interaction of this gene form and an abusive home life is likely to lead to conduct disorder. These gene-environment interactions are likely to play a role in SpLDs, though as yet evidence is minimal. This is an area for potential future research. For example, it may well be that a good home literacy environment is more important for individuals with a genetic risk of dyslexia.

Gene-environment correlations also play an important role in the development of SpLDs. Individuals often choose an environment in line with their early strengths and weaknesses – in other words, children will spend more time on a task on which they are relatively successful. Underlying reading ability is a strong predictor of time spent reading (van Bergen et al., 2018).

6.3 Brain structure and function

In the past three decades, our capabilities to examine brain structure and function in children and adults has increased almost beyond recognition. We are able to describe the areas of the brain involved in cognitive tasks such as reading, language, and mathematical calculations, and abnormal activity in these areas is often found in individuals with SpLDs (Fletcher & Grigorenko, 2017). There are also some interesting preliminary findings which point to the potential from neuroscience. For example, Hoeft et al. (2011) describe a longitudinal study in which specific patterns of brain structure and brain activity during a phonological task predicted improvement in reading over two years in a sample of individuals with dyslexia. However, this study uses a small sample size and findings must be interpreted with caution. Importantly, this field of research has also demonstrated considerable variation between individuals (see Box 1 for further details), making interpretation of findings highly complex. At present, there are relatively few findings from neuroscience that have direct implications for education (Bowers, 2016), but these findings have an important role in refining and constraining theoretical explanations of disorders (Howard-Jones et al., 2016).

Box 1: Spotlight on innovative UK research: The CALM project

A recent large-scale study (the CALM project: http://calm.mrc-cbu.cam.ac.uk/) by the University of Cambridge has examined both the appropriateness of diagnostic categories and the patterns of brain connectivity that might underlie these categories, by studying over 600 children referred by their schools or doctors as having developmental difficulties. While this research found some evidence for some different profiles of difficulties, patterns of brain connectivity were not neatly aligned with these different cognitive profiles. Most cognitive profiles were aligned to three or four different brain patterns, and the brain patterns also aligned to several different cognitive profiles. The authors conclude that it is not straightforward to align brain structure with cognitive profile. However, they argue that the structure of the brain, around a few key ‘hubs’, plays an important role in how resilient to difficulties the brain is (Siugzdaite, Bathelt, Holmes, & Astle, 2020).

6.4 The role of working memory and executive function in SpLD

Working memory is the memory used to ‘hold things in mind’, such as visual or verbal information, while processing it (e.g. when carrying out calculations). Executive functions are the skills of planning, inhibition and focusing attention. Difficulties in working memory are common to dyslexia (Peng & Fuchs, 2016), DLD (Archibald & Griebeling, 2016) and dyscalculia (David, 2012), and, more broadly, children who struggle at school (Gathercole et al., 2016), though the pattern of impairments may differ across the different disorders (Moll, Gobel, Gooch, Landerl, & Snowling, 2016; Willcutt et al., 2013). Difficulties in executive function are common symptoms in all of the SpLDs discussed above, though the extent to which these can be explained by comorbid attention difficulties is unclear (Willcutt & Pennington, 2000).

Despite the finding that working memory difficulties are often implicated in SpLDs, there is limited evidence that training working memory is a useful or even possible way to overcome these difficulties (Melby-Lervåg & Hulme, 2013; Melby-Lervag, Redick, & Hulme, 2016). Instead, a focus on reducing the requirement for working memory in everyday tasks, by providing written instructions, ensuring that the materials used are familiar, and practising the operations regularly, is likely to be more useful (Quigley, Mujis, & Stringer, 2018).

6.5 Mental health implications

There is growing evidence that SpLDs are commonly associated with difficulties in mental health, particularly anxiety (Francis, Caruana, Hudson, & McArthur, 2019). Anxiety in SpLDs can be a self-perpetuating cycle: heightened anxiety places greater demands on working memory, making cognitively demanding tasks such as spelling, reading aloud or mathematical calculations more difficult, which in turn increases anxiety (Ashcraft & Kirk, 2001).

Anxiety is particularly associated with mathematics, with maths anxiety a recognised condition in its own right. It is worth highlighting that the association between maths anxiety and dyscalculia is relatively low: many individuals show maths anxiety without maths difficulties, and vice versa (Devine et al, 2018).

6.6 Different factors involved in SpLDs: Implications for Educators

- All SpLDs run in families. Understanding the role of genetic influences in the development of SpLDs is complex because genes act in complex ways and the effects of genes are influenced by gene-environment interactions and correlations.
- Hence, knowing that a child has a family history of an SpLD is useful in understanding whether they have a high risk of developing an SpLD, but there are unlikely to be genetic ‘tests’ for SpLDs in the near future.
- Knowledge of brain development in SpLDs is increasing, but many studies are small in scale and variations in the relationship between brain structure and function in different disorders are not understood.
- Working memory difficulties occur in a range of different SpLDs, but may differ according to the type of SpLD. It appears that focusing on reducing cognitive load is more successful than trying to train working memory itself.
- Children with SpLDs are at an increased risk of anxiety and depression, though it is not the case that most children with SpLDs show anxiety and depression.

7. Identification of SpLDs

7.1 Identification pathways

Most SpLDs are initially detected within education settings such as schools, colleges and universities. There are currently significant differences in the identification pathways in compulsory and post-compulsory education and employment in the UK. This can make the world of SpLD diagnosis and support a complex and daunting world for learners and their families.

In schools, the SEND Code of Practice (Department for Education, 2015) advocates a needs-based approach to support: support should be provided according to the needs of the learner, and learners do not need to have a diagnosis to access support. In principle, this should allow widespread support tailored to children's needs. In practice, it seems that these disorders are very under-identified in schools. In 2018, less than 2% of school pupils were registered as having SEND with SpLD as their primary need, in comparison to estimated prevalence (above) of 5-10%. Similarly, less than 3% of learners have speech, language and communication as their primary need, in comparison to the Norbury et al. (2016) estimate of 7%. In both cases, this suggests that over half of learners with SpLD and DLD do not have their needs formally recognised in school, though it should be noted that they may be recorded as having other 'primary needs'. Similarly, Harrowell et al. (2018) find that 40% of their sample of adolescents with severe DCD had not had any support through school.

While dyslexia and dyscalculia are normally diagnosed by an educational psychologist or specialist dyslexia assessor, there are different pathways to diagnosis for other SpLDs. Developmental Language Disorder would normally be diagnosed by a speech and language therapist. A paediatrician, often working as part of a multi-disciplinary team, would diagnose DCD and commonly co-occurring diagnoses such as ADHD. This multiplicity of assessors and identification pathways can be frustrating and confusing for families of children with difficulties, especially since so many children show co-occurring difficulties. Diagnosis is valuable, both for accessing appropriate support and services and for learners and families to have an understanding of their difficulties and a positive self-concept. However, at present the diagnosis that an individual receives is dependent on their chosen identification pathway, creating a 'postcode lottery' in diagnosis.

When individuals leave school, identification is no longer governed by the SEND Code of Practice. However, the Equality Act (2010) states that individuals with disabilities are entitled to receive 'reasonable adjustments' to support their difficulties. In order to receive this support, individuals with SpLD are required to provide a diagnostic assessment of their difficulties, often carried out by private specialists. In effect, this creates a disjointed system, where the identification and support pathways are very different in school and beyond school. This adds further to the confusion and frustration of individuals progressing through the system. There is a need for greater clarity and consistency in the assessment, identification, and diagnosis of individuals throughout the lifespan.

There are also very different issues around identification and diagnosis of SpLDs in higher education and employment. In higher education, there is a perception that a diagnosis of an SpLD may lead to benefits (such as extra time in examinations) and very few negative consequences. Hence, it has been argued that diagnostic assessment at higher education should include validity measures to distinguish individuals feigning their difficulties (Harrison, Edwards & Parker, 2008; van den Boer, de Bree, & de Jong, 2018). Conversely, disclosure within employment can be associated with stigma, and many adults with dyslexia choose not to disclose their difficulties to their employer for fear of negative consequences, despite the legal protection of the Equality Act (Morris & Turnbull, 2007).

Box 2: How educators can use the MDM: Embracing Complexity

"Embracing complexity" is a call to action from a coalition of 38 charities representing different neurodevelopmental conditions and mental health. They provide examples of services which support individuals with multiple complex neurodevelopmental conditions, including SpLDs.

(http://embracingcomplexity.org.uk/assets/documents/Embracing-Complexity-in-Diagnosis.pdf).

7.1.1 Identification pathways: Implications for education policy and research

- Needs-based identification and the graduated approach, as espoused in the Code of Practice, fits well with current research showing the interactions between multiple factors in SpLDs.
- However, there is a disconnect between the needs-based identification used in schools and the formal diagnosis required by universities and employers, and also the 'identification pathways' used by health services. It is timely to align these systems more.
- As most children show difficulties in school as some of the early warning signs for SpLDs, teachers and SENDcos need to be much better equipped to identify and support SpLDs. In particular, all teachers should be aware that:
    - SpLDs are very common – there are likely to be 2 or 3 children with SpLDs in every classroom.
    - There are no clear dividing lines between typical and atypical learners with respect to SpLDs.
    - SpLDs co-occur more often than would be expected by chance with other developmental disorders.
    - All children should be supported according to their needs, and their needs will change over time.
- With respect to research, more information is needed on the role of identification in the progress of SpLDs over time. This requires longitudinal approaches.

7.2 The role of age and development in identification

As described above, there are significant changes with age in the prevalence and presentation of different SpLDs. DLD, in particular, is often identified early in primary school, while dyslexia would not generally be identified until at least two years of schooling have been completed. According to Department for Education figures, 29% of pupils with SEND have speech language and communication needs as their primary need in primary school, while only 11% of children with SEND have this as a primary need in secondary school. In contrast, 9.5% of children with SEND have SpLD as a primary need in primary school, while 21% of children with SEND have SpLD as a primary need in secondary school. This is cross-sectional data, so it is not possible to determine developmental pathways. However, given the research linking DLD with literacy difficulties in adolescence (Snowling, Bishop, & Stothard, 2000), it is likely that many children with early speech, language and communication needs go on to show SpLD at secondary school (Botting, Simkin, & Conti-Ramsden, 2006). This is likely to be partly due to changes in the skills of the learners, and partly due to changes in the demands of the educational environment, as written communication becomes more prominent than verbal communication.

7.3 The benefits and limitations of early identification, and where improvements are most needed

It is widely argued that early identification and support is important (Colenbrander, Ricketts, & Breadmore, 2018). There are several examples in the research literature where early intervention for high-risk individuals has had a positive influence throughout childhood (Byrne, Fielding-Barnsley, & Ashley, 2000; Sylva, Melhuish, Pam Sammons, Siraj-Blatchford, & Taggart, 2004; Tymms, Merrell, & Bailey, 2017).

Early intervention appears to be particularly useful in for those children most at risk of later difficulties (Dion, Brodeur, Gosselin, Campeau, & Fuchs, 2010; Hatcher, Hulme, & Snowling, 2004). It is therefore worthwhile identifying individuals at high risk of SpLDs and DLD early in education (around 5-7 years old). However, there are caveats to this. The first is that identification and diagnosis should be an ongoing process rather than a single event, given the role of age and the environment in developmental disorders. Along the same lines, early intervention should not be thought of as an inoculation against future difficulties. Instead it is a starting point. Individuals with SpLDs are likely to require ongoing support as the demands of the academic curriculum change with age. This is perhaps most pertinent in the case of DLD, where there is much greater support for children with DLD in the age range 4-7 years than there is later in development, despite the finding that children with DLD are at high risk for other difficulties in adolescence (Snowling et al., 2006).

There is some evidence that interventions later in development may show more long-term effects (Suggate, 2014), though this is somewhat controversial. It is difficult to examine directly, as the content of the interventions provided at different ages will vary in line with the needs of the learners. Because interventions given to younger and older children differ, it is difficult to know whether it is the content of the intervention (including the dosage) or the age of the learners that is most pertinent.

7.4 Focus on a profile of cognitive strengths and weaknesses versus diagnosis

Multiple findings lead to the conclusion that it is more useful to focus on an overall profile of strengths and weaknesses of a learner rather than seeking a particular diagnosis. This approach fits with the multiple deficits model and avoids the limitations imposed by using a single diagnostic category to represent a heterogeneous group of children. It focuses attention on the needs of the learner rather than on a diagnostic label. However, there are some reasons to be cautious about relying on information concerning underlying cognitive difficulties. Early studies attempting to match cognitive strengths and weaknesses to patterns of reading or language difficulties have met with only limited success (Miciak, Fletcher, Stuebing, Vaughan, & Tolar, 2014; Pennington et al., 2012). This suggests that this modelling will not be simple to understand, but nonetheless it is a useful avenue to pursue. Recent advances using computational modelling to understand disorder pathways may prove fruitful in the future (Astle, Bathelt, & Holmes, 2018).

7.5 Focus on responsiveness to intervention

In the USA, the preferred model of identification of SpLDs is responsiveness to intervention (Catts, Nielsen, Bridges, Liu, & Bontempo, 2015). Within this framework, all children who are identified as being at risk of SpLDs receive low intensity (normally small group) intervention, and their progress is monitored. Those children who do not improve following the small group intervention would then be the children labelled as having an SpLD, and would be eligible to receive more focused, intensive support. This system has a great deal to recommend it, but its success relies on well planned interventions and careful monitoring of progress. It is also important to be aware that even successful intervention will not necessarily prevent future difficulties later in schooling. A potential concern with this approach is that individuals with relatively mild difficulties respond well to early intervention and are ‘discharged’, but go on to have difficulties when academic demands change.

7.6 Factors in identification: Implications for SEND policy

- No single method of identification of SpLDs is ideal. Identification needs to be an ongoing process gaining information from multiple sources (parents, teacher, standardised measures) over a period of time.
- Focus on a single area of processing for identification and diagnosis is not helpful, because of the interactions between different risk factors and the high levels of co-occurrence of different disorders.
- Early identification is useful but should be accompanied by regular updates and reassessments to understand how needs change over time.

8. Summary: Implications for future research priorities

Recent research findings indicate that studies including multiple methodologies and levels of explanation are a fruitful future research area in SpLDs. Studies combining genetic, neuroimaging and behavioural measures are useful in other developmental disorders (Viding et al., 2011; Siugzdaite et al., 2020), and are likely to become useful in understanding SpLDs.

The role of development and change over time has an increasingly important role in understanding SpLDs. Longitudinal data are understandably difficult to collect. However, the UK has a strength in large-scale longitudinal studies, having carried out regular national cohort studies since the first British Cohort Study in 1958. There is also a wealth of longitudinal data collected as part of the National Pupil Database, and similar databases with respect to higher education. Data from the National Pupil Database are now routinely linked to data from longitudinal cohort studies, allowing analysis of educational progress in addition to data on health, home environment and change over time. There are opportunities for large-scale longitudinal data analysis of SpLDs using these data. These data also provide an opportunity to understand the divisions between research and practice in more detail, as the NPD provides some information on the patterns of identification and support for individuals with SpLDs.

With respect to intervention, the creation of the Education Endowment Foundation and related initiatives (e.g. the What Works Clearinghouse) has resulted in a large increase in the numbers of high-quality randomised control trials in education. However, it has also made us more aware of the limitations of these trials, and the importance of understanding implementation and teacher views in outcome.

With respect to learners with SpLDs, more studies are needed to understand how and why response to intervention varies across learners, and it may be that genetic and neurobiological factors play an important role in this. A recent editorial (Tomlinson et al., 2020) argues that we can usefully combine intervention studies with longitudinal cohort studies to allow these types of analyses.

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Review 2: The support systems for individuals with SpLDs

Dr Helen Ross, Helen's Place

1. Executive summary and key recommendations

This review summarises evidence relating to the support systems for individuals with SpLDs. An overview of the report signposts the content in each section, and the methodology of this review is described. Findings are then briefly summarised. The key recommendations arising from the review are then outlined.

1.1 Overview

This review firstly outlines findings and recommendations arising from the Rose Report on 'Identifying and Teaching Children and Young People with Dyslexia and Literacy Difficulties' (Rose, 2009). This report was commissioned by the then-Labour administration. However, a change of government in 2010 led to a shift in policy. Reform of the policy framework for SEND (Special Educational Needs and Disabilities) provision was undertaken. These reforms are described, including discussion of SEN support and the introduction of Education, Health and Care Plans (EHCPs).

The legal responsibilities and role of the Local Authority in overseeing provision for young people with SEND are outlined, with reference to their importance in monitoring implementation of EHCPs. Following this, the professional knowledge and expectations of education professionals are outlined. Limitations in training are highlighted. Subsequent sections consider roles of professionals in supporting young people with SpLD. Parents' position within policy and pragmatically to support their children is reviewed and evidence about their experiences is discussed.

All evidence is then evaluated and summarised. Conclusions are drawn based upon reviewed evidence where possible. However, the lack of evidence highlighted in some areas led to conclusions being drawn based upon the reviewer's own professional experience and academic expertise. Where this is the case, it is explicitly stated. It is also important to note that 'grey' literature was reviewed i.e. "academic publications that have not been formally published (and… not formally peer reviewed)" (Anderson-Levitt, 2015: 770). Where grey literature is cited, this is discernible in the 'References' section, as well as the text. Gaps in knowledge are highlighted, with recommendations for policy and further study concluding the review.

1.2 Methodology

Three educational databases were searched (ERIC; British Education Index; Education Source) for relevant research studies and systematic reviews, on supporting learners with specific learning difficulties (SpLD) within an English context. Evidence covering Wales, Scotland and Northern Ireland to contextualise English policy and practice was focussed on. Fifty-nine papers were identified initially (specifically, UK-focused research linked to parental engagement, assistive technology, SpLD, dyslexia, dyscalculia, learning environment and/or school). Of those, 26 were relevant topically. Additionally, evidence from the Education Endowment Fund (five items), 'grey' literature (as defined by Anderson-Levitt (2015: 770)) (five items) and government publications (10 items) was included.

Methodological differences and terminological inconsistencies prevented full meta-analysis.

1.3 Summary and conclusions

Parents'/carers' roles in supporting their children with SpLD within policy are unclear, and parents'/carers' ability to meaningfully engage with procedures is variable. Multiple studies have emphasised the inadequate consideration of their views, and poor support for children with SpLD. Policy evaluations have highlighted the difficulties with SEND support procedures experienced by parents/carers whose children have no EHCP.

Educational psychologists and specialist assessors can diagnose need; teachers are not expected to but should identify areas of need to facilitate referrals. However, teachers lacked knowledge of supporting young people with SpLD. The role of the Special Educational Needs Coordinator (SENCo) is relatively clear, but is subject to considerable external constraints: examination regulations; policy guidelines; the Equality Act 2010. Most interventions are delivered by Teaching Assistants (TAs), who often lack sufficient training to deliver programmes. This is despite recommendations for significant investment in training specialist teachers/assessors to identify and support learners at risk of literacy difficulties (Rose, 2009). There has been little investment into this type of training, resulting in inadequate awareness of SpLD amongst professionals. Despite gaps in teachers' knowledge, initial teacher training (ITT) frameworks still contain no compulsory SEND component (DfE, 2019).

1.4 Key recommendations for policy and further research

- Central government and local policy should clearly define expectations on parents in devising support programmes/interventions for their children. For example, alternative formats (e.g. video) for their contributions should be supported.
- Procedural consistency in identification and support for young people with SpLD across Local Authorities in England: it was impossible to outline procedures in England, due to regional/local operational, policy and accessibility differences.
- ITT frameworks should include instruction about SEND, which specifically addresses the needs of learners with SpLD. This should be developed through liaison between the Department for Education, professionals and third-sector bodies such as the British Dyslexia Association and The Dyspraxia Foundation, amongst others.
- Post-graduate (level 7) standard professional development for teachers relating to areas of need within the SEND Code of Practice, linked to SENCo training routes. SENCos locally could develop skills networks; this needs further research and development. This should be developed through liaison and appropriate research with third-sector organisations, professionals, and the Department for Education, as well as education and training providers.
- Investment in accredited training for Teaching Assistants working with students with SpLD to facilitate schools' access to highly trained individuals to support students with SpLD.
- Lack of prior work, and need for professional knowledge suggest that the following work should be undertaken:
- Research into efficacy of intervention programmes, both technological and staff-led to form a high-quality evidence base.

- Further research into the efficacy of diverse technologies with consistent language and methodology for comparability of results.
- High-quality research into experiences/views of parents/carers whose children have SpLD.
- Exploration with the Joint Council for Qualifications (JCQ) to develop regulations and hardware apps to facilitate use of students' own technology in public examinations, such that the examination is not compromised (i.e. internet access blocked), but so that students 'reasonably adjust' materials, congruent with their normal way of working. This will also support efficient deployment of staff.

2. Specific Learning Difficulties: Government initiatives, legislation, and policies

2.1 Rose 2009

In 2009, Sir Jim Rose's review of dyslexia and literacy difficulties in schools was published. The purpose of the review was to establish an evidence base for interventions to support young people with dyslexia. The report included a revised working definition of dyslexia and its characteristics. Of particular focus in Rose's recommendations were "intervention programmes which systematically prioritise phonological skills" (Rose, 2009: 14). It was recommended to ensure "better access for schools, parents and children to the advice and skills of specialist dyslexia teachers" (Rose, 2009: 18), so that all schools can draw on specialist advice from such teachers. As such, Rose (2009: 21) recommended that:

> *… the DCSF should fund a number of teachers to undertake appropriately specialist teaching in teaching children with dyslexia to provide substantially improved access to specialist expertise in all schools and across all local authority areas.*

It was hoped that those specialist teachers would be aware of best practice in supporting those with SpLD other than dyslexia, through high-quality teaching. The type of interventions to support literacy development was not stipulated in the report. Instead, progress via 1:1 support, small group support or a mixture was viewed as contingent on teaching quality rather than type of intervention. High-quality training and access to specialist teachers for support were viewed as key to supporting young people's literacy development within the report. A change in government in 2010 led to the recommendations in the report not being implemented. Instead, a review of support structures for young people with special educational needs (SEN) was undertaken (DfE, 2010).

2.2 Special Educational Needs and Disability (SEND) Since 2009

The 2010 Coalition Government report, 'Support and aspiration: A new approach to special educational needs and disability' (DfE, 2010), highlighted problems with previous support structures for young people with SEN. It also explicitly included disability within SEN policy frameworks for the first time.

The report (DfE, 2010: 100) acknowledged that early identification of young people's needs, and access to specialist support/advice can "make a powerful difference to a child's progress and their happiness in school". However, schools' difficulties in accessing such early interventions/support under current policies were also noted.

Proposed pathways to access resources and training for professionals had altered since Rose's (2009) recommendations. Congruent with the Rose Report, specialist teachers were expected to advise and support their colleagues in meeting needs of young people with dyslexia (other SpLDs were given little consideration) and other SEN. However, the source of funding for the necessary specialist teaching is unclear in this documentation. It was also unclear how proposed 'flexible' training resources would fit into formal 'specialist teaching' qualifications. Scholarships for some post-graduate qualifications were proposed.

2.2.1 Introduction of EHCPs

The most significant change in SEND legislation since 2009 is the Children and Families Act 2014, and related SEND Code of Practice (DfE and DH, 2015). These removed 'School Action' and 'School Action Plus' levels of need, replacing them with one classification of need: SEN Support. Details of provision for young people with 'SEN Support' are largely decided at local level but must adhere to the SEND Code of Practice (DfE and DH, 2015). They are implemented in school, and reviewed regularly by the educational setting, young person and their parents/carers. Within this legislation the Statement of Special Educational Need was replaced by the 'Education, Health and Care Plan,' (EHCP) which draws together support from education, social care and health into one, legally binding document (The Stationery Office, 2014).

EHCPs detail statutory provision for students with SEND, with funding liabilities for resources/support provided within 'Section F- SEND Provision Required' (DfE and DH, 2015: 171). In practice, while EHCPs nominally outline funding sources, schools may not ring-fence SEND funding, meaning EHCP funding pays for staff requirements of multiple EHCPs. Where technology for an individual student is required, this affects 'notional' budgets for other students; students cannot use another student's equipment. However, TAs can support multiple EHCP requirements simultaneously (dependent on individual documentation). This, combined with the relatively small proportion of EHCPs for students with SpLD in England (3.6% (DfE, 2019)), suggests that across educational phases (including Early Years), access to technology-based support vs TA-led interventions is limited even for students with EHCPs for SpLDs.

2.2.2 Local Authorities

Under the Children and Families Act 2014 (s.19), provision for students with Education, Health and Care Plans (EHCPs) is overseen by LAs. They must ensure individuals' stipulated support is implemented and review this provision annually. This is the case across all phases, including Early Years. The 'Local Offer' is a key feature of the Children and Families Act 2014 (s.20). The SEND Code of Practice (DfE and DH, 2015: 59) states that:

Local authorities must publish a Local Offer, setting out in one place information about provision they expect to be available across education, health and social care for children and young people in their area who have SEN or are disabled, including those who do not have Education, Health and Care Plans. In setting out what they 'expect to be available', local authorities should include provision which they believe will actually be available.

The SEND Code of Practice details access procedures to services available, including services outside an area, which may be used by local students. The Special Educational Needs and Disability Regulations 2014 (SI 2014/1530) outline procedures for preparation and dissemination of the Local Offer. Neither these nor the SEND Code of Practice (DfE and DH, 2015) detail service-user referral processes. Therefore, LAs' referral procedures, funding levels and access thresholds differ: some have 'open access' support services available to all local settings; others have 'buy-in' services funded by schools. Where a student resides in a different LA from their school, disparity in provision may exist due to LAs' differing policies. It is important to note that SENCos usually make referrals to services, although some services permit parental referrals, dependent on local policy.

3. Professional knowledge and education/training

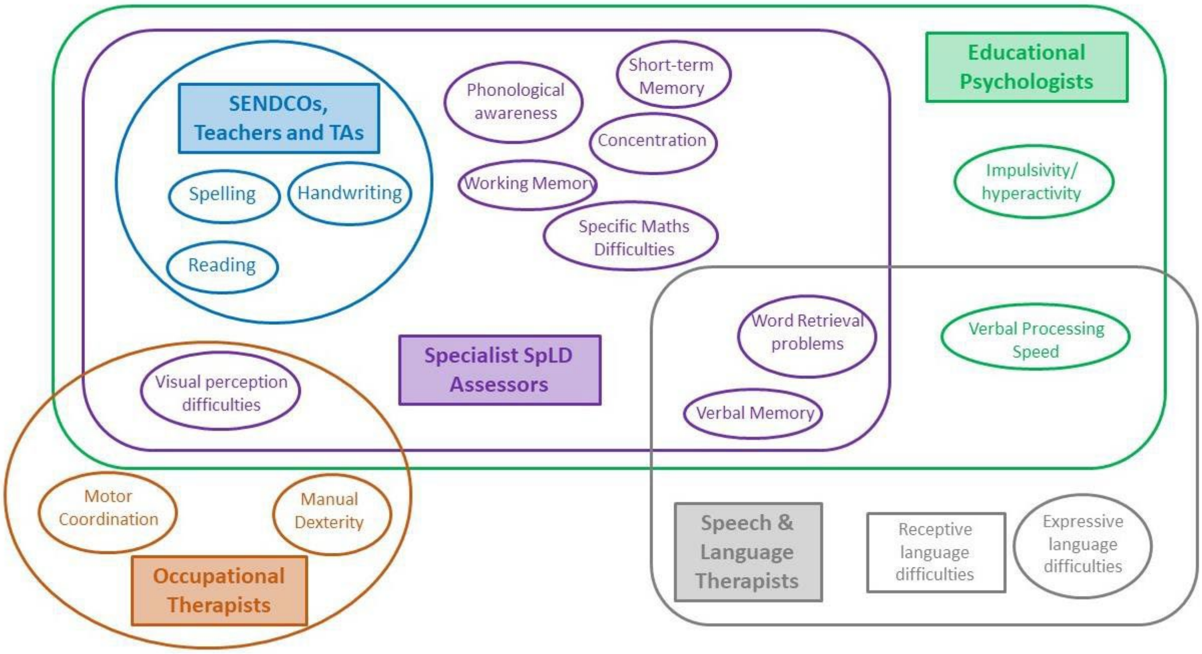

Figure 1: Overview of assessment of SpLD characteristics by professional (drawing on Colley (Updated))

Here I mainly consider teachers' training, but also examine training for specialist teachers/assessors and other professionals. Figure 1 shows the range of professionals who are involved in the identification and assessment of SpLD and the specific areas of performance they focus on. The roles of professionals in supporting young people with SpLD are described in subsequent sections.

Teachers must "be able to use and evaluate distinctive teaching approaches to engage and support" learners with SEND (DfE, 2013a: 12). Trainees should also adapt teaching to meet learners' needs (DfE, 2019):

> *The ITT Core Content Framework deliberately does not detail approaches specific to particular additional needs – to reflect the importance of quality-first teaching – while also providing opportunity for providers to tailor their curricula to the needs of their trainees. (DfE, 2019: 6)*

Reference to meeting the needs of learners with SEND through differentiated work by teachers (DfE, 2013a) is echoed within Teachers' Standards (Early Years) (DfE, 2013b): Early Years teachers should demonstrate understanding of and plan to meet the needs of children with SEND. Teachers and trainees must meet these standards across phases (DfE, 2013a; 2013b). A recent review of ITT found that school-centred ITT provides better SEND-support training than university-based ITT (Ofsted, 2020). Control of quality and accreditation of ITT lies with Ofsted, as they can ensure appropriate training on SEND and SpLD through their inspection frameworks.

My professional experience leads me to conclude that training relating to the four areas of need outlined in the SEND Code of Practice (DfE and DH, 2015) should be delivered through compulsory modules as part of ITT to ensure that all teachers receive high-quality input. Formal inspection by Ofsted of ITT SEND/SpLD training against SEND-training content criteria will maintain high standards. I believe that with sound ITT coverage of all areas of SEND, teachers will better meet needs of learners with SpLD. Technology, such as projectors, facilitates delivery of lessons which mitigate the effects of dyslexia and improve learners' curricular access (Ross, 2017; 2019), subsequently relieving other resources such as TAs. Where learners use technology, digital resources (such as soft copies of PowerPoints for students) mitigate the need for out-of-class interventions and facilitate independent learning. However, much is contingent on resourcing and teacher/TA knowledge.

Despite the paucity of evidence on supporting learners with SpLD, I have combined the existent evidence and my experience to identify gaps in professionals' knowledge and suggested mitigation strategies (Table 1).

Table 1: Teacher training needs and accompanying literature-based mitigation strategies

Training need	Literature-based mitigations
Teachers' lack of understanding of students with SEND and SpLD (Beck, et al., 2017; Bell et al., 2011; Earey, 2013; Knight, 2018)	ITT Core frameworks must include SEND training, including SpLD (Beck et al. 2017; Bell et al., 2011) Ensure schools' access to specialist teachers/assessors (Rose, 2009)
Lack of governmental/employer investment in training (Bell, 2013; Higgins et al., 2012; Woolhouse, 2012)	Fund accredited professional development e.g. AMBDA (BDA, undated) for TAs/teachers (Beck, 2017; Bell et al., 2011; Ross, 2019; Woolhouse, 2012)
Lack of capacity to assess needs (Beck, et al., 2017; Earey, 2013; Ross, 2017; 2019)	Facilitate schools' access to screeners to informally identify need Fund training for specialist teachers/assessors (Rose, 2009; Ross and Hicks, 2019; Woolhouse, 2012)
High-quality training for TAs/teachers (Beck et al., 2017)	Fund accredited professional development e.g. AMBDA (BDA, Undated) for TAs and teachers (Beck, 2017; Bell et al., 2011; Ross, 2019; Woolhouse, 2012) Ensure schools' access to specialist teachers/assessors and trained TAs (Rose, 2009)
High-quality training on SpLD in Early Years	Early years practitioners' required knowledge of phonics and mathematics instruction (DfE, 2013b) should be underpinned by awareness of manifestation of SpLDs in those settings to facilitate early intervention and support.

3.1 SENCos and class teachers

Subject and class teachers usually do not formally identify learners' need. They support identification of learners at risk of literacy difficulties, dyslexia or other SpLD (Knight, 2018; Ross, 2019). SENCos hold a crucial role within English policy (DfE and DH, 2015). In Early Years Foundation Stage, school and FE settings, SENCos should support colleagues to identify, understand and meet needs of students with SEND (DfE and DH, 2015: 88, 108-109). Research shows co-occurrence of SpLDs within individuals (Colley, undated). Therefore, SENCos should ensure that other staff can recognise potential SpLDs (McKay and Neal, 2009). For assessment of SpLDs, SENCos may refer to Educational Psychologists (EP), specialist assessors, and/or other professionals (contingent on local policies).

SENCos, with support from other professionals and their own professional knowledge, develop intervention strategies for young people with SpLD. Work by the Education Endowment Fund (2019a; 2019b) has found that there is little robust evidence on efficacy and cost-effectiveness of different interventions. As such, in this report, views relating to interventions are largely based upon my professional experience and expertise, drawing on evidence where possible.

Cost and structural flexibility must be considered when implementing any intervention. The comparisons made in Figure 2 relating to cost are based in part on my professional experiences, as research evidence across studies was incomparable due to methodological and terminological inconsistencies. Those responsible for provision usually bear the cost of support. However, multiple studies identified budgetary constraints as barriers to implementation of high-cost interventions, despite potential benefits to learners. Schools must make 'reasonable adjustments' for learners with SEND, including SpLD (Equality Act, 2010; DfE and DH, 2015).

Expectations that their needs are met in the classroom (DfE, 2010), combined with a lack of resources, has meant that high-cost or resource-intensive interventions are used sparingly (Higgins et al., 2019; Ross and Hicks, 2019; Ross, 2019).

Cost to providers from groups 1 and 4 may be low or high, depending on funding sources (Figure 2). Where educational settings finance equipment for students, it is prohibitively expensive for all but the 'most needy' students. This connects to external structures such as 'Access Arrangements' for public examinations (JCQ, 2020). For example, students may be refused use of computer equipment as their 'normal way of working' to minimise exam equipment costs to schools. However, could students supply their equipment, schools' costs would reduce, facilitating students' use of technological interventions. Schools must consider that allowing students to supply equipment may contravene the Equality Act 2010. Where settings acknowledge students' need for equipment, not providing it for them could be discriminatory. School policies would need careful consideration to prevent this. Learners' internet safety and safeguarding must also be considered: use of technology should not compromise students' safety. Evidence suggested that small-group and 1:1 intervention are highly effective for students with SpLD. High-quality teaching had a larger effect on progress than technology alone. Due to lack of evidence on the efficacy of different types of interventions, it is not possible to conclude which interventions that SENCos may implement are the most effective. However, it is possible to conclude that SENCos are constrained as to what interventions are implemented, due to budget, legislation, and examination regulations.

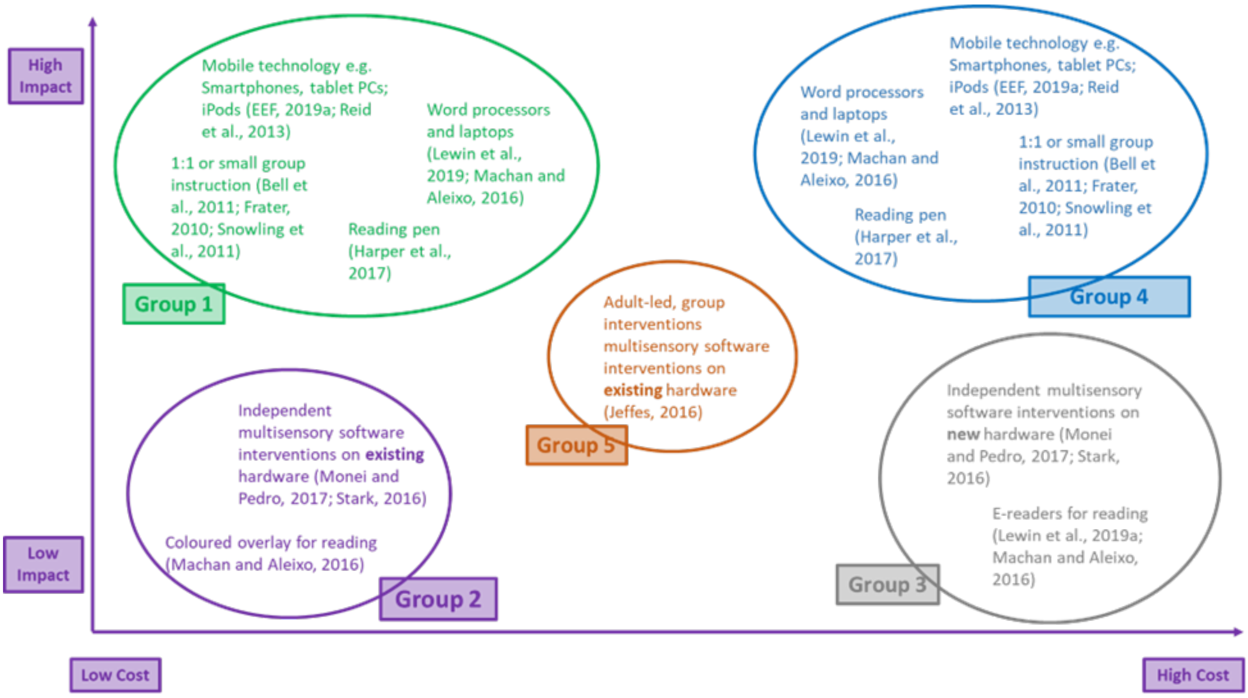

Figure 2: Impact and cost of interventions

Evidence highlighted discrepant views on EPs' roles in the assessment of SpLD. Long and McPolin (2009) found that some professionals linked to the identification of SpLD felt distanced from EPs by their specialist terminology. However, Stothard et al. (2018), Woods et al. (2013) and Arnold (2017) underscored EPs' importance in identifying SpLD, despite schools' limited ability to commission their services (Ross, 2019). EPs' 'public' role in identifying students with SpLDs is diminished; EP assessments are often commissioned privately (McCormack-Colbert et al. 2017).

3.3 Specialist teachers

Specialist assessors formally identify some SpLDs (BDA, undated). Within the literature, little research explored their role in supporting students with SpLD. In addressing the role of specialist teachers/assessors, Bell (2013: 104) argued that they should support class/subject teachers to adapt according to learners' needs, and foster "awareness of dyslexia and SpLD across educational institutions, workplaces or the wider community". Training costs for specialist teachers/assessors was an identified barrier by Bell (2013), and Griffiths and Kelly (2018); individuals usually pay their own fees. Due to training costs, the training of specialist assessors and teachers has not received investment as recommended by Rose (2009). I believe that school-/LA-sponsored accredited programmes would improve the uptake of specialist training, as shown previously by Bell (2013); professionals value formally accredited courses. Where employers cover course-fees, to protect their investment, a retainer clause could form part of the training agreement.

3.4 Teaching assistants

Research suggests that TAs deliver most interventions for students with SpLD. Bell et al. (2011) envision TAs as supporting teachers with provision of either in-class, small-group, or 1:1 support for learners with SEND, echoing Griffiths et al. (2018). They found that where TAs have formal, accredited training, their roles included whole-school training, advising parents and staff inductions.

4. Parents

Here, I discuss the development of parents'/carers' roles within English Special Educational Needs and Disability (SEND) policy since 2009. I describe parental roles, expectations, and rights within legislation. I outline literature on parents'/carers' roles in supporting their children at school and describe their role at home.

4.1 Parents in policy

Legislation introduced in 2014, and guidelines introduced later (DfE and DH, 2015), focused on parents'/carers' views on educational provision for their children. Governmental evaluations of pilots of the 2014 framework found that parents had difficulty accessing decision-making processes (Craston et al., 2013). This particularly affected parents whose children had hidden disabilities and/or SpLD (Ross, 2019).

4.2 Parents' roles at school

Knight (2018) and Earey (2013) noted parents' 'uphill struggle': schools failed to assess children, despite parental concerns. Affluent parents commissioned private needs assessments (Long and McPolin, 2009) where schools failed to assess need. This echoes Ross and Hicks' (2019) work: parents felt schools avoid costly interventions or assessment. Earey (2013) uncovered schools' rejections of independent reports, where support was linked to parental persistence, not level of need. Stothard et al. (2018) uncovered schools' resistance to 'parent power' and participation. Harper et al. (2017) found that supporting families' engagement in decision-making engendered better-supported children. However, where need is unclear (as with SpLDs), positive engagement can be problematic. In Scotland, Riddell (2009) also highlighted schools' resistance to parental engagement in decision-making. Thus, parallels can be drawn between parental experiences in England and Scotland.

4.3 Parents' roles at home

As research on parental experiences of their children's SpLD is limited, we cannot generalise about their home-based roles. However, Long and McPolin (2009) argued schools should accept parental expert-knowledge of their children. Earey (2013) found that in 'supportive' homes, children and young people's needs are identified sooner. Ross (2019) found that parents' home roles heavily focused on homework, disproportionately implicating mothers. Grey literature (Ross and Hicks, 2019) uncovered homework as a 'battleground' for families, highlighting the impact of dyslexia on siblings; parents' finances were depleted by costly tuition for their children; and their mental health compromised. While their work provides an interesting insight, it is important to remember that Ross and Hicks' (2019) study is not peer reviewed and was not written within a fully academic framework. As such, further robust and methodologically-sound research into these roles is necessary.

Livingstone (2012; 14) noted that "parental resourcing of the home has traditionally been regarded as a private matter, not subject to public policy." Thus, engagement with the home-setting is not clear-cut for researchers, despite Kelly et al. (2017) highlighting the value of home-school collaboration for supporting learners with SpLDs (the research did not detail the type of intervention or the nature of need). This is particularly important as interventions may require access to a computer and/or the internet. Where homes do not have this, supporting young people may be more challenging.

5. Summary and conclusions

Parents'/carers' roles in supporting their children with SpLD within policy is unclear. Their access to resources may vary and professionals should consider this when engaging them in decision-making processes. Lack of research persists on views/experiences of parents whose children have SpLD. However, policy evaluations highlighted the difficulties with SEND support procedures experienced by parents/carers whose children have no EHCP. Multiple studies have emphasised the inadequate consideration of their views, and poor support for children with SpLD.

Professional roles are clearer: classroom teachers are not expected to diagnose formally but should identify areas of need to facilitate referrals by SENCos and parents/carers. While the role of the SENCo is relatively clear, they are also subject to considerable external constraints: examination regulations; policy guidelines; the Equality Act 2010. Educational Psychologists may diagnose need. However, specialist assessors are more likely to do so. Teaching assistants tend to deliver interventions in school; specialist teachers/assessors do so outside of school. Teachers lacked knowledge of supporting young people with SpLD.

In 2009, Rose recommended that significant investment be made into training specialist teachers/assessors to identify and support learners at risk of literacy difficulties. Specialist assessors can identify several SpLDs; investment in such training would reduce reliance on EPs. There has been little investment into this type of training, resulting in inadequate awareness of SpLD amongst professionals. Despite gaps in teachers' knowledge, ITT frameworks still contain no compulsory SEND component (DfE, 2019). Evidence considered in this review suggests that teachers and teaching assistants are inadequately prepared to deliver 'high-quality teaching' to students with SpLD.

6. Gaps in evidence

Research highlighted a paucity of evidence on parental experiences of the English SEND framework. While a small amount covered dyslexia, other SpLDs were scarcely included in studies. The review found 12 relevant UK-based studies, where five focused on parental views; others prioritised professionals. Relevant studies found that parents of dyslexic children feel that they ‘enter battle’ when engaging with educational settings (Ross, 2019), despite statutory requirements for consideration of their views (DfE and DH, 2015; The Stationery Office, 2014). Notwithstanding updated SEND legislation, parental experiences and confidence remain unchanged since the Rose Review (2009) (Ross, 2019; Ross and Hicks, 2019).

Evidence on efficacy of different types of intervention to support SpLD is currently lacking. Much is small-scale or omits appropriate detail to facilitate comparison across studies. Limitations on using technology in the classroom relate to examination guidelines, budget, and schools’ ability to maintain up-to-date technology. While data suggest that students with SEND benefit from technology and/or person-led interventions, how was unclear. Research suggested that technology should not replace person-led instruction; high-quality teaching was key in supporting students with SpLD.

7. Recommendations

The lack of clarity in both professionals' and parents/carers' roles and responsibilities shown in evidence, and my own professional experience, lead me to make the following recommendations:

- Central government and local policy should clearly define expectations on parents in devising support programmes/interventions for their children. For example, alternative formats (e.g. video) for parents' and children's contributions should be supported.
- Procedural consistency in identification and support for young people with SpLDs across Local Authorities in England: it was impossible to outline procedures in England, due to regional/local operational, policy and accessibility differences.
- Support parents/teachers through workshops to provide training on interventions used to support learners with SpLD.
- For parents of children with SpLD, ensure interaction with schools is accessible.

As argued in this review, education professionals are not sufficiently prepared to meet the needs of young people with SpLD. As such, I recommend the following:

- ITT frameworks should include instruction about SEND, which specifically addresses the needs of learners with SpLD. This should be developed through liaison between the DfE, professionals and third sector bodies such as the British Dyslexia Association and the Dyspraxia Foundation, amongst others.
- PG (level 7) standard professional development for teachers relating to areas of need within the SEND Code of Practice, linked to SENCo training routes. SENCos locally could develop skills networks; this needs further research and development. This should be developed through liaison and appropriate research with third sector organisations, professionals and DfE, as well as education and training providers.
- Investment in accredited training for teaching assistants/working with students with SpLD to facilitate schools' access to highly trained individuals to support students with SpLD.
- Training for professionals/parents/carers on accessibility features of ICT already available in school such as MS Office, Adobe, inbuilt features of Apple devices, etc.

There is a lack of evidence relating to parental experiences, the impact/efficacy of different types of interventions and their implementation, which lead me to recommend the following:

- Research into efficacy of intervention programmes, both technological and staff-led to form a high-quality evidence base.
- Further research into the efficacy of diverse technologies with consistent language and methodology for comparability of results.
- High-quality research into experiences/views of parents/carers whose children have SpLD.

It is vital to support SENCos (and school staff) to carry out their role of providing appropriate support and making ‘reasonable adjustments’ for young people with SpLD to make exams accessible. This must also reflect budgetary considerations. As such, the following should be undertaken:

- Exploration with JCQ of development of regulations and hardware apps to facilitate use of students’ own technology in public examinations, such that the examination is not compromised (i.e. internet access blocked), but so that students ‘reasonably adjust’ materials congruent with their normal way of working. This will also support the efficient deployment of staff.
- Research on the use of mobile technology in the classroom whilst maintaining online safety but allowing for ‘reasonable adjustments’ to curricular materials by students.
- Encourage use of e-readers/eBooks through text-to-speech features already available e.g. Office 365, or mobile technology.

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Review 3: Technology-led interventions for SpLDs

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1. Executive summary

There are substantial numbers of people with SpLDs in the UK and enormous potential for science and technology to be leveraged for the benefit of this population.

Science and technology can be used for diagnosis and screening, it can be used with learners and teachers to support the education of those with SpLDs, and it can be used for evaluation and increasing our understanding of how and under what circumstances learners with SpLDs achieve their best.

The science that supports the diagnosis and improvement of the information processing difficulties at the heart of SpLDs is advancing rapidly, but still embryonic. This leads to the prospect of possibilities for early diagnosis of problematic processing mechanisms and early treatment. At this stage, the robustness of the evidence is from early stage research which is small in scale and in need of replication.

Technology should always be seen as a contribution to the education of learners with SpLDs, but must never be the whole story. Supporting learners and teachers with technology can be achieved through a wide range of technology. Any technology-based intervention for learners with SpLDs must be informed by evidence. This evidence must be accessible and understood by educational technology developers and educators alike. Research is early stage and patchy, but promising. It lacks scale and an accepted set of appropriate, validated methodologies.

Examples of technologies that have been shown to improve learning for people with SpLDs include tangible devices that allow physical engagement and multisensory interaction. Mobile devices and tablets, such as the iPad, have been demonstrated to increase student motivation. When used judiciously by skilled educators, mobile technologies can also improve academic achievement, including mathematical skills and mathematical computation fluency. There is also evidence that such devices, when used well, can improve student behaviour and help students participate in self-directed learning.

The evidence for the use of Virtual Reality (VR) and Augmented Reality (AR) is mixed, with positive results about the use of VR for the treatment of specific phobias and fears amongst individuals with ASD, but a lack of evidence more widely.

Game-based learning to support people with SpLDs can provide exciting learning activities and maintain learner motivation to practise skills they find difficult to master. However, game-based learning is a challenging area of research, and designers must take pedagogical principles and accessibility into account.

Artificial Intelligence (AI) has the potential to bring great benefit to all learners, particularly those with SpLDs. Well-designed AI enables personalised learning that adapts constantly to address the needs of each individual students. AI can also provide ways in which learners can interact with technology that are more suitable for people with SpLDs, such as voice-activated interfaces and robotics.

In addition, AI also has the promise to help us better evaluate and understand how and under what circumstances learners with SpLDs achieve their best. At a national level, a data-driven approach that can leverage the evidence generated as technologies are applied in education is required in order to exert the power of technology for the benefit of people with SpLDs. Such an approach must be built on an ontology that can be used to construct a data hub that can enable the development of smart tools to open-up data to search, visualisation, evaluation, triggering and decision-making tools.

2. Methodology

As a team of researchers with considerable expertise and experience in the field, we used our knowledge to guide our research, and we also tapped into the networks built up by each of us over the years and through work on the EDUCATE programme. In addition, we searched for research from the last 10 years, using relevant peer-reviewed academic journals and conferences, as well as reports from well-respected agencies. We used IEEE, ACM and Google Scholar, and then used the 'snowball effect' strategy (Efron and Ravid, 2018) to find additional studies with the same criteria. The criteria we used focused on children with SpLDs. We used the following search terms: Specific learning difficulties, SpLD, technology, technology-based, Artificial Intelligence (AI), dyspraxia, dyslexia, dyscalculia, attention deficit hyperactivity disorder (ADHD), autism spectrum disorder (ASD). We acknowledge that there is a view that ASD is not within the definition of an SpLD, but the definitions of SpLD vary and are still evolving as more is understood about different SpLDs and their relationships to other learning difficulties. We have included ASD in order to be inclusive and to provide the widest and most useful set of examples of the ways in which technology can be used for interventions with learners who have an SpLD.

In terms of the quality of the research that we included, we focused on ensuring that there was an empirical basis for the findings being proposed and that the design of empirical studies was sound and well thought through. This approach was used even for small scale the findings, there being a lack of large-scale empirical work available.

3. Science and technology for diagnosis

The research and implementation regarding the diagnosis and improvement of these information-processing difficulties is advancing rapidly as new technologies are being used to mediate the learning difficulties of these children:

> *New understanding is already leading to new ways of addressing learning difficulties and mental disorders; advances in new technology for learning has the potential to play an important role in the personalisation of education; and new technology could also help everyone to flourish by changing how we socialise, work, learn and communicate* (Foresight Mental Capital and Wellbeing Project, 2008, p.12)

In the same report, the authors also argue that the biggest challenge will not be the development and implementation of these new technologies, but, rather, ensuring equality of access to the benefits. There is certainly more advanced technology available now than in 2008, when this Foresight report was written, but the issue of providing equality of access to these resources remains a huge challenge.

Goswami's 2011 report identifies that recent advances in genetics and neuroscience provide new insights into the heritable neural basis for some common learning difficulties, and this offers opportunities for earlier diagnosis. For example, there is a relationship between atypical sensory processing that happens in the visual, auditory, motor, and spatial systems of the brain and higher-level cognitive deficits in language, social cognition, reading, and number. This atypical processing can be recognised to support early diagnosis. Additionally, early diagnosis of problematic processing mechanisms may lead to early treatment, when the brain is still highly plastic and may be re-trained to "alter the developmental trajectory for higher-level cognition (as in cochlear implants for some deaf children)" (Goswami et al., 2011). Similarly, there is increasing evidence for the neural basis of developmental dyslexia, which not only provides possibilities for diagnosis, but also for innovations in providing support using rhythm and music (ibid.). There is also research into the automatic identification of dyslexia using multimedia capturing, interaction storage and analysis, with the support of big data analytics (Hassanain, 2017). Hassanain and his colleagues use a tablet PC-based multimedia framework with four different dyslexia testing modules: reading, writing, drawing, and eye tracking. User interactions with the test modules are stored as a video, along with the data about a user's eye gaze or pupil movement. The data is uploaded, and a set of algorithmic analytics are used to detect dyslexia phenomena. The algorithms try to automatically detect dyslexia from the available multimedia files. The test can be administered by a school and each individual test can be examined by an expert if it shows signs of dyslexic patterns.

Beyond dyslexia, Song and colleagues (Song et al., 2019) have reviewed the use of AI in data-driven methods for screening and diagnosing ASD. They note that many studies have attempted to incorporate artificial intelligence (AI) technologies to identify a specific subset of assessment instruments that are predictive of ASD, and in so doing reduce the assessment process time. There is reason for optimism about the potential of AI for such purposes, with improvements in the accuracy in the classification of ASD and non-ASD individuals. However, the authors report that "there remain many challenges regarding feasibility in the real-world that need to be resolved before AI methods can be fully integrated into the healthcare system as clinical decision support systems" (Song et al., 2019, p.145).

3.1 How robust is the reported evidence?

Genetics, neuroscience, and AI are all areas of science that are advancing at a great pace, with significant developments already being seen for screening and diagnosis of SpLDs. However, this work is still at an early stage and there is a lack of scaled empirical research. There are many challenges yet to be addressed, including:

- There are limitations to the SpLD-associated genes that are known for a particular SpLD, and more than one gene relationship is likely to be relevant. For example, ASD is likely to be associated with a combination of interacting variants of several genetic biomarkers (Yoo, 2015). As a result, these associations are only capable of explaining a small percentage of cases.
- Studies that use neuroimaging techniques combined with AI have resulted in inconsistent findings (Xiao et al., 2017).
- The use of observable behavioural markers for diagnosis is also fraught with challenges. For example, there is no objective system to capture the constant changes in the behaviour of an individual and there is always therefore some level of interpretation needed.
- Machine-learning AI techniques require large datasets and most of the existing repositories of data about people with a SpLD are not large enough.
- The ethical obstacles to the widespread data collection and algorithm design involved in using machine learning have not yet been addressed.

The research reported is sound and robust in and of itself, but is small scale, exploratory and focused only on some SpLDs and some aspects of these SpLDs. We would rate it as: promising early-stage research based on well-researched tools and methodologies.

4. Evidence-based approaches to technology-led interventions

4.1 Foundations

Young children are observed to be highly motivated by technology, which can be used in their classroom to help students to achieve the required academic skills fully, and at an early age (Musti-Rao et al., 2015). Helping children at an early age so that their education is not hindered because of their specific learning difficulties (for example in reading and writing) is one of the findings from multiple disciplines (education, psychology and neuroscience) that needs to be taken into account when developing policies.

The development of optimal approaches and technologies to support those with SpLDs requires some initial foundational thinking to provide a specification about what represents a valuable technology-based intervention to support learners with SpLDs. Essential to this specification is the existence of evidence that supports the potential of a technology-based intervention to successfully support learning and/or teaching. To be useful, this evidence must be accessible and understood by educational technology developers and educators alike.

A growing body of research about the way in which technology can impact positively on education, in general as well as with respect to SpLDs, already exists. However, the evidence generated by this research is rarely known about by the people who design technology for education, or by the people who use technology in education. It therefore rarely informs the way technology is developed or used in education. In addition, there is a disconnect between the people who understand how to generate this evidence, the people who build technology for use in education and the people who use technology in education.

These three communities represent the points of the golden triangle at the heart of the EDUCATE programme, which was developed to connect these communities and to drive the better generation and application of evidence by the educational technology community (Luckin and Cukurova, 2019). At EDUCATE, we believe that bringing educators and developers together in inter-professional co-design teams helps all parties develop a research and evidence mindset. The generation and communication of evidence about how and when a technology supports learning is essential, and it can be aided by a clearer understanding that goes beyond the nature of the technology itself.

4.2 Science and technology to support teaching and learning in students with SpLDs

A range of technologies have been researched to explore the benefits they can bring to children with SpLDs. It must, however, be acknowledged that recent research in this area is still early-stage and small-scale, with limited funding available to support such studies. In this section we discuss the following technologies: Tangible mobile applications; mobile devices and tablets; Google glass, AR and VR; games and AI.

4.2.1 Tangible mobile applications

Tangible devices allow users to experience physical interaction when using them. As a result, they allow physical engagement and multisensory interaction. This makes them promising tools to facilitate learning for students with a SpLD, and have been shown to be enjoyed by students and used easily, correctly and effectively, when used in science teaching (see for example Polat et al., 2019).

Fan et al. (2017) explored how tangibility impacts on reading and spelling acquisition for young anglophone children who have dyslexia. They focused on the effectiveness of PhonoBlocks on trained words, on new words, and on both, with a small sample of children with dyslexia who were aged seven to eight years. The results showed that PhonoBlocks was an effective technology for both trained words and new words. The researchers argue that tangibility is important because reading is, in part, a spatial activity. It is possible to represent letters as objects with spatial-visual properties. Words can then be formed as linear sequences of letters and the position of letters in the words dictates the sound in the words.

In another study, Sitdhisanguan et al. (2012) investigated the effectiveness of a tangible user interface (TUI) on colour recognition in young boys (aged five years) with ASD. The authors compared the learning efficacy of a touch-based system, a TUI system (tabletop) and a conventional colour stick system. Results showed that for learning efficacy, the TUI-based system achieved higher skill improvement, compared with both the table-top and the conventional setting.

Tangible technology has also been positively evaluated for children with a range of needs. For example, for teaching multiplication to children with mild intellectual disability (Bouck et al., 2009), and to improve linguistic skills for students with severe disabilities (Garzotto and Bordogna, 2010).

4.2.2 Mobile devices/tablets

There is growing evidence that, more broadly in education, teaching with mobile technology brings learner benefits, including increasing student motivation (see, for example, Musti-Rao et al., 2015). However, there is also a developing body of research concerning students with SpLDs. For example, Vogelgesang et al. (2016) illustrated that students with ADHD showed improvements in academic achievement when they practised math and reading skills on the SCORE IT app on the iPad.

Much of this research has focused on the iPad. In Australia, the Victorian Department of Education and Early Childhood Development integrated iPads in a school for children with intellectual disability in 2010 (Ellis, 2016). They began by teaching children how to use certain apps and to use of the apps throughout the entire day. Teachers in this study found that the iPads enabled students to participate in self-directed learning (Ellis, 2016) In the USA, iPads have been shown to improve the mathematical skills of students with special needs and to bridge and diminish the gap between non-special education students and those with special needs (Zhang et al., 2015). A study in Maryland, USA, demonstrated that students with moderate to severe cognitive disabilities increased in mathematical computation fluency and student achievement. The advantages of using the iPads included student acceptance and motivation, the ability to progress to a learning objective that was not possible without the iPad, and the enhancement of teachers' teaching skills (O’Malley et al., 2013).

Other studies have shown that tablet can act as incentives and to improve rote memorisation skills, such as counting, in students with special needs (Chen, 2012), and to maintain engagement (Kaur et al., 2017). Mobile tablets can also be used to improve student behaviour in classrooms (Bruhn et al., 2015), and to increase the amount of praise delivered by teachers to low-performing students with autism. The praise helped students with autism to reinforce good behaviour (Rivera et al., 2015).

4.2.3 Augmented Reality (AR) and Virtual Reality (VR)

There is mixed evidence about the potential value of AR and VR for learners with SpLDs. Recent literature continues to support the efficacy of visual strategies for teaching tasks to individuals with ASD (see Cihak et al., 2016, for more). In their investigation, Cihak et al. (2016) conducted a qualitative study to learn more about the effects of augmented reality when teaching step-by-step tasks to students with ASD. All the participants learned how to brush their teeth independently and could still do so after nine weeks. In work by Maskey and colleagues (2014), a virtual reality environment (VRE) was used to increase the accessibility of traditional treatments of specific phobias and fears for individuals with ASD. The VRE also provided an opportunity for students to try newly learned skills, such as social understanding, understanding facial expressions, road safety and fire alarm procedures in a safe environment (Maskey et al., 2014).

Handheld and smartphone AR have also been shown to be beneficial. For example, an AR learning game environment has been used to help high school students in Taiwan overcome learning barriers and improve their English speaking and listening skills (Liu, 2009), and smartphone-based AR was used to help dyslexic people with their reading (Gupta et al., 2019). The smartphone camera was used to enable users to adjust their background-text contrast ratio and text customisation in real life. However, in a literature review, Akçayır and Akçayır (2016) revealed a notable gap in AR studies that focused on students with special needs. Only one of the articles they reviewed addressed this issue and investigated teachers' perceptions concerning mobile device AR usage by students with special needs, and most studies concluded that very few technologies were designed and tested for students with special needs.

4.2.4 Games

Game based learning can help children with learning disabilities by providing exciting learning activities and maintaining their motivation to practise skills they find difficult to master (Lamsa et al., 2018). Wilson et al. (2006) argue that adaptive game software is successful in the remediation of dyslexia. They describe the cognitive and algorithmic principles underlying the development of similar software for dyscalculia. The software called ‘The Number Race’ is based on our current understanding of the cerebral representation of number and the hypotheses that dyscalculia is due to a "core deficit" in number sense or in the link between number sense and symbolic number representations. The software trains children on an entertaining numerical comparison task, presenting problems adapted to the performance level of the individual child. The results indicate that the software adapts well to varying levels of initial knowledge and learning speeds, and the feedback from children, parents and teachers was positive.

Content based adaptation in learning games is often seen as a way to adapt the challenge to an ideal level (to maintain the flow), and it is one key feature of game design that is beneficial for learning purposes. In studies of two different games GraphoGame Math and Number Race adaptation was used to increase variation

in the practised context with respect to number skills performance of students with

dyscalculia (Räsänen et al., 2009 and Salminen et al 2015

However, utilising games to support learning by people with SpLDs is a challenging process and game designers need to take pedagogical principles and accessibility requirements into account.

4.2.5 Artificial Intelligence (AI)

There are a range of ways in which Artificial Intelligence (AI) can be used to support the education of students with SpLDs. For example, the use of natural language processing to enable the development of voice-activated interfaces can be helpful for students with written language-related SpLDs, and offer possibilities for younger children's language development prior to developing writing skills.

The combination of AI with other technologies such as VR and AR can help students with SpLDs that cause emotional- and anxiety-related complications to engage with virtual environments and take part in activities that would be impossible for them in the real-world. For example, 'FearNot!' is a school-based intelligent virtual environment that presents bullying incidents in the form of a virtual drama. Learners play the role of an invisible friend to a character in the drama who is bullied. The learner offers the character advice about how to behave between episodes in the drama and, in so doing, explores bullying issues and heightening empathy (Vannini et al., 2011).

Drawing on work from the Intelligent Tutoring Systems tradition, AI can also be integrated to provide ongoing intelligent support and guidance to ensure that learners engage properly with the intended learning objectives without becoming confused or overwhelmed. Virtual pedagogical agents might also be included, acting as teachers, learning facilitators, or student peers in collaborative learning 'quests'. These agents might provide alternative perspectives, ask questions, and give individualised feedback. For example, Porayska-Pomsta et al. (2018) examined the educational efficacy of a learning environment in which children (aged 4-14) diagnosed with ASD engage in social interactions with an AI virtual agent and where a human practitioner acts in support of the interactions. The results indicated a significant increase in the proportion of social responses made by children to human practitioners and also an increase in initiations by ASD children. This work also shows the possibilities of AI technology design and use for autism intervention in real school contexts. Further work with people who have ASD using pedagogical agents and personalised learning can be seen in Mohamad et al., 2004.

The AI software applications that are available today can be helpful, if they are well designed and carefully used. The future, however, will go far beyond the current stage of individual applications to an intelligence infrastructure that can inform all the learning interactions a learner engages in (Luckin, 2018). This *intelligence infrastructure* is created from the skilful integration of big data about human behaviour, deep-learning algorithms, and our own human intelligence to interpret what the algorithms tell us. It will leverage the science that has helped us to understand how humans learn, and the science that has helped us build machines that learn.

The implications of this intelligence infrastructure for education and society are significant. We can collect and analyse huge amounts of data about how we move, what we say and how we speak, where we look, how fast our pulse is racing, what problems we can and cannot solve and which questions we answer correctly. The processing and AI-enabled analysis of multimodal data like this will show us much more about our progress than how much better we understand science, maths, history or Mandarin. It will show us how well we work with other people, how resilient we are, how self-aware, how motivated and how self-effective, plus, a great deal more. This is true for all of us, but can be particularly important for learners with SpLDs, for whom we can much better tailor their educational interactions as a whole to their specific individual needs.

4.2.6 How robust is the evidence?

The research about the use of technology to bring educational benefit to children with a range of SpLDs is patchy and small scale. The individual studies are mostly well designed, but there is rarely the contextual data that would enable the findings to be used by learners beyond those involved in the particular research study being reported. Other limitations include:

- Lack of findings that are accessible to educators or technology developers to inform their practice.
- Research is driven by a particular technology rather than by the learning need of the SpLD learners, which may require the combination of multiple technologies.
- The robustness of the evidence varies across technologies, for example that involving mobile technologies has a longer history and has generated more evidence, whereas research involving Augmented Reality and Virtual Reality is sparse.
- AI has a great deal of promise, but few studies have been undertaken and the evidence is at an early stage in its evolution.

The research reported is small scale and patchy; there is a great deal promise, but the evidence is inconsistent. We would rate it as promising early-stage research that lacks scale and a clear set of validated appropriate methodologies.

5. Risks and barriers to leveraging the opportunities for technology-based interventions

The complexity of SpLDs and the right of children with SpLDs to adaptations and additional professional assistance in their educational environment has associated costs. The addition of technology will add to this cost. However, the financial resources used to help SpLD learners with technology and professional assistance is one of the best investments that can be made. The adequate preparation and treatment of children with SpLDs alleviates the problems associated with their education, employment and social inclusion, and delivers high returns that far exceed the initial costs involved (Kavkler et al., 2015).

The current and accepted practice of inclusive education is very important to help these learners at an early stage. Most of the evidence we reviewed demonstrated that learners with SpLDs enjoyed using technology. However, one study included in this review reported that a participant felt discomfort about using the 'Pentop' computer in front of other children (Bouck et al., 2009), suggesting that the stigma of being labelled as 'different' is important for some children.

The most important issue is helping teachers to gain adequate knowledge and skills to help children in their classrooms. Teacher training programmes need to prepare teachers to use technological solutions comfortably with their students. This move needs to be supported at the institutional level. A close-up study of how schools can be supported to help children with SpLDs (in this case, dyslexia) indicates that, in addition to teacher preparation, there is a key role to be played by senior management teams, as well as developing dyslexia friendly teaching and learning (including the use of tablets and apps). Following a dyslexia-friendly teaching and learning approach benefits all children (Griffiths et al., 2016).

In terms of the effectiveness of interventions and the possible barriers or unintended negative effects of technology used in inclusive classrooms, none of the studies reviewed for this report mentioned any negative effects or risks for learners with SpLDs. However, we must bear in mind that the number of studies for different SpLDs is not equal (dyslexia is the most studied SpLD), nor are the number of participants. Additionally, the participants in studies need to be supervised by researchers or teachers during these experiments. The resourcing of this extra support is a potential barrier. In addition, teachers need to be given adequate training to be able to recognise any discomfort experienced by children. They also need to be helped to develop their own understanding about students with SpLDs, which influences both teachers' classroom behaviour and students' academic outcomes (Woodcock and Moore, 2018).

6. Environments that support the development of specific interventions that link research, practice, and commercial providers

In the section on evidence-based approaches to technology-based interventions, we stressed the importance of evidence and discussed the EDUCATE programme. In addition to evidence, we also need a way of formalising the way that we talk about technology-based interventions that goes beyond the type of technology being used. We need a representational vocabulary for describing and communicating each evidence-informed technology-based intervention. This formalised representational vocabulary, or ontology, can then be used for grouping, classifying, and defining inter-relationships and evaluating each technology-based intervention. The existence of an ontology is also an essential factor for the use of data science to better understand and leverage the evidence that is generated as technologies are applied in education.

The EDUCATE programme has worked closely with over 270 educational technology businesses and has developed an ontology. The EDUCATE ontology is for use with any educational technology intervention and it can be adapted for the specific application to the design and application of technology to support learners with SpLDs. An ontology can be used to build a data hub that can enable the development of smart tools to open up data to search, visualisation, evaluation, triggering and decision-making tools (for example, to enable the formalisation of a rich, unified language, to encourage collaborative research).

The EDUCATE ontology is illustrated in Figure 1 and is composed of eight static classes and one dynamic class. This is to enable the retrieval of both static types of information, such as “I’m looking for a product to address Year 11 girls’ English learning, using tablets for informal learning within a constructivist pedagogy”; or dynamic types of information, such as “find me companies which are in their early financial days, but are engaged in developing their research and evidence mindset, and which have an image-based product for Geography education in secondary schools”.

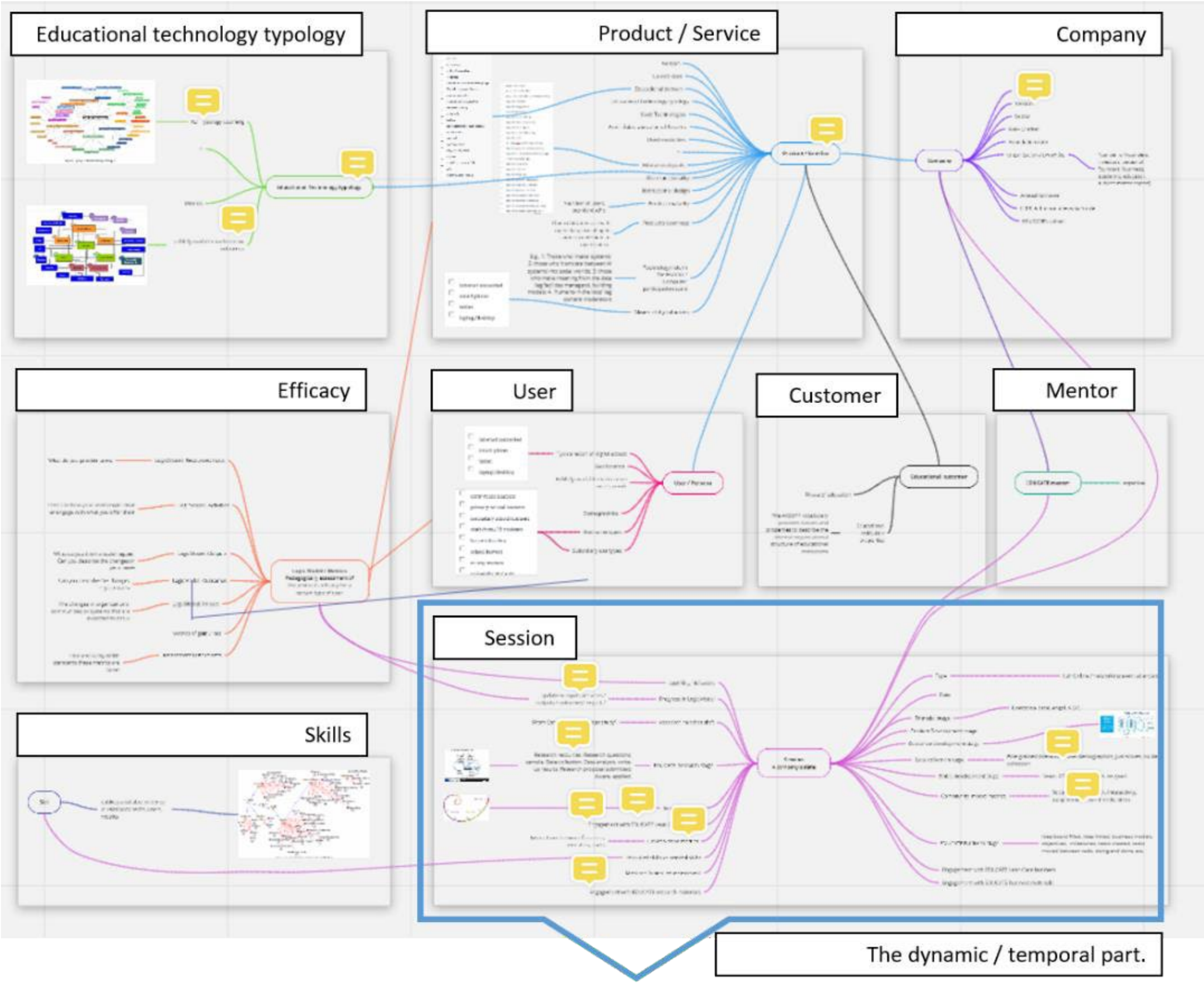

Figure 1: The ontology is comprised of nine main classes: Company, Product / Service (related to the company), Educational technology (related to the product), User (related to the product), Customer (related to the product), Mentor (related to the company), Efficacy (related to product and user), Session (related to the company, a mentor and to the progress in the product's efficacy and the company's learning), and Skill (related to both the session and to the educational technology).

The EDUCATE core ontology could be applied to the special case of technology-based interventions for learners with SpLDs. The core ontology is modular and can serve as a basis for a 'specialised' ontology for a range of specific areas, such as SpLDs.

As an example, we can extend the core ontology by adding classes and attributes that are of particular value for learners with SpLDs. A new attribute in the User class could specify the type of SpLD (dyspraxia, dyslexia, dyscalculia, ADHD or ASD); a new attribute in the Product / Service class could be added to classify equality of access; and diagnosis of learning disabilities could be added in the educational goal attribute. The Educational Technology Typology would cover all the technologies where there is evidence that they bring benefit.

7. Conclusions and policy recommendations

The evidence summarised in this review suggests that more people will be identified with SpLDs due to advances in science and technology that enable diagnosis that is more accurate, earlier, and on a larger scale. The education system will need to address the increasing numbers of people who are therefore identified as having a SpLD.

- The challenging teacher recruitment situation in the UK can be ameliorated for learners with SpLDs through the leveraging of technology to support both early diagnosis and effective learning support.
- The evidence about the way that technology can be used to support education for people with SpLDs summarised in this review is still relatively embryonic, patchy and lacks consistency and scale. Unless this paucity of evidence is addressed, there is a risk that the potential benefits of technology will not be effectively expedited for people with SpLDs. More evidence needs to be generated and a set of widely accepted methodologies agreed.
- If developments in AI technology and in our understanding about how people with SpLDs learn continue to progress as they have in the last decade, and we leverage them effectively, the potential for increasing educational achievements for people with SpLDs is great.
- A clear SpLD educational technology ontology, as described in section 5 of this review, will enable the application of data science and help the Government to leverage technology effectively for the education of people with SpLDs.
- If academic researchers were required to make their findings accessible both to educators and to technology developers, there would be an improved prospect for technology suitable for learners with SpLDs to be developed and effectively applied in education.
- The generation and accessibility of large datasets about people with a SpLD is a challenge, but as more people are diagnosed earlier in their lives, datasets should be collated and made available to those developing machine-learning AI techniques for both screening and support of those with SpLDs.
- The potential and increased use of AI presents ethical obstacles to the widespread data collection and algorithm design involved in using machine learning AI. These obstacles must be addressed in order to ensure that the education of learners with SpLDs benefits from advances in science and technology.
- Early intervention and support for reading and writing difficulties should be given priority.

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Annexes

Annex 3.A - Technology-based resources to assist students with SpLDs

Websites with VR experience

Boulevard (http://blvrd.com) is the developer of arts-based experiences shared through virtual, augmented, and mixed reality technologies.

Nearpod (https://nearpod.com/s/vr-explorations-F985) VR lessons for teachers and students

YouTube has its own VR platform: www.youtube.com/360

'Discovery' VR app for immersive VR education

AR experiences (not specifically for children with SpLD)

Dinosaurs everywhere uses Augmented Reality technology to place dinosaurs in the real world

Starwalk enables a view of night sky with augmented reality

Quiver3Dcoloring adds interactivity and learning to colouring

Jig space is a library of AR content from ancient Greece to Mars, toasters to jet turbines, to enable learning at a personal pace and satisfy curiosity.

RAF 100 AR flypast is a library of augmented reality flypasts with a facility to capture iconic RAF aircraft through your device camera.

Catchy words is word game for ARKit-powered devices. The player needs to catch floating letters and arrange them in the frame, so they make out a word in English.

Zookazam allows a 3D view of animals from every angle with full animation.

MeasureKit measures straight lines on any surface, such as a desk or wall.

Lego AR studios allows control of animated characters in the real-world and recording of favourite bits in short video clips.

Q moment AR is a Merge cube paired with your device using their app to help kids learn about and discuss emotions and their consequences.

Rouli: Augmented Reality for Autism.

Guiding Technologies: A Temple University spin off based on NSF funded research is conducting intensive trials to use AI enabled software to overcome problems in delivering Applied Behaviour Analysis (ABA), the gold standard in treating developmental delays due to autism spectrum disorder (ASD) and intellectual challenges.

Annex 3.B - EDUCATE companies working on technologies to help SpLD and SEN learners

Pakabo - games for tuning of fine motor skills

Pakabo combines physical play with EdTech and provides a platform for young learners aged 3-7 an opportunity to develop their motor skills while learning. It is a game system designed to strengthen hand muscles, develop fine motor skills, and improve graphomotor skills. Pakabo was tested by a special needs expert in Slovenia and developers believe that it is suitable for use by special needs learners.

www.pakabo.com/

Zaprendo - Assessment and language learning

Zaprendo has developed Sounds English Phonics, an early literacy app that helps readers accelerate word recognition in order to progress them more quickly through the early stages of reading. Built for a word recognition reading age of about 6 9 years, it teaches 92 commonly occurring written sounds and contains over 1 800 practice words. The app also personalises learning for each user, uses formative assessment, synthetic phonics and speech formation tuition. The app has been used in a school, with an intervention and control group study and the results show that children using the app have performed significantly better compared to the control group. This improvement for the Sounds English Phonics class was recorded for all boys and girls, including Special Educational Needs (SEN) Phonological Processing Disorder (PP) and English as an Additional Language (ESL) students.

https://zaprendo.com/

Auris Tech: Fonetti - reading comprehension

Fonetti uses an innovative voice recognition technology. Books in the app can listen to readers, rewarding them when they read correctly and helping them when they are stuck. Children can do this in their own time wherever they feel comfortable. When a word is pronounced correctly it will light up green Young readers can take stories word by word, sentence by sentence, at a pace that works for them.

www.fonetti.com/

Ketka - interactive storytelling

Ketka uses interactive storytelling to deliver mental wellbeing and Personal, Social, Health and Economics (PHSE) education. It can be used b y schools or parents. Audio only experiences are designed to make social and emotional growth an adventure. In addition to delivering activities in line with PSHE education, Ketka is designed to boost vocabulary, improve imagination and helps children learn how to make decisions as a group and collaborate.

https://ketka.co.uk/

Mangahigh - maths

Mangahigh maths offers game based learning where students learn mathematics using purpose built casual games that balance fun and learning. Games dynamically adapt in difficulty to the learners’ level of ability, provide an environment for plenty of practice, develop learners’ self regulation and offer authentic activities.

www.mangahigh.com/en-gb/

Ogenblik OliTool - behavioural/fidgeting/stay on task product

OliTool is an interne t of things system comprised of a patent pending ' connected object, Oli, and a companion app. It was developed by Ogenblik with psychologists and behaviour scientists. It uses behavioural therapy principles and behaviour change practices to help people tackle issues such as anxiety, worry and other personal challenges. The team is working towards OliTool for children with special education needs Wi th a Smart Award Grant from Innovate UK, the Ogenblik team is adapting OliTool for children, with a chi ld friendly tactile user interface and dedicated app, providing learning and insight opportunities for children and their adult support community.

www.ogenblikltd.com/our-story

Timely Practice - maths app

Timely Practice is a maths teaching tool to accelerate the progress of under achieving and low attaining students. The app creates personalised PDF assignments of mixed practice questions whi ch schedule retrieval practice. The optimally scheduled practice embeds this learning over a number of weeks. Timely Practice's aim is that almost all teaching becomes embedded learning which is demonstrated by students consistently, independently and accurately answering questions on that learning. Timely Practice makes assessment for learning, feedback, mastery learning and retrieval practice quick and easy for the teacher to integrate into their everyday planning, teaching and assessment. Timely practice h as been used with students in a UK school. The results indicate that it helps low achieving students to progress in maths class and improve their learning.

www.srslearning.com/

SwopBots - SEN game designs

SwopBots introduces young children to the world of computer science using stories and games. The SwopBots story features a brother a nd sister who use coding and engineering to overcome all kinds of problems. The game based approach teaches coding, problem solving and creativity and the product is also used by SpLD children.

https://swopbots.com/

iSandbox

iSandbox uses Augmented Reality to turn a traditional sandpit in to an interactive and dynamic tool. A unique interactive softw are program, projector and depth measuring sensor work together to transform the sandpit into realistic 3D textures of water, mountains, volcanoes, snow and many other objects. It offers children an environment where they can experiment freely, interact with other children, solve science and maths problems, develop social skills and fine motor skills and express their creativity. It has potential to help children with SpLD and SEN.

https://isandbox.co.uk/?gclid=EAIaIQobChMIgIq5wNe6AIVCLrtCh3d3QtvEAAYASAAEgKmIvD_BwE

Review 4: The role of science and technology in improving outcomes for the case of dyscalculia

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1. Executive summary and key recommendations

This report reviews the evidence and implications for each of the previous three themes but focuses on research relevant to the particular case of learners with developmental dyscalculia (DD) and mathematics learning difficulties (MLD).

Relative to other SpLDs, dyscalculia receives limited recognition within the wider education support system and lacks the same level of funding and research interest. In 2000-2010 in the US, for example, dyslexia received 46 times as much funding as dyscalculia for twice the prevalence. In the UK, between 2010 and 2020, the Wellcome Trust funded dyslexia by £3m and dyscalculia £1m; UKRI 2005-2019 funded dyslexia with £107m and dyscalculia £23m.

The following recommendations for policy and research surrounding dyscalculia, and SpLDs more generally, arise from this review:

- Re-establish official recognition for DD. Official government recognition would help policymakers, parents, and schools act. It cannot be left to non-governmental bodies. The US and Italy have laws requiring intervention for dyscalculia.
- Promote the use of reliable screening tools that focus on the efficiency of numerosity processing tasks in order to ensure the validity of interventions for dyscalculia.
- Increase funding for DD research to match that for dyslexia, which has a similar prevalence and impact on education and employment.
- Encourage cross-professional collaborative research between teachers, specialists in schools, and parents to establish what types of intervention work for DD.
- Train teachers, other education professionals, and parents in what DD is and what it is not, and how to support it, especially using concrete manipulables, a focus on foundational concepts, and the procedural skills using formal representations of arithmetic.
- Ensure that all training courses for teachers embed modules for all teachers that enable them to recognize and respond appropriately to every learner, as well as provision for specialisms in SpLDs.
- Direct funding towards technology-based interventions that focus on the most challenging concepts for the most challenging learners, as these will also be of value to all early learners.
- Provide specifications around the design of interventions to ensure reliable and comparable data that is based on learner performance in the classroom.
- Require research and development projects to maintain good practice on screening for the specific diagnosis for each SpLD considered, and its related milder conditions, such as dyscalculia and MLD.
- Use research on technology-based interventions, with standardised, trackable, and measurable data on learners' interaction analytics that enable properly controlled trials of which work best.

- Use MOOC platforms for open online collaborations, to engage teachers in the R&D process by guiding the large-scale empirical testing of digital interventions with their help.
- Government should endorse and require the certification supplied by MOOC platforms to motivate teachers and other education professionals to collaborate on effective innovation for SpLDs.
- Develop online courses, webinars, and support sites to provide collaborative professional development on all SpLDs, which are often not covered adequately in training courses. Access should be extended to parents, other education professionals and policymakers.

2. Methodology

Sources:

Peer-reviewed academic journals in related fields with clear criteria for dyscalculia; reviews and meta-analyses of the field; reports from reputable agencies.

Relevance:

Typical and atypical numeracy development; interventions for dyscalculia that include use of a learning technology; technology-based methods for supporting teachers of special needs.

Dates:

2010-2020

Search terms:

Typical mathematical development, atypical mathematical development, dyscalculia, specific learning disability in mathematics, mathematics learning difficulties/disabilities, dyscalculia+brain, intraparietal sulcus+numerical, frontal lobe+calculation, brain+calculation, acalculia, Gerstmann's Syndrome, dyscalculia + digital / games / learning / technology, special needs, AI + dyscalculia, assistive technology + math, constructionist/ism

Quality of research:

Results based on >=10 subjects; learners are tested for dyscalculia using an appropriate test (i.e. not results below a %, but using identifying characteristics, such as inability to estimate the numerosity of a set); pedagogic principles of the interactive design are clear and appropriate; appropriate controls (i.e. that set out to teach the same concepts or skills); appropriate pre/post-tests (i.e. curriculum-related); significant results for dyscalculics and learners with MLD. A good research design would show significant results against an appropriate control group of students receiving the usual teaching and working on maths problems covering the same mathematical skills.[4] Very few studies meet this criterion, partly because the control group simply takes the pre and post-tests so the amount of maths practice is not controlled. In addition, almost none provide a rationale for the pedagogical design, beyond an assumption that either instruction or programming is appropriate. That is why several studies in this review, and many of those covered in the previous review papers cited, do not meet all our original criteria.

3. Current understanding of the causes and diagnosis of dyscalculia

3.1 Underlying causes and distinction from other types of academic difficulty

Dyscalculia is a condition that affects the ability to acquire arithmetical skills. Dyscalculic learners may have difficulty understanding simple number concepts, lack an intuitive grasp of numbers, and have problems learning number facts and procedures. Even if they produce a correct answer or use a correct method, they may do so mechanically and without confidence. (DfES, 2001)

Developmental dyscalculia (DD) is a deficit of 'number sense', the specialised inherited capacity for understanding numbers, a vital tool in 'the starter kit' for a developing understanding of numbers and number operations. Thus, DDs take longer to acquire basic numerical competencies than typical learners.[1,2]

Poor number sense can be assessed by the efficiency of estimating the number of objects in a set, a task that is relatively independent of home or school contexts. This test in kindergarten predicts low numeracy each year to the age of 11.[3] A very large-scale prevalence study (11,500 children aged 6-16), found that the test is very strongly related to poor arithmetic, while good number sense is a strong predictor of typical development.[4] Prevalence of DD has been estimated at 4-7%, whereas low numeracy of all types is about 9-15%. DD is present from birth and persists into adulthood.[3]

Unlike typically developing (TD) learners, DD learners report fundamental problems in understanding even very simple numerical concepts:

- DDs have no intuitive understanding of numerical structure: for instance, they may know '8' is composed of 8 ones, but not that it is also 4 + 4.
- DDs find the base ten structure of the number system difficult or even the decade structure to 100: for instance, 39 represents all the counting sequence ones that it takes to count up to 39, but it is also 9 more than 30, and 1 less than 40
- DDs will fail to meet the Early Learning Goals for Numbers, including counting back from a given number, doubling and halving, and some may even fail to given 'one less than' a given number.

Reports of failures to understand basic numerical concepts:

> *Ryan, a cheerful and intelligent 7-year-old from a specialist dyscalculia facility in London was unable to select or count out three objects confidently.*
>
> *Paul Moorcraft, journalist and novelist, and DD: for him numbers are like "being asked to speak in an unknown foreign language".*[66]
>
> *The singer, Cher, in her autobiography, wrote that "Math was like trying to understand Sanskrit."* [67]
>
> *Samantha Abeel, a prize-winning author, wrote a memoir about her experiences as a dyscalculic child and adult, My Thirteenth Winter: "I am twenty-five years old and I can't tell the time. I struggle with dialling phone*

> *numbers, counting money, balancing my checkbook, tipping at restaurants, understanding distances, and applying basic math to everyday life".*[5]
>
> *Dyscalculic schoolchildren feel stupid and miserable, are teased by other children, and can be disruptive in class.*[6]

The brain learns through attention, active engagement, prediction-error feedback and consolidation through practice.[7,8] Neural network modelling assumes that a deep learning network can learn anything provided that input data is appropriate and sufficient. The input from home and school is sufficient for typical learners to acquire basic numerical concepts. The question is why DDs, who can learn many other concepts using these mechanisms, and who typically have opportunities to learn, fail to acquire simple arithmetical concepts and competences. So, what is missing for dyscalculic learners? One possibility is that for a network to learn to add, subtract and compare numbers, the basic number concepts in terms of sets need to be programmed into the network, analogously to how we may have inherited this capacity.[9] That is, the 'starter' network needs the addition of a special number component, the 'number sense', if it is to work normally.

Indeed, twin studies suggest that number sense is heritable.[10] Moreover, genetic abnormalities, such as Turner Syndrome, can selectively affect numerical competencies including efficiently representing the numerosity of sets.[11] The mechanism for estimating the number of objects in a set or display can be found in many other creatures, suggesting that there is an evolutionary basis for this capacity, and, like colour vision,[12] a genetic mutation could be a cause of disability.

DD has been linked to abnormal structure and activations in the brain network known to be involved in calculation, particularly in the left and right parietal lobes.[13] It is one symptom of Gerstmann's Syndrome, a parietal lobe abnormality. Several studies reveal lower grey matter density in the parietal lobes in both DD adolescents[14] and adults,[5] and relatively greater activations in the frontal lobes during number tasks, suggesting that number tasks, even very simple ones, require more planning and monitoring. Neuroimaging of infants at familial risk of dyslexia shows different neural activations from typical infants when hearing speech sound.[16] Something similar may be the case for DD when watching a change in the number of objects on a screen, which we know typical learners are sensitive to.[17] It would be worthwhile to investigate this, as it would enable very early identification and interventions before the child suffers at school.

DD often co-occurs with other SpLDs, such as a Developmental Co-ordination Disorder, dyslexia, and Specific Language Impairment, but these do not cause DD, even though they may affect numeracy, along with many other aspects of education. The neural and cognitive basis of dyslexia, for example, is quite distinct from DD. Dyslexia is linked to brain abnormalities in specific regions of the temporal lobe which are not implicated in DD,[18] and, as far as is known, there are no genes in common with these other conditions.[19]

3.2 Critical analysis of the current research approaches to understanding dyscalculia

The core deficit model is well supported by the research evidence, as presented above. However, alternatives have been proposed.

- Access deficit model. The fundamental deficit may not be in representing the number of objects in a set, its "numerosity", but in linking the representation to the number words and number symbols.[20,21]
- Multiple deficits model. "The heterogeneous clinical picture of DD is at odds with a single core deficit assumption" according to an international group of experts.[22] However, it has been argued that different clinical presentations are due to an interaction between a single core deficit and domain-general cognitive processes, such as attention and memory.[23] One version of this model is that dyscalculia is just at the lowest end, arbitrarily specified, of a continuum defined by a standardised test, performance on which will be influenced by general cognitive abilities as well as social and education background.

These alternatives are based on samples of the lowest 16% of the age group on a standard arithmetic test, and so will contain children with poor arithmetic for many reasons. Hence the sample will be more heterogeneous than the 4-7% DDs.

3.3 Challenges for research

There is a serious disparity in the level of funding for the different types of disability. According to an analysis of National Institutes of Health (US) funding for 2000-2010, dyslexia received $107m, and SLI $94m, while dyscalculia had $2.3m, and dyspraxia (DCD) $3.7m. The estimated prevalence of these conditions was, in this analysis, dyslexia 6%, SLI 7.4%, dyscalculia 3%, and dyspraxia (DCD) 6.5%. Thus dyslexia, for example, was getting 46 times as much funding as dyscalculia for twice the prevalence.[24] Equivalent figures are not available for the UK, but, over the last 10 years, the Wellcome Trust funded research into dyslexia by £3m and dyscalculia £1m[5]. UKRI between 2005 and 2019 funded dyslexia with £107m and dyscalculia £23m; however, in 2018-19, neither received funding from UKRI.[68]

Currently there is no official recognition of dyscalculia. The DfE website now offers nothing helpful to sufferers, parents, or professionals. This is despite the following:

- The Foresight Mental Capital and Wellbeing report (2008) had a special chapter on it and referred to DD in the Executive Summary.[25]
- The National Council for Excellence in the Teaching of Mathematics has offered definitions and guidance.
- DfES also offered definitions and guidance DfES-0512-2001.

3.4 International comparisons

The US has the *Individuals with Disabilities Education Act* (IDEA 2004) that includes DD as a specific learning disability requiring appropriate assessment and intervention via its Office for Special Education Programs.

[5] https://wellcome.ac.uk/grant-funding/funded-people-and-projects

Italy has Law 170 *Nuove norme in materia di disturbi specifici di apprendimento in ambito scolastico* (New regulations concerning specific disorders of learning), which requires appropriate assessment and intervention for dyscalculia. One effect of this law has been to dramatically increase the number of children treated for SpLDs, and specifically for dyscalculia, which increased by 160% from 2013 to 2018.

Another challenge is the widespread belief that poor maths is due to a lack of confidence or maths anxiety. However, a recent study of 1,800 8-9-year-olds challenges this.[26] Developing research on the emotional aspects of maths learning should be a priority.

There has been only one large-scale genome-wide association study (GWAS) for DD as there have been for dyslexia, but there has been a failure of replication.27 These need sample sizes of tens of thousands, such as international consortia GenLang and NeuroDys, which were aimed at the genetics of language and reading disorders. Relevant genes would provide a way of identifying children at risk almost from birth and would be easier to administer than neuroimaging.

3.5 Implications for action by government

1. **Re-establish** official recognition for DD. Official government recognition would help policymakers, parents and schools take action. It cannot be left to non-governmental bodies. The US and Italy have laws requiring intervention for dyscalculia.
2. **Promote** the use of reliable screening tools that focus on the efficiency of numerosity processing tasks in order to ensure the validity of interventions for dyscalculia. Teachers and professionals should be encouraged to use screeners such as this.
3. **Increase funding** for DD research to match that for dyslexia, which has a similar prevalence and impact on education and employment, to:
    a. Investigate the value of neuroimaging for early identification, using modern portable devices such as functional near-infrared spectroscopy.
    b. Investigate emotional causes and sequelae of DD.
    c. Fund large-scale genome-wide association studies (GWAS) for DD. Coordinate and harmonise the criteria in existing studies, e.g. GenLang and NeuroDys, to provide a template for integrating future work.
    d. Create a national dataset for DD and linked cognitive and socio-economic factors. Neural and genetic factors would be desirable.

4. Supporting students with dyscalculia

Economic impact analysis: KPMG estimated the long-term cost to the nation of the lowest 6% in maths (below UK entry level 3) at £2.4 billion p.a. (2009 prices) in education, taxation, social, health and crime. The estimated return on £1 spent on extra education is at least £12. [28] OECD modelling shows that raising the attainment of the lowest (below PISA level 2) would increase GDP by 0.44% p.a.[29]

Assessment is key. Dyscalculia screeners are simple to use, and necessary to distinguish DDs from other causes of mathematics learning disability (MLD) but are not widely used. Separate assessment from other SpLDs, and therefore separate intervention, is essential because dyscalculia is not caused by dyslexia, DCD or DLD.[19]

Current interventions in schools are directed at remediation rather than compensation. Some use neuroscience to target interventions precisely in order to develop DDs' concept of number because this is fundamental to arithmetic. Merely compensating for its absence is not sufficient.[30] (p623).

Learners with MLD need support in making an explicit connection between numerical objects (dots, lines, counters, blocks) and symbols (digits, signs) to understand the numbers represented in equations.[31](p132) The mental manipulation of numbers is seen as the key factor that drives the link between the primitive number sense and the use of arithmetic symbols,[32] (p16)and some research suggests that concrete manipulables (blocks, counters, etc.) may help.[31,33](p25) However, a systematic review of research on the concrete-representational-abstract framework for MLD, recommended further research, including work on 'virtual' manipulables.[34] (p220).

Special needs teachers know that dyscalculics are able to make much better sense of all areas of number work if they are guided in the early stages to use concrete materials to help them think and develop the all-important foundational understanding.[6] (p10)

Specialist teaching for dyscalculia is required, but it has only recently been possible to enrol at Edge Hill University for a Postgraduate Certificate in Education (Dyscalculia) and gain accreditation with the British Dyslexia Association. A similar scheme has started at Bath Spa University. Apart from these courses, specialist teachers learn on the job from other specialists in specialist centres such as Emerson House.

It is very difficult to run properly controlled randomised control trials studies of interventions for DD. Specialist teachers use 1-1 teaching for low-attaining learners, which cannot be standardised for RCTs. Evidence-based policy must find an alternative methodology for the SpLD field (see Theme 3 on technology-led interventions).

4.1 Implications for action by government

4. Establish what types of intervention work for DD. This requires cross-professional collaborative research, engagement of all teachers, specialists in schools, and parents.
5. Train teachers, other education professionals, and parents in what DD is and what it is not, and how to support it, especially using concrete manipulables, a focus on foundational concepts, and the procedural skills using formal representations of arithmetic.

For all SpLDs:

6. Ensure that all training courses for teachers embed modules for all teachers that enable them to recognise and respond appropriately to every learner, as well as provision for specialisms in SpLDs.

5. Technology-based interventions for dyscalculia

5.1 Types of digital intervention for maths

There are three basic types of digital intervention for maths: (i) game-like tutorials that emulate 1-1 instructional teaching, (ii) AI-based tutorials that use learner modelling to guide the next task to set, and (iii) microworlds that simulate a mathematical world for learners to act in to achieve a mathematical goal. All three types can take the form of game-like interactions and may use conditional rules or AI modelling to adapt the sequence to the learner's current performance. All of them are best embedded within teacher-led blended learning (mixing conventional with digital), even when they are being used at home.

5.2 Methods of instruction

Game-like tutorials use primarily the pedagogy of instruction: presentations of concepts, exercise tasks to practise and test understanding, and extrinsic feedback that tells the learner they are right or wrong, or offers hints. They are 'game-like' because they represent mathematical tasks and ideas in terms of familiar objects such as toys or animals, with set goals, and rewards such as animations. *AI-based tutorials* develop an individualised learner model in terms of their performance on the tasks presented and adapt the sequence of mathematical tasks according to the learner's current knowledge state.

The digital pedagogy of tutorial instruction emulates the time-honoured value of 1-1 teaching, an approach that is well understood in formal education, and derives from both behavioural and social theories of learning.

5.3 Methods of construction

Game-like microworlds use primarily the pedagogy of construction. The digital pedagogy of construction derives from approaches to understanding mathematical ideas that use the goal-oriented manipulation of mathematical objects, such as counters, rods, numberlines, and geometric shapes, which give informative feedback to the learner on what they have constructed. This is crucial because it requires them to think about the relationship between their action, the result, and the goal, and so how to improve their action. The learning sequence scaffolds the thinking about mathematical ideas from concrete materials to symbolic representations. This approach is less familiar than instruction, but it links closely to the neuroscience of learning (prediction-error learning), as well as the techniques used by special needs teachers.[6,35] It reflects the kind of learning through construction articulated by Seymour Papert at MIT. He provided a 'microworld', in which learners manipulate virtual representations of mathematical concepts linking them to the abstract symbols of formal maths in ways that are more personally meaningful to them.[36]

In section 3, we suggested that 'number sense' is inherited, so it follows that inherited neural differences might compromise it, which leads to poor estimation of set size. They do not see numbers as having internal relationships to each other. They therefore have to rely on counting procedures for doing arithmetic, which is highly inefficient.[35] (p1049)

This is why construction games are important for dyscalculia. The repeated cycle of goal-action-result-revised action requires continual generation and modification of their concepts and practical actions and should thereby support the development of their conceptual understanding. Unfortunately, digital interventions for low numeracy are dominated by the pedagogy of instruction. Very few offer game-based learning.[37] Most digital tutorial programs, especially commercial apps, rely on multiple choice questions (MCQs) as the main learning task.

5.4 Reviews of the literature

There have been several reviews of the research on technology-led interventions for dyscalculia over the past 10 years. They show mixed results.

- A review of research studies on technology interventions for MLD from 2000-2016 found them to be primarily instructional, and only show “promising effects” for these learners.[38] (p121)
- A 10-year systematic review of digital games for SpLD reinforced the issue that this area of research does not problematise pedagogic design, and concluded that there is a need to rethink and focus more on the role of game design in empirical intervention studies.[39] (p605)
- A review in 2012 of AI-based modelling interventions for special needs concluded that the learner modelling provides useful information for teachers and parents, but no value is found for learners.[40] (p1371)
- A 2018 review suggests that technology-led research on improving maths in grades 2 and 3 mainstream learners derives entirely from obsolete US systems (which is not the case), but that concrete manipulables and alternative representations have particular value, and more research is needed on technology-based methods.[41] (p93)
- A 2019 overview of AI approaches argues that commercial AI developers should use knowledge about the learning sciences and teaching.[42] (p2385) The three recent studies cited as showing significant effects of AI for mainstream learners showed only low effects or matching to usual teaching, but less need for teacher support,[43,44] (p499) and used AI only for selecting the next task, or provided diagnostic reports for teachers.[45] (p506)
- A 2019 review of technology-supported special education research reported that the educational software applications on the market are generally not appropriate for learners with SpLDs.[37] (p17) A recent review of online learning for cognitive disabilities in general concludes that there is not sufficient evaluation of the effectiveness of digital interventions for special needs.[46] (p34)

These reviews show that the field of digital interventions for special needs in general, and maths in particular, is immature. They point to the need for well-designed research that focuses on pedagogic design based on reliable outcomes from the learning sciences.

5.5 The features of pedagogy that distinguish types of digital intervention

Few digital interventions are currently available for dyscalculia, and even fewer meet our criteria for quality of research (see Methodology):

- The focus for research on technology-based solutions for maths is usually on mainstream learners
- A small number of studies analyse results for low attainers on the basis of performing in, for example, the lowest 16% on a standard test, but this includes more than DDs
- Even fewer use tests for dyscalculia (the lowest 4-7%).

We therefore relaxed our condition to include in the review some studies that report effects for typically developing learners and MLDs, in order to illustrate the different types of digital intervention on offer.

Sections 3 and 4 of this review, together with the studies cited here, suggest the principal pedagogic features that are important for helping dyscalculic learners:

- **Forms of representation** necessarily use mathematical symbols relevant to the curriculum topics in focus. Some also use virtual manipulables (e.g. objects, sets, numberlines).
- **Intended learning outcomes** for instruction studies are often only factual knowledge and procedural skills, whereas construction studies always aim for conceptual understanding.
- **Task goals** must be shared by the learner. In the context of construction this can be problematic if the learner is content with producing an output other than the target.
- **Learner action** engages them in thinking about the mathematics. This is necessary if they have to type an answer or construct something, but not if they simply select from given choices.
- **Forms of learner input** must match the nature of the action required, and must be easy for learners to do. Typing and dragging require more thought than selecting from choices.
- **Feedback** may be *extrinsic* to the action, saying it is right/wrong, or giving a hint; or *intrinsic* to the action, showing the result, which the learner must interpret to improve their action.
- **Revise learner action** enables the learner to revise their initial input in the light of the feedback of right/wrong, hint, explanation, or knowledge of result. Revision is not always available.
- **Choice of next task** shows how adaptive the pedagogy is to a learner's needs. Algorithms or AI learner models can adapt the level of the next task to the tracked learner performance so far.

Representative interventions selected from recent relevant research studies and research reviews (see Methodology) are listed in Table 1. The table compares them in terms of their pedagogic features, and the discussion below reviews the results they achieve.

Table 1: Comparison of the main types of digital intervention in terms of their pedagogical features

Pedagogical feature	Instruction through game-like tutorials	Instruction through AI- based tutorials	Construction through microworld games
Forms of representation	Virtual objects and positions (e.g. sets, numberline), symbols (e.g. 1, 2, +, x, =), expressions (e.g. 2 + 2 = 4, 6/8 = ¾)		
Intended learning outcomes	greater factual knowledge fluency in procedural skill motivation to practice	greater factual knowledge fluency in procedural skill motivation to practice	transfer of conceptual understanding fluency in procedural skill motivation to practice
Task goal	answer questions correctly	answer questions correctly	match a given target output
Learner action	select from choices (MCQs) input an answer	select from choices (MCQs) input an answer	construct the answer to match the target goal
Forms of learner input	type/click/touch to select from choices type to input answer drag to change object or symbol position	type/click/touch to select from choices type to input answer drag to change object or symbol position	drag to combine objects drag to combine symbols drag to construct expressions
Feedback	Extrinsic: Correct OR Incorrect, try again; give formal principle; give hint; show correct answer	Extrinsic: Correct OR Incorrect, try again; give formal principle; give hint; show correct answer	Intrinsic: show the result of the action reward if right, leave result if wrong
Revise learner action	no opportunity select another option use the given principle/hint to select another option	select another option use the given principle/hint to select another option	compare result with target goal to construct a revised action
Choice of next task	a pre-specified task sequence that is always the same generated at random within a specified range	via adaptive sequence using a learner model of their current state of knowledge	via adaptive rule using current data on learner performance

5.6 Reviewing digital interventions for maths

Instructional game-like tutorials (*Rekenweb, Tom's Rescue, Meister Cody, Number Race, DynamoMaths*) embed mathematical tasks in game-like features, e.g. objects are toys or creatures to provide context; goals are story-like, such as journeys or mysteries, to provide a meaningful context and narrative momentum; rewards are animations or accumulations of objects, to motivate the learner.

The potential advantages are that learners enjoy these interactions, so are motivated to practise. The disadvantage is that the game goal is to answer questions, and the learner input is typically to select an answer from given options. Some game tutorials, such as *Number Race* and *Cody*, also use dragging and typing for input, which provide more options. They also make use of the digital world by mixing the forms of representation to give meaningful feedback, such as a seesaw that does not balance if the number dragged to one side does not match the set on the other side.

Results are mixed:

- Rekenweb: for special education learners their knowledge of multiplication facts improved significantly, but not their procedural or conceptual knowledge.[47]
- Number Race: showed no statistically significant short-term improvement for low-performing children relative to controls.[48]
- Tom's Rescue: DDs significantly improved their capacity on three basic skills which are important for arithmetic, but there were no results reported on the intended conceptual development.[49]
- Meister Cody: results for the only published research study of these games show small training gains for mainstream learners in primary school, over a 3-week period.[50]
- DynamoMaths: There are no published results of effectiveness.

Only the interventions focused on DDs and MLDs attempt to remediate their learning by prioritising the specific activities that research says should help to develop their number sense. For the rest, the results for typically developing (TD) learners will not necessarily transfer to the low attaining groups. However, even the best results for TDs show little more than the ability to match, and therefore complement the usual teaching.

The **AI-based tutorials** (such as ActiveMath and ALEKS) are designed for mainstream learners. The AI modelling is used to model the learner's current knowledge state and select the next task on that basis. This personalises the learning sequence. However, learners are typically directed to instructional teaching resources, or given multiple choice question (MCQ) tasks. The main results are to show that the learner modelling faithfully represents the differences in learner ability. Results for learner improvement show either small learning gains, or no significant differences.[16,51]

For maths **microworlds**, there are very few recent examples, even for mainstream learners. *Calcularis* is the closest example. This microworld is a numberline, and learners must position a rocket on it to match a given number, or the number of a set of objects, or an addition, or a subtraction. If correct, the rocket takes off; if not, they must try again.

Results showed a significant improvement for DDs in locating the correct position of a number or addition/subtraction result on a numberline, and in their calculation of additions and subtractions.[52] (p791) A later neuroimaging study showed that the intervention led to a reduction in the kind of neural hyperconnectivity typical of DDs, i.e. less connectivity is linked to better maths ability.[53] (p296) Thus, *Calcularis* has the best, and only significant result for DDs, from the numberline training on where to position a number or calculation, i.e. a construction, not a multiple choice response.

A recent project to develop such games for DDs and MLDs has piloted NumberBeads, with a pedagogic design that emulates prediction-error learning and constructionist pedagogy within a microworld of manipulable sets.[54] Initial results from current studies of the effectiveness of *NumberBeads* show significant effects for low attainers (see Annex).

Both educational and neuroscience research on designing digital interventions for dyslexia and autism, using a mainly tutorial style of pedagogy, have a similarly mixed history. Recent reviews and papers also point to queries about the quality of the research studies, from inception to evidence,[55] (p446), [56,57] (p867). Nonetheless, they also conclude with expectations of future potential.

5.7 Implications for action by government

All these implications are applicable to all SpLDs, though exemplify those for DD and MLD.

7. Direct funding towards technology-based interventions that focus on the most challenging concepts for the most challenging learners, as these will also be of value to all early learners.

8. Specify that interventions must predict and test the efficacy of specific pedagogic designs, and adaptive sequencing based on learner performance.

9. Require research and development projects to maintain good practice on screening for the specific diagnosis for each SpLD considered, and its related milder conditions, such as dyscalculia and MLD.

10. All research projects should be judged on the quality of their design of pre- and post-tests, design of control groups, and the collection and analysis of learner performance data.

11. Use research on technology-based interventions to enable properly controlled trials of which ones work best. This is because they provide standardised, trackable and measurable data on learners' interaction analytics. This should be done for each specific SpLD considered, such as DDs and MLDs, comparing them with, for example, usual teaching and homework.

6. Costs and benefits of digital methods for teachers of DDs and MLDs

A recent OECD study on teachers as lifelong learners showed that the form of professional development (PD) most valued by teachers is collaborative learning, through networking with peers, because it has the most positive impact on their practice. However, they still lack good support in 'developing advanced ICT skills' and 'teaching students with special needs', the principal topics of this review. Around half of teachers also have little time or incentive for professional development.[58]

We know from the earlier review on the support system for SpLDs that teachers of SpLD learners have a lot to contribute to our understanding of what works, and yet they have very little support, and few opportunities to exchange ideas. For the rapid development of effective innovation in this field it is essential that we find ways to harness this hard-won experience and expertise. A 2019 review of 30 years of research on teacher collaboration concludes that, given the complex challenges now faced in classrooms, it is essential that policymakers enable teachers to collaborate, and that school and system leaders enable and empower them to do that.[59] (p17)

Digital methods can help. Recent experience of using MOOC platforms to run 'open online professional development collaborations' for teachers shows that this form of flexible but collaborative learning fits very well with teachers' needs.[60,61] What works for teachers can also work for their equally time-poor but highly knowledgeable professional peers, such as educational psychologists, policymakers, and also parents. A community of practice of this kind needs careful nurturing, guidance and support, which is the role of the university running it, but the advantage of an online community is its much greater reach, and therefore greater impact than any place-based course.

Economic impact analysis. Online collaborations are expensive to create but are worthwhile: once created they can be re-run, adapted for other uses, and the resources made widely available to others. However, it is more difficult to create an income stream than for campus-based PD because there is an expectation that digital is free. Education providers successfully charge £100s for a campus-based 6-hour workshop for 20 people, which costs only a few £1000s to develop and run. By contrast, only a small proportion of participants pay £10s for a MOOC that provides 12 hours of study time over 4 weeks, and costs £10,000s to develop and run.[62] Nonetheless, a recent international analysis shows that, if the comparative costs and benefits of the two modes are carefully modelled using an activity-based costing approach, it is possible to show that there is a substantial benefit from an online course after a few re-runs, because of the economies of scale and the additional advantages of flexibility and reach.[63] With endorsement from government, as in China for example, completion and certification can reach >90% of participants.

Such collaborative opportunities would support teachers in using digital interventions designed for dyscalculic learners that would also help TD, MLD, and adult learners with dyscalculia, thereby improving the benefit-to-cost value per student. Research findings from several studies of online PD for teachers and other education stakeholders on platforms such as FutureLearn show that:

- Universities can use online platforms to orchestrate the collaboration between policy, research, teaching, and developer communities, using recently developed digital tools for needs analysis, learning design, local testing, large-scale data collection, and peer review.[63,64]

- There is great potential for scaling up effective digital learning for teachers, to support them in using digital methods in class and at home, and there are affordable solutions that could be immediately actioned by government.[63]

6.1 Implications for action by government

All these implications are applicable to all SpLDs.

12. Use MOOC platforms for open online collaborations, to engage teachers in the R&D process by guiding the large-scale empirical testing of digital interventions with their help.
13. Use activity-based costing analyses to test the teaching costs and the learning and research benefits of an online collaborative community.
14. Develop online courses, webinars and support sites to provide collaborative professional development on all SpLDs, which are often not covered adequately in training courses.
15. Extend this access to parents and other education professionals and policymakers.
16. DfE to endorse and require the certification supplied by MOOC platforms to motivate teachers' and other education professionals to collaborate on effective innovation for SpLDs.

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Annexes

Annex 4.A - Current research project on 'NumberBeads'

A current project to develop maths microworlds for DDs and MLDs has piloted 'NumberBeads', with a pedagogic design that emulates prediction-error learning and constructionist pedagogy54.

NumberBeads is a microworld of number sets that can be joined, split, added or subtracted to make a target number/set. Learners must work out how to change their action if they make a non-target set. Every input and reaction time is recorded in the game analytics to feed into rules that adapt the next task or level to the learner's needs.

It has been adopted by colleagues at the Department of General Psychology at the University of Padua. Their research aim is to test whether NumberBeads is helpful for unsupervised home-based learning for low attainers, who lack sufficient time on these tasks within the school curriculum. They are also testing it in a controlled school-based study with low attainers.

The game has also been adopted for an educational neuroscience research study on maths for low attaining students, funded at the National Institute for Education in Singapore, which is testing its comparative value for both MLDs and TDs.

The research studies and results so far are shown in Table 2.

Table 2: Results for initial controlled studies of NumberBeads

Participants using NumberBeads	Procedure	Pre/post test	Control conditions	Results
London 3 schools, 5-7 years 26 TDs, 11 DDs	15 mins per day for 3 weeks. Then cross over	Year 1 curriculum-based	NumberChoice Usual teaching	% correct & fluency NB>NC> UT DDs and TDs similar effects
Italy home trial 6-7 years 111 TDs, 29 low attainers	15 mins per day for 3 weeks.	AC-MT (a standardized school test of arithmetic.	NumberChoice	Calculation fluency NB>NC very large effect size Improvement correlated with game play analytics
Italy 6 kindergartens 5-6 years 58 low attainers	15 minutes per day for 15 days	AC-MT	Usual teaching	NB > UT calculation accuracy improved Very strong evidence

Participants using NumberBeads	Procedure	Pre/post test	Control conditions	Results
Singapore 7 schools 141 low attainers	From one hour per week to 15 mins per day	Timed single-digit additions and subtractions	Usual teaching (in progress)	Efficiencies for addition and subtraction improve Large effect size

These initial results show significant improvements in both accuracy and mental calculation time for the low attainment group (<16% on standard tests) using NumberBeads, but not for those using a multiple-choice question version of the same game, ‘NumberChoice’. The same was true for the comparison with usual teaching. Only the London study screened for dyscalculia, but the others all studied the learners in the lowest class for maths attainment, according to school testing.

Publication of these results is imminent.

This publication is available from: www.gov.uk/cst

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