Journal of Mathematical Behavior 60 (2020) 100807

Contents lists available at ScienceDirect

Journal of Mathematical Behavior

journal homepage: www.elsevier.com/locate/jmathb

Exploring MLD in mathematics education: Ten years of research

Michel Deruaz[a], Thierry Dias[a], Marie-Line Gardes[b], Francesca Gregorio[a,c], Cécile Ouvrier-Buffet[d,*], Florence Peteers[e], Elisabetta Robotti[f]

[a] Haute école pédagogique (HEP) Vaud, UER MS, Avenue de Cour 33 – 1014, Lausanne, Switzerland
[b] Université de Lyon, Centre de Recherche en Neurosciences de Lyon (CRNL), Équipe EDUWELL, 95 Bd Pinel, 69500 Bron, France
[c] Université de Paris, LDAR, Universités d'Artois, CY Cergy Paris, Paris Est Creteil, Rouen, Bâtiment Sophie Germain – case courrier 7018, 75013 Paris, France
[d] Univ Paris Est Creteil, LDAR, Universités de Paris, Artois, CY Cergy Paris, Rouen, 61 avenue du Général de Gaulle, 94010 Creteil, France
[e] CY Cergy Paris Université, LDAR, Universités de Paris, Artois, Paris Est Creteil, Rouen 33 Boulevard du Port, 95000 Cergy, France
[f] University of Genova, Via Dodecaneso 35, 16146 Genova, Italy

A R T I C L E I N F O

Keywords:
mathematical learning disabilities
mathematical learning difficulties
dyscalculia
mathematical disorder
MLD
mathematics education
inclusion

A B S T R A C T

Mathematical learning disabilities or difficulties (MLD) are an increasing source of educational inequalities. This article explores research about MLD in Mathematics Education over the past ten years. The methodology focuses on specific, validated keywords. These keywords are used to identify articles in leading journals in mathematics education. Our work makes several new contributions to the field of mathematics education, notably: a reusable methodology and keywords for a literature review; an exhaustive list of articles about MLD in leading mathematics education journals; a discussion of the definitions and features of MLD used in these articles; and a tool to classify research dealing with MLD (categories that characterize students with MLD). We also highlight some unexplored dimensions regarding MLD in Mathematics Education research.

Recent decades have seen an increase in international research on learning difficulties and learning disabilities. Specific Learning Disorders (DSM-5; 5th ed., American Psychiatric Association [APA], 2013) such as those concerning reading and writing are better characterized and identified as compared to mathematics and mathematical reasoning. Cognitive science seems to be the most advanced field in specific learning disorder research, especially in mathematics. In this field, several terms are used to qualify these disorders: mathematical learning disabilities, mathematical learning difficulties, and (developmental) dyscalculia. As already noticed by Butterworth (2005), several authors use a different terminology to refer to learning disorders in mathematics and this can lead to confusion. In the Encyclopedia of the Sciences of Learning, De Smedt, Verschaffel, and Ghesquière, 2012, p.2121) claimed at the entry *Mathematics Learning Disability* (MLD) that the above-mentioned difficulties "(…) have been referred to as mathematics learning disability, mathematics learning difficulties, or dyscalculia (Berch and Mazzocco, 2007)". Therefore, in this article, when we use the acronym MLD, we refer to these synonymous expressions used in cognitive science. MLD (e.g. Lewis & Fisher, 2016; Berch & Mazzocco, 2007) are estimated to affect up to between 5% and 10% of students population (Szűcs & Goswami, 2013) and last throughout the school years (Geary, Hoard, Nugent, & Bailey, 2012). A stable definition of MLD remains elusive, notably in mathematics education, but also in educational, psychological and cognitive science research (e.g. Lewis & Fisher, 2016; Szűcs, 2016; Verschaffel et al., 2018). Definitions are constantly evolving: recent research points out that MLD are heterogeneous and affect

* Corresponding author.
E-mail addresses: michel.deruaz@hepl.ch (M. Deruaz), thierry.dias@hepl.ch (T. Dias), marie-line.gardes@univ-lyon1.fr (M.-L. Gardes), francesca.gregorio@hepl.ch (F. Gregorio), cecile.ouvrier-buffet@u-pec.fr (C. Ouvrier-Buffet), florence.peteers@cyu.fr (F. Peteers), robotti@dima.unige.it (E. Robotti).

https://doi.org/10.1016/j.jmathb.2020.100807
Received 30 March 2019; Received in revised form 18 July 2020; Accepted 23 July 2020
Available online 11 September 2020
0732-3123/

several mathematical skills (Fias, Menon, & Szũcs, 2013; Karagiannakis, Baccaglini-Frank, & Roussos, 2016; Kaufmann et al., 2013), and not only basic arithmetic. Currently, mathematics education is inclined to consider that MLD may have multiple origins involving not only cognitive dysfunction, but also contextual and social aspects (e.g. Sfard, 2017; Heyd-Metzuyanim, 2013); this perspective has also been adopted by some research in cognitive science (e.g. Dowker, 2005; Jordan, Hanich, & Kaplan, 2003; Mazzocco & Myers, 2003; Szũcs, 2016).

Unlike research that has predominantly conceptualized MLD in terms of *cognitive deficits* (e.g. Geary, 2010), Lewis (2014) conceptualized them in terms of *cognitive differences*. Her alternative approach used a response-to-intervention classification model and identified the resources students drawn upon, rather than the skills they lacked. Although researchers in cognitive science agree that MLD have a biological (i.e. cognitive) origin (Mazzocco, 2007), the field continues to struggle to accurately identify students who are affected.

As noted above, currently there is no consensus regarding the operational definition of MLD (Mazzocco, 2007), and researchers often rely on an achievement test score cutoff (between the 2nd and 45th percentiles) to identify students (Lewis & Fisher, 2016). Clearly, this method cannot determine if a student's low test score is due to cognitive or environmental factors – consequently minorities, students from a poor socioeconomic background, and non-native speakers are overrepresented. The conflation of low achievement and MLD continues to be a central challenge in the field of mathematics education.

When investigating MLD, it is necessary to consider the interplay between mathematics education and research domains such as mathematics, psychology, cognitive sciences and special education. How these fields interact is crucial for research concerning MLD, and raises the question: how has the field of mathematics education integrated definitions, results and investigations from other scientific domains that address MLD? In the *Encyclopedia of Mathematics Education*, Nunes (2014, p. 346) rightly pointed out that theoretical divergences and different conceptions of learning difficulties had led to a "discrepancy in the explanations" for such difficulties – and their measurement. Thus, we adopt an overall point of view, referring to cognitive science, with a contextualization of MLD to the specific features of the field of mathematics education. This process is conducted in the theoretical part of this article (section 1). Moreover, the field of mathematics education needs to be circumscribed as the domain continues to expand, with ever-more subfields, methodologies and *problématiques* (Kilpatrick & Sierpinska, 1998, p. 3–8). Consequently, in this study we adopt Toerner and Arzarello's (2012) classification of leading journals in mathematics education. This classification is based on the opinion of experts in the field and delimits a representative sample of the mathematics education community.

Our literature review addresses the following research question: **what is the state-of-the-art regarding current research findings on the topic of mathematics education and MLD?** We explore how MLD is studied in the field of mathematics education based on a systematic literature review. The review is divided into several stages: define the most efficient keywords and related methodology, classify and analyze the selected articles.

In this article, we firstly present our theoretical background. To do so, we have a threefold objective: to argue our choices regarding terminology and vocabulary used in this article, to identify relevant categories to classify students in the experiments explored in the selected articles, and to present criteria to analyze the selected articles. Secondly, we describe the (bibliographical) methodology to filter articles dealing with MLD in Mathematics Education. Thirdly, we shed some light on how we developed our (bibliographical) methodology, specifically the usage of keywords and the selection of articles. Fourthly, we analyze the results of the selected articles as a function of five main axes: the definitions of MLD used (even implicitly) in mathematics education, the countries and the years of the articles following our classification criteria, the mathematical content used in such studies, the level of schooling, and the research interests addressed in mathematics education. To conclude, we highlight some new perspectives regarding MLD in Mathematics Education.

1. Theoretical background

In the first part, we discuss the problem of definition of MLD in psychological and educational research literature. We also examine two articles, one of which is a comprehensive review (Lewis & Fisher, 2016) and the other is a survey paper (Scherer, Beswick, DeBlois, Healy, & Opitz, 2016) about studies in mathematical learning difficulties or disabilities in these different fields. The above-mentioned discussion and analysis of the scientific papers allow us to specify our theoretical background. This leads us to clarify the meaning of the term MLD in Mathematics Education that we use, define some categories to classify selected papers and present the analysis criteria used in our review.

1.1. Mathematical learning disabilities: discussion on definitions and classification

We evaluated prior studies done on MLD populations to examine the different approaches taken by researchers to classify and categorize individuals with MLD. In doing so, we identified the existing definitions and results from MLD in the field of cognitive science and psychological research.

The field of cognitive science has a long history of studying cognitive difficulties in learning mathematics but, as noted above, disagreement remains concerning the question of a definition, and operational criteria (Mazzocco, 2007). The term *Mathematical Learning Disabilities* is broadly used to describe a wide variety of deficits in mathematics skills, typically regarding arithmetic and problem solving. However, the following definition seems to have been adopted by most cognitive science researchers (Butterworth & Laurillard, 2010; Butterworth, 2005; Kaufmann et al., 2013; Landerl, Bevan, & Butterworth, 2004; Shalev et al., 2001): MLD is a neurodevelopmental disorder characterized by persistent difficulties in acquiring mathematical skills, despite normal intellectual abilities and adequate schooling. This view has gained considerable popularity not only in the research community, but also in educational settings and in the public discourse. In mathematics education, several researchers distinguish between "learning disabilities" and "difficulties". For example, Heyd-Metzuyanim (2013) argues that the problem with using the term "learning disability" is that it becomes difficult to distinguish between a stable, long-term learning disability and problems that are a result of deficient teaching (González & Espínel, 1999; Mazzocco & Myers, 2003). She underlines the importance of the "response to intervention" (or instruction) as a criterion for distinguishing a learning disability from other difficulties (e.g. Fletcher & Vaughn, 2009), and notes the lack of research into the design and nature of such interventions at the time. Both Heyd-Metzuyanim (2013) and Sfard (2017) highlight the need to take into account social and affective, as well as cognitive aspects of learning difficulties in mathematics. Moreover, the literature often uses the word "dyscalculia" to refer to difficulties faced by students with MLD such as in understanding numbers, arithmetic, sets and their cardinality (Butterworth, Varma, & Laurillard, 2011). However, in cognitive science dyscalculia refers to various issues (for example, mathematical learning disabilities or difficulties, arithmetic deficits) accompanied by various tests and criteria (Butterworth, 2005). The cause of the terminological confusion is the lack of a consensus on the classification of developmental mathematical weaknesses (Szũcs, 2016).

The issue of the terminology used is very important, especially to conduct a research review about MLD in Mathematics Education. In fact, it leads to inclusion or exclusion criteria for a literature review. We present below two studies (Lewis & Fisher, 2016; Scherer et al., 2016), one in psychological and educational research and the other in mathematics education and special education, to highlight this issue. We also present how the articles were analyzed in these two literature reviews.

How MLD was identified and what topics were explored in educational and psychological research was the subject of Lewis and Fisher's study (2016). For that, they used four criteria for classification. The first one was the classification criterion used for the diagnosis of MLD. The second criterion was the demographic composition of the groups. Thus, they also analyzed racial, class, language or gender differences between the students classified as having an MLD and those classified as typically achieving. The third criterion was the mathematical topic considered by the studies. To do that, they coded the mathematics topic investigated and the age or grade of the participants. The fourth criterion was the decade of publication and the country in which the study was conducted in order to analyze changes over time and to determine if trends differed in the United States and elsewhere. Their main results indicated significant variation in classification methods used to identify students with MLD, a focus on arithmetic problems and students at the elementary level, and that "studies rarely reported demographic differences between the groups, which may mask non cognitive causes of low achievement and result in the field conflating low achievement and MLD" (Lewis & Fisher, 2016, p. 366).

How research can support practice to assist students with mathematical learning difficulties or disabilities was the subject of Scherer et al. (2016). In their survey paper, they used four criteria to analyze recent research in mathematics education and special education. Firstly, they described definitions of mathematical learning difficulties, discussed vocabulary issues in different countries and raised the problem of terminology. The second criterion was related to effective teaching practices and intervention strategies. The third criterion was about the concepts of assistance in the context of inclusive education. Finally, their fourth criterion focused on the teacher's role and beliefs and on more general aspects of teacher training education programs for students with mathematical learning difficulties or disabilities. In their results, the authors underscored that the expressions "learning difficulties" and "learning disabilities" were sometimes used in different countries and in different contexts with the same meaning. For example, "learning difficulty" in the United Kingdom, and "learning disability" in the United States, Canada and Australia both characterized a group of people who have "specific learning difficulties" but "do not have a general impairment of intelligence" (Scherer et al., 2016, p. 634). Moreover, they underscored that a key challenge in providing high-quality mathematics education involved rethinking the institutional structures that mediated both teaching and learning, for example curricula and assessment methods. For the authors (Scherer et al., 2016), the question of the design of educational interventions and the construction of a mathematics education system that no longer disadvantaged so many students was crucial.

1.2. Defining categories to classify the selected articles

As seen in the previous section, the terminologies dealing with difficulties/disabilities related to mathematics are unclear and complex. In cognitive science, the persistence of difficulties, identified by a diagnosis, is fundamental. However, in a classroom, the diagnosis is not always available, so it seems necessary to take into account the fact that a teacher should be able to help every student, whether they are diagnosed or not. Thus, in mathematics education research, it is important to adopt a more global point of view than in cognitive science. It is also fundamental to consider specific difficulties in mathematics or persistent difficulties in mathematics or both specific difficulties in mathematics and persistent difficulties in mathematics. We chose to consider students with severe mathematical difficulties without a medical diagnosis and students with MLD in the sense of cognitive science.[1] The specificities of the field of mathematics education led us to define the three categories below. These categories were representative of what we call "MLD in Mathematics Education".

Like Lewis and Fisher (2016), we used a criterion for classifying articles according to the types of participants in each study. In their review, these authors only selected articles where participants had specific and persistent difficulties in mathematics, attested by a diagnosis with clear quantitative criteria. As we investigated the mathematics education domain, we also had to take into account students with specific but not necessarily persistent difficulties and students with persistent but not necessarily specific difficulties. Students with MLD could therefore be identified with tests without clear criteria or sometimes identified by teachers. Furthermore, it

[1] We remind the reader that there is a consensus in cognitive science in considering MLD a neurodevelopmental disorder characterized by persistent difficulties in acquiring mathematical skills, despite normal intellectual abilities and adequate schooling.

should be noted that, following Scherer et al. (2016), we did not consider all the disabilities included in the definition of the United Nations' Convention on the Rights of Persons with Disabilities. The latter defines people with disabilities as having long-term physical, mental, intellectual or sensory impairments which, in interaction with various barriers, could hinder their full and effective participation in society on an equal basis with others (UN-United Nations, 2006). We focused only on learning disabilities and not other types of disabilities such as physical, mental, sensory impairments.

At last, we defined three categories (see below) to classify the articles which were selected in this literature review.

"Math Disorder" designated a "specific learning disorder with impairment in mathematics" (APA, 2013). The term "disorder" underlined the biological or cognitive origin of the problem. Thus, the following criteria were used:

- students with a specific learning disorder in mathematics but no primary diagnosis;
- students assessed with a specific mathematics test (e.g. psychometric tests such as the WJ-Test, or a researcher-designed assessment);
- students diagnosed with a specific criteria (e.g. cutoff, discrepancy, growth).

It should be noted that this group corresponded to students with MLD in the sense of cognitive science. Studies distinguished between students with low achievement and students with MLD. Moreover, additional tests eliminated other explanatory factors such as gender, language, SES (socioeconomic status), etc.

In mathematics education, it was important to take into account learning difficulties without any diagnosis in mathematics: this led to the following categories.

"Learning Disabilities" designated students with a specific learning disorder, referring to APA, 2013APA (2013): "one essential feature of specific learning disorder is persistent difficulties learning keystone academic skills" (p. 68). These students had more general problems (such as a deficit in working memory) with consequences for mathematical learning. It should be noted that the diagnosis did not always include specific tests in mathematics. Thus, although it was clear that the students in this category had persistent learning difficulties, it was not clear whether these difficulties were specific to mathematics or not. Note that we used the term "learning disabilities" and not "learning disorder" because we did not have information about a possible clinical diagnosis, in particular in mathematics. This choice was consistent with Penesetti (2018) who specified that "Specific learning disorder is a medical term used for diagnosis. It is often referred to as "learning disorder." "Learning disability" is a term used by both the educational and legal systems".

"Severe Difficulties in Mathematics" referred to studies where participants had severe difficulties in mathematics or had been identified as being at risk of MLD. When assessed, these students were less successful in mathematics than other students. Therefore, both the test and the criteria used to classify the participants were different with respect to the "Learning Disabilities" group. In the Severe Difficulties group, the tests could be administered within the institution (for example by teachers), and the classification criteria were not explained or defined. Thus, although we could be sure that the students in this category had specific difficulties in mathematics, we could not know for sure if these difficulties were persistent, or what their nature was.

In summary, "Math Disorder" included students with specific and persistent difficulties in learning mathematics. "Learning Disabilities" included students with persistent – but not necessarily specific – difficulties in learning mathematics. "Severe Difficulties in Mathematics" referred to students with specific – but not necessarily persistent – difficulties in learning mathematics.

1.3. Defining criteria to analyze the selected articles

We defined five criteria to analyze the selected papers based on the studies of Lewis and Fisher (2016) and Scherer et al. (2016).

The first two criteria were based on general features to highlight geographic differences and similarities. The first one concerned the number of publications per year (following the method of Lewis & Fisher, 2016). Moreover we cross-referenced this data with the country in which the research took place and with the above-mentioned three categories. The second criterion was related to keywords and countries. Taking into account the research findings on the differences in terminology about mathematical learning difficulties or disabilities across countries (Scherer et al., 2016), we looked at the terminology used about MLD in Mathematics Education based on our keywords for each country.

The third and fourth criteria (school level and mathematical content) were related to the school context. Like Lewis and Fisher (2016), we looked at the different school levels of the participants in each study and then at the mathematical content considered by the studies. The aim was to examine the gaps in research on school levels and mathematical content.

The fifth criterion concerned research interests addressed in mathematics education. Lewis and Fisher (2016) highlighted "an increase in rigor with respect to the assessment criteria used to identify students with an MLD. (…) the movement toward more stringent criteria for MLD identification suggests that researchers are actively attempting to address this outstanding methodological challenge" (p. 360). Here, we seek to identify how mathematics educators characterize students with Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics, and how they are identified. In particular, what tools and devices are used to detect students in difficulty? Following recent research (Dias, 2019; Peteers & Ouvrier-Buffet, 2019) in the mathematics education domain, we identified three key areas of investigation: the identification of students with Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics, educational interventions for these students, and their characteristics.

2. Bibliographic review methodology

Our work was inspired by the methodologies found in Lewis and Fisher (2016) and Joklitschke, Rott, and Schindler (2018)). Lewis and Fisher (2016) conducted a literature review of articles published between 1962 and 2013 found in three databases (PsycINFO, ERIC, and Education Source) containing any of the six keywords (math* disabl*, math* learning disabilit*, math* disabilit*, dyscalculia, arithmetic* disabl*, and arithmetic* disabilit*). They also conducted a manual search of "leading journals in the field[s]" of educational and psychological research (*Exceptional Children,* the *Journal of Learning Disabilities,* the *Journal of Special Education, Learning Disabilities Research and Practice,* and *Learning Disability Quarterly*). Their review focused on empirical studies that were published in English in a peer-reviewed journal, where participants were classified as having a specific mathematics learning disability, and studies that provided specific criteria regarding the classification of students with MLD. Joklitschke et al. (2018) analyzed how creativity was described and conceptualized in contemporary research. They developed a systematic process to select a list of keywords founded on research published in the proceedings of the *International Group for the Psychology of Mathematics Education* (IGPME) conference about creativity. These keywords were used to identify related papers found in official databases, which were then read in order to categorize statements found in these articles.

We adopted a part of Lewis and Fisher (2016) methodology, and used keywords to identify articles concerning MLD in Mathematics Education. Like Joklitschke et al. (2018), we identified a list of relevant keywords. Specifically, our methodology was based on the following three phases. The first was to define and validate a list of keywords found in the semantic field of mathematics education. The second was to use these keywords to search for articles about mathematical learning disabilities or difficulties in the leading journals in mathematics education designated by Toerner and Arzarello (2012). The third was to define classification criteria for the qualitative analysis of selected articles.

The specificities of our methodology were:

- We only used leading journals in the specific field of mathematics education (Toerner & Arzarello, 2012);
- Our list of keywords was specific to mathematics education, and we generated new keywords in this field;
- We took into account the difference between "learning difficulties" and "learning disabilities", and considered severe mathematics difficulties (see below for further details);
- Our criteria for the analysis of articles focused on definitions, mathematical content, and results regarding MLD in Mathematics Education.

We aimed to explore the way mathematics education research dealt with MLD.

2.1. Identifying relevant keywords

In this step we created a list of appropriate search terms in order to find articles about MLD in Mathematics Education.

We began by considering the keywords used by Lewis and Fisher (2016): *disab**[2] and *dyscalcul**. As these terms are widely used in education and psychology, we hypothesized that they would not identify all articles about MLD in Mathematics Education; we therefore extended the list based on a systematic screening of the Proceedings of the Congress of European Society for Research in Mathematics Education (CERME) (held every two years since 1998) and the International Group for the Psychology of Mathematics Education (IGPME) conferences held between 2009 and 2018. The CERME aims to promote ongoing research in mathematics education and provide opportunities for cooperation and inter-European collaboration. The IGPME was established in 1976 and includes researchers from all over the world: members are from more than 40 countries and about 500–800 people attend the annual conference. These congresses were selected because they are two of the leading events in mathematics education, and represent the state of ongoing research in the field.

We selected all articles published in the conference proceedings with *disab** or *dyscalcul** in their title, or at least two occurrences in the text. We then noted the keywords used in these articles in order to find expressions that were used synonymously with MLD. This process identified a list of keywords representative of MLD in Mathematics Education, which was used to conduct a full search for articles on the topic.

The results regarding this phase are described in detail in paragraph 3.1.

2.2. Article selection

To ensure the quality of analyzed articles, we only chose journals graded A*, A, and B (according to Toerner & Arzarello, 2012; see Table 1). Most are published in English. These leading journals clearly focus on mathematics education, have a strict peer-review process and are recognized internationally.

The MathEduc (Mathematics Education Database)[3] was chosen as it contains all of the twelve selected journals[4] . We restricted the

[2] This included the two keywords *disabl** and *disabilit** found in Lewis and Fisher (2016). We did not associate these keywords with *math** and *arithm** because the considered conferences (PME and CERME) are specialized in mathematics.

[3] https://www.zentralblatt-math.org/matheduc/.

[4] We also used the *Scopus* database in order to validate the results obtained with *MathEduc*. The results of these two databases converged, except

Table 1
Journals graded A*, A and B by the European Mathematical Society (Toerner & Arzarello, 2012, p. 53).

A*	Educational Studies in Mathematics (ESM) Journal for Research in Mathematics Education (JRME)
A	For the Learning of Mathematics (FLM) Journal of Mathematical Behavior (The) (JMB) Journal of Mathematics Teacher Education (JMTE) Mathematical Thinking and Learning (MTL) The International Journal on Mathematics Education (ZDM)
B	International Journal of Mathematical Education in Science and Technology (IJMEST) International Journal of Science and Mathematics Education (IJSME) Mathematics Education Research Journal (MERJ) Recherches en Didactique des Mathématiques (RDM) Research in Mathematics Education (RME)

time period from 2007 to 2016. We chose not to consider the years 2017 and 2018 in order to avoid the problem of an incomplete update of the database. Articles were selected based on their title, abstract, keywords or sometimes the full text. The results of this phase are described in detail in paragraph 3.2.

3. Implementation of the methodology

This section presents a detailed description of the process of establishing keywords. It goes on to discuss the selected words and the selection of the analyzed papers, and report on the classification of articles. The analysis of the articles will be presented in section 4.

3.1. Identification of relevant keywords

The aim of this step was to create a set of keywords used to select relevant articles. We began by considering the keywords found in Lewis and Fisher (2016): *disabl**, *disabilit**, *dyscalcul**. We considered that placing the wildcard after the "b" in *disab** was more efficient for our purposes than using both *disabilit** and *disabl**. However, this list (*disab*, dyscalcul**, termed K1) needed to be extended to better represent the mathematics education domain.

Therefore, we selected conference proceedings that were specific to mathematics education: all PME (from PME33 to PME42)[5] and CERME (from CERME6 to CERME10)[6] proceedings from 2009 to 2018 were considered. The steps used to identify relevant keywords are described in the following sections and represented in Fig. 1.

3.1.1. First step: analysis of the title

First, we searched for the two initial keywords (*disab** and *dyscalcul**) in the titles of articles published in PME and CERME proceedings. But this only identified 5 articles (see Table 3). This list was expanded in the second step.

3.1.2. Second step: analysis of the text

Next, we searched for the two initial keywords (*disab** and *dyscalcul**) in the full text of articles. An article was included if one of the keywords occurred at least twice in the body of the text (excluding the list of references). This identified 30 articles (see Table 3).

3.1.3. Third step: expanding the list of keywords

The first and second steps identified a set of 30 articles. Next, for each of these articles, we extracted all their keywords (if present). If no keywords were listed, we read the abstract, and identified new keywords based on the principal concepts described therein. This resulted in a second, longer, list of keywords (termed K2), which was reduced by grouping keywords into categories defined by semantic areas. For example, the keywords *learning difficulties, difficulties in learning mathematics* and *difficulties* were grouped into one category labeled *difficulties*. This resulted in a third list of 65 keywords (K3, for details see Table 2). However, this list was too long to be effectively managed and was reduced by:

- retaining keywords that appeared more than twice. For instance, *artifact*, which appeared only twice, was not selected; and
- removing keywords that were off topic.

(*footnote continued*)
for two journals. One was not referenced by *Scopus* (*Recherches en Didactique des Mathématiques*), and some of the abstracts of the second (*For the Learning of Mathematics*) were missing in *Scopus*.

[5] Taking into account plenaries, research reports and national presentations.

[6] We did not take posters into account.

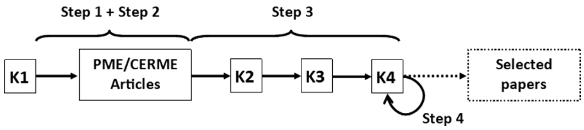

Fig. 1. Steps used to identify relevant keywords.

Table 2
K3 and selection criteria.

Occurrence ≤ 2	Occurrence > 2	
	Off topic	In topic
"maths counsellor", achieving proficiency, artefact, cognitive aspect, cognitive development, cooperative learning, counting-on, deaf students, deficit, delay, derivation strategies, detection test, disadvantage, discourse, ***dyscalculia****, dyslexia, diversity, early years education, emotion, experiential learning, flexible mental calculation, fraction, geometry, gifted, group discussion, heterogeneity, heterogeneous grouping, hearing impairment, identification, in-service teacher education, inquiry-based learning, intelligent tutor, interaction, intervention, language impairments, learning progressions, learning trajectories, lower achievement, lower performance, mathematical skills, mathematics instruction, motivation, national high-stakes testing, nonverbal communication, number line, number understanding, performance groups, poor achievement, pre-service teachers, proficient performance, reasoning, self-efficacy, self-regulation strategies, social valorisation, special education, special needs, student participation, teacher beliefs, underperforming, universal design for learning, value*	*problem-solving*	*difficulties, disabilities, inclusion*

Table 3
Frequency of occurrence of keywords in CERME and PME articles published between 2009 and 2018. The Total indicates articles that contained both keywords.

	First step - K1 in Title		*Second step - K1 in Text*		*Fourth step - K4 in Title*	
	Occurrence of *disab*	Occurrence of *dyscalcul*	Occurrence of *disab*	Occurrence of *dyscalcul*	Occurrence of *difficult*	Occurrence of *inclus*
CERME	1	0	14	0	13	10
PME	3	1	15	3	11	4
Total	**5**		**30**		**37**	

Table 2 highlights that the K3 list contains many keywords that only occurred once or twice. One, *problem-solving*, occurred four times, but was not particularly related to our topic. Although it is a key topic in mathematics education, including it would mean finding articles about problem solving in general, and not about problem solving by students with mathematical learning disabilities or difficulties in particular. Therefore, we chose not to include it. Although the word *dyscalculia* appeared only twice, we retained it because it was one of the two initial keywords. Finally, all possible variations were taken into account by wildcards: for example, we used the keyword *inclus**, which can refer to *inclusive* but also to *inclusion*. This process resulted in a fourth, final list of keywords (K4) containing *disab**, *dyscalcul**, *difficult**, and *inclus**.

3.1.4. Fourth step: checking the consistency of K4

The goal of the last step was to check the consistency of K4 and ensure that no keywords were missing. We therefore searched for the four K4 keywords (*disab**, *dyscalcul**, *difficult**, *inclus**) in the titles of PME and CERME articles. This process resulted in a set of articles that were then resubmitted to the third step in the process (paragraph 3.1.3) to look for other keywords. This established that no keywords had been overlooked. We therefore concluded that K4 was a consistent list of keywords used in mathematics education linked to MLD. These keywords were used to select the reviewed articles.

3.1.5. Discussion of keywords

Some points concerning the keyword selection process merit particular attention. As shown in Table 3, the first step of the selection process (paragraph 3.1.1) only identified four occurrences of *disab** and one of *dyscalcul**. In the second step (paragraph 3.1.2), the occurrence of *disab** increased to 29, but the occurrence of *dyscalcul** only increased to 3. Furthermore, in the second step, two of the three articles that included the keyword *dyscalcul** were also found to include *disab**. This suggests that the word *dyscalculia* is not commonly used by the mathematics education community and, consequently, is not a popular research topic. Rather, as stressed by Lewis and Fisher (2016), the cognitive domain seems to be more relevant. This suggests that the two fields remain very distinct and do not share content, vocabulary or purposes.

Moreover, it should be noted that the word *disorder* (APA, 2013) is not a term that is used by the mathematics education community. In fact, it never appeared in our search and, like Lewis and Fisher (2016), we did not use it.

The word *difficult** posed a particular problem. This polysemic word is often used in everyday language. For example, the sentence "calculus is difficult for university students" includes the keyword *difficult** but is irrelevant to our research. This raised the question of whether articles that included this word but no other keywords would actually be relevant (in other words, is it really efficient?). Section 3.2 elaborates on this point.

3.2. The selected papers

The aim of this step was to identify a set of papers about MLD in Mathematics Education to be used for our literature review. Here, we present the results of the methodology described in section 2.2.

3.2.1. Initial list of papers

We searched the *MathEduc* database (in August 2018) for the K4 keywords in the title, abstract and lists of keywords[7] (in *MathEduc*, the command is: "disab* | difficult* | inclus* | dyscalcul*"). The date range was limited to the years 2007 to 2016, which resulted in a dataset of **449 articles.**

3.2.2. Second list of papers

Within this first list of 449 papers, we sought to understand the reason why articles had been selected by reading their titles, keywords and abstracts. This highlighted that many of the selected articles appeared for a reason that was not linked to MLD. For example:

- the article focused on teachers' knowledge or difficulties (e.g. Passelaigue & Munier, 2015. "Difficulties" appeared in the title: *Schoolteacher trainees' **difficulties** about the concepts of attribute and measurement*);
- the author(s) used the word 'difficulty', 'difficult' or 'inclusion' in their everyday meaning (e.g. Groth, 2007. "Inclusion" appears in the title: *Understanding teachers' resistance to the curricular **inclusion** of alternative algorithms*. Another example is Harwell, Post, Medhanie, Dupuis, and LeBeau (2013)) where the following sentence appeared in the abstract: "high school mathematics curricula were unrelated to college mathematics achievement or students' course-taking patterns for students who began college with precalculus (college algebra) or a more **difficult** course";
- the 'difficulties' addressed by the article dealt with a concept, problem, task, level, or proof. For example, in Ellis (2007), the following sentence appeared in the abstract: "Research investigating algebra students' abilities to generalize and justify suggests that they experience **difficulty** in creating and using appropriate generalizations and proofs";
- the article focused on everyday difficulties encountered by students. For example, in Gueudet (2008) the following sentence appeared in the abstract: "The secondary–tertiary transition has been studied in a great amount of research in mathematics education, adopting different focuses and theoretical approaches. I present here how these focuses led the authors to identify and study different students' **difficulties**";
- 'difficulties' referred to gender, language, culture, or policies. For example, in Solomon, Radovic, and Black (2016)) the following sentence appeared in the abstract: "A common theme in accounts of choosing mathematics is that of persistence in the face of troubles or **difficulties** which are often associated with the structuring effects of gender, class, culture and ethnicity".

As these articles were not linked to MLD, they were removed from the dataset. This process eliminated 404 articles, leaving a second corpus of **45 papers**.

3.2.3. Final set of papers

Finally, we read the full text of the 45 remaining papers, to ensure that none was off-topic. In that stage, we focused on the population and tried to classify learners using our three categories described in section 1.2 (i.e. Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics). We eliminated studies for the same above-mentioned reasons (paragraph 3.2.2) applied to the whole article or because they focused on other types of population (with intellectual or sensitive impairment). For example, the article by Kyriakides and Houssart (2016) contained the keyword *difficult**, but was eliminated because it focused on hearing impairment. Through this process, we obtained a third and final list of **19 papers**.

3.2.4. Discussion of the paper selection process

As shown in Table 4, only six journals were represented in our final dataset: the *Journal for Research in Mathematics Education*, *Educational Studies in Mathematics*, *Mathematical Thinking and Learning*, the *Journal of Mathematical Behavior*, *ZDM - International Journal on Mathematics Education*, and *Research in Mathematics Education*.

Most papers were published in ZDM, notably because it has published two special issues on cognitive science. Nevertheless, not all of the articles published in these special issues were retained in the final dataset, mainly because the population concerned was composed of ordinary students.

It should be noted that the same paper was found through more than one keyword. In the first list, 16 articles contained the keyword *disab**, while 12 remained in the final list. Similarly, 6 articles contained the keyword *dyscalcul**, and 4 remained at the end. Although those two keywords were efficient, they did not identify all of the articles in the final dataset.

[7] The *MathEduc* database includes authors' keywords and database keywords.

Table 4
Number of papers found at each step for each journal.

	First list (paragraph 3.2.1)	Second list (paragraph 3.2.2)	Final list (paragraph 3.2.3)
ESM	**71**	**8** Heyd-Metzuyanim & Graven, 2016; Jankvist & Niss, 2015; Lambert, 2015; Bouck, Joshi, & Johnson, 2013; Heyd-Metzuyanim, 2013; Herbert & Pierce, 2012; Boesen, Lithner, & Palm, 2010; Traoré, Lajoie, & Mura, 2007	**4** Jankvist & Niss, 2015; Lambert, 2015; Bouck et al., 2013; Heyd-Metzuyanim, 2013
JRME	**20**	**4** Lewis & Fisher, 2016; Blanton et al., 2015; Lewis, 2014; Xin, 2008	**3** Lewis & Fisher, 2016; Lewis, 2014; Xin, 2008
FLM	**12**	**0**	**0**
JMB	**38**	**6** Hunt, Westenskow et al., 2016; Hord et al., 2016; Hunt, 2015; Sofronas et al., 2011; Eriksson, 2008a; Eriksson, 2008b	**3** Hunt, Westenskow et al., 2016; Hord et al., 2016; Hunt, 2015
JMTE	**23**	**0**	**0**
MTL	**17**	**4** Hunt, Tzur et al., 2016; Salminen et al., 2015; Nunes, Bryant, Evans, & Barros, 2015; Shepherd, Selden, & Selden, 2012	**2** Hunt, Tzur et al., 2016; Salminen et al., 2015;
ZDM	**85**	**12** Ginsburg, Lee, & Pappas, 2016; Scherer et al., 2016; Vogel et al., 2016; Pfister, Opitz, & Pauli, 2015; Tropper, Leiss, & Hänze, 2015; Wischgoll, Pauli, & Reusser, 2015; Broza & Kolikant, 2015; Attridge & Inglis, 2015; Van Garderen et al., 2014; Stavy & Babai, 2010; Landgraf, Van der Meer, & Krueger, 2010; Butterworth & Laurillard, 2010	**5** Ginsburg et al., 2016; Scherer et al., 2016; Pfister et al., 2015; Van Garderen et al., 2014; Butterworth & Laurillard, 2010
IJMEST	**79**	**2** Herrera, Bruno, Gonzalez, Moreno, & Sanabria, 2011; De Vleeschouwer, 2010	**0**
IJSME	**45**	**1** Wu, Lei, DiPerna, Morgan, & Reid, 2015	**0**
MERJ	**30**	**1** Jupri, Drijvers, & van den Heuvel-Panhuizen, 2014	**0**
RDM	**12**	**3** Assude, Perez, Suau, Tambone, & Vérillon, 2014; Tambonne, 2010; Giroux, 2008	**0**
RME	**17**	**4** Kyriakides & Houssart, 2016; Gifford, 2014; Holmes & Dowker, 2013; Gifford & Rockliffe, 2012	**2** Holmes & Dowker, 2013; Gifford & Rockliffe, 2012
Total	**449**	**45**	**19**

Many of the 449 papers in the initial dataset contained the keyword *difficult**. However, most of the articles containing this keyword alone were eliminated in the second dataset, usually because the word ‘difficulty’ was used with its ordinary meaning (see 3.2.2). 26 articles were removed from the second dataset. Among them, only 20 contained the keyword *difficult**. On the other hand, 4 papers in the final dataset only contained the word *difficult**. For example, Salminen, Koponen, Räsänen, and Aro (2015)) would not have been found without the use of the keyword *difficult**. We therefore concluded that although the keyword *difficult** was time-consuming to analyze, it was essential.

Likewise, it should be noted that some papers were only identified by using all of the keywords, and could not be found by using individual keywords. Therefore, all of the K4 keywords were necessary.

4. Results: analysis of the selected articles

In this section we present our classification and analysis based on the categories identified above. We describe some general features of selected papers (year, country of publication, keywords) and analyze the mathematical content and school level. Finally, we study the main issues that concern MLD in Mathematics Education.

4.1. Classification of the selected papers

Once the dataset of papers had been identified, as described in section 3.2, we classified them using the categories described in section 1.2. As noted above, the labels Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics were based on the population analyzed in the study. We briefly summarize them as:

- **Math Disorder**: students identified through a specific mathematics assessment (e.g. a psychometric test such as the WJ-Test, Wisc, or a researcher-designed assessment) i.e. in the sense of MLD in cognitive science;
- **Learning Disabilities**: students diagnosed as having persistent learning difficulties (but not necessarily specific to mathematics);

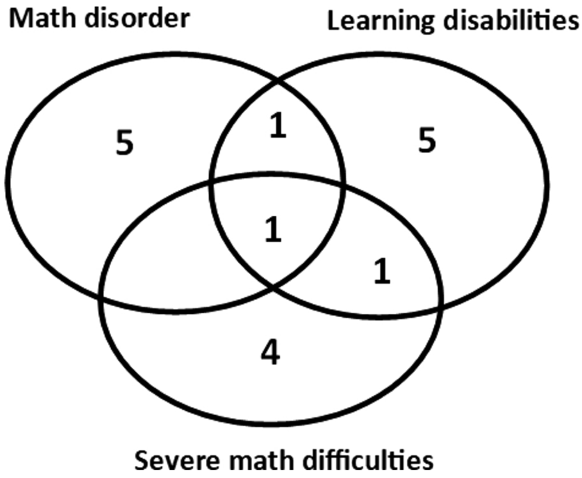

Fig. 2. Venn diagram illustrating the number of papers classified as Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics.

and

- **Severe Difficulties in Mathematics**: students who were less successful than other students in a mathematics assessment. Tests were administered by the institution and classification criteria were not explained or defined.

We did not take into account two reviews (Lewis & Fisher, 2016; Scherer et al., 2016) as they did not experiment with a particular population. Therefore, the final classification was based on a dataset of **17 articles.**

Fig. 2 presents the number of articles found in each of the three categories. Articles at the intersection between categories indicate that the population was composed of different types of students. For example, the article at the intersection between Math Disorder and Learning Disabilities concerns students with Math Disorder and others with Learning Disabilities. It should be noted that articles focused on a single student could not be at the intersection because the categories were exclusive.

This classification provided some partial answers to our research question, and the features of MLD addressed by mathematics educators. An unexpected initial finding was that the three categories were equally distributed. This emphasized the need to analyze the role of all these categories in mathematics education. A more in-depth study was then required to explore the nature of the mathematical content, research questions and results of these studies.

4.2. General features

The first analysis concerned the country, year of publication and the label associated with the paper, which is to say the studied population. A summary of the results is reported in Fig. 3. We did not take into account the two overview articles (Lewis & Fisher, 2016; Scherer et al., 2016) as they did not refer to a single country or a particular population.

As shown in Fig. 3, most (10) papers referred to the United States (US) or the United Kingdom (3) out of a total of 17. The rest of Europe was poorly represented (3 papers). Most American research is recent, dating from 2013 to 2016. Similarly, most research into MLD in Mathematics Education is recent: 14 of the 17 articles were published after 2013. Although this increase is almost totally

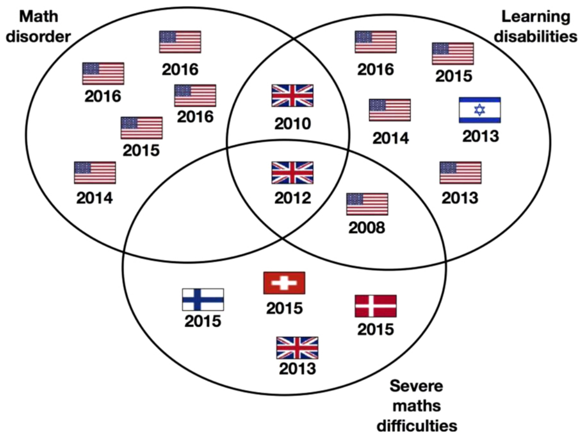

Fig. 3. The 17 papers classified by category, country and year (without the two overview articles).

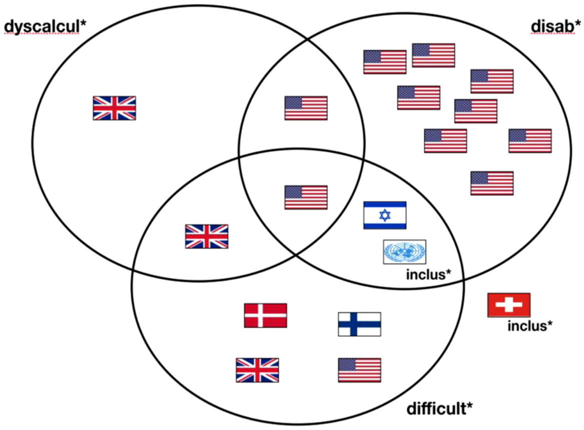

Fig. 4. The 19 papers classified by keywords and country. The label *inclus** only refers to 2 articles, one from Switzerland and the other one from an international research group.

linked to an increased American interest (9 of the 10 papers were published after 2013), these studies emerged during the past ten years.

Regarding our categories (Math Disorder, Learning Disabilities and Severe Difficulties in Maths), all of the analyzed papers were written after 2008, and the three oldest (dating from 2008, 2010 and 2012) addressed all three categories. This could be interpreted as a lack of clarity in identifying the object of research and appropriate participants in initial explorations of the theme. Post-2013 studies were more centered on specific categories of participants, who had specific characteristics (including Math Disorder, Learning Disabilities or Severe Difficulties in Mathematics). This change may have been influenced by the publication of DSM-5 in 2013, which (re)defined a "specific learning disorder" as a neurodevelopmental disorder that impeded the ability to learn or use specific academic skills. According to DSM-5 (APA, 2013), skills that are substantially and quantifiably below those expected for the individual's chronological age are a diagnostic criterion for learning disorders, which begin during the school-age years and must be persistent and specific.

The second analysis looked at keywords as a function of country. It was possible to take into account the two overview articles (Lewis & Fisher, 2016; Scherer et al., 2016) because the criteria were well identifiable. As shown in Fig. 4, the term *disability* is widely used in America (10 out of 11 American papers use the keyword *disab**), while the European community prefers to use the term *difficulty*. Thus, the keyword *disab** can be considered as typical in the US. This finding confirms previous research (Scherer et al., 2016).

As noted above, the terms *disab** and *difficult** are used in several countries, but may refer to different populations. We therefore examined the relationship between population categories and country. As shown in Fig. 3, American papers are characterized by the labels *Math Disorder* and *Learning Disabilities*. For both categories, the population was identified by diagnostic tests such as ICD 10 (WHO-World Health Organisation, 2003) or APA, 2013APA (2013), based on medical models.

On the other hand, it seems that the European educational community has adopted a broader definition of students with mathematical learning difficulties, referring to any group of students with low achievement:

> *Low achievement is the situation where a child fails to acquire basic skills while they do not have any identified disability and have cognitive skills within the normal range. In those cases, low achievement may be considered as a failure of the education system.* (European Commission, n.d., p. 4, from Scherer et al., 2016, p. 636).

This confirms the inclusion of the population identified by the keyword *difficult** in our study.

4.3. School level and mathematical content

Our analysis of school level and mathematical content did not take into account the two overview articles (Lewis & Fisher, 2016; Scherer et al., 2016) because they did not focus on a specific population or a specific mathematical subject. Therefore, we analyzed 17 papers.

Concerning the age of the population studied, Table 5 shows that most studies (12) involved very young students, aged 4–12. Only

Table 5
Papers classified by population age.

	Preschool (4-7 years)	Elementary School (7–12 years)	Middle School (12–14 years)	High School (14–18 years)	Adults (> 18 years)
Number of papers	1	11	3	1	1

three articles studied middle school children, one looked at high school students, and one investigated adults. It seems that students with Math Disorder, Learning Disabilities or Severe Difficulties in Mathematics who are identified in elementary school are not studied again during their schooling. This may be explained by the difficulty in identifying older students with MLD (Math Disorder): indeed, most diagnostic tests are designed for students aged between 4 and 11 years old (Peteers, 2018). There is a clear need for research into MLD among older students. One solution could be the development of longitudinal studies that would help to understand the evolution of students with MLD. However, this would require an in-depth analysis of learning processes in different mathematical fields. In a similar vein, research in cognitive sciences has underscored the importance of the development of studies and interventions in early childhood (for instance, Baroody, Lai, & Mix, 2006).

Only one of the 17 articles focused on 4–7 year-old students. This is probably linked to institutional contexts and educational policies. The absence of diagnostic tests for this group of children could explain the lack of research with this age category and it would be reasonable to expand the field of investigation to include mathematics education in the wider sense and not necessarily focus specifically on students with MLD.

Our analysis of the mathematical content of studies found that the majority of papers addressed arithmetical skills and arithmetical word problems (16 of the 17 papers). Topics included arithmetical operations (addition, subtraction, multiplication, etc.) or fractions (4 of the 16 papers). Two papers focused on arithmetical and algebraic word problems, in both cases the focus was on pre-algebraic competences. Seven articles examined word problems and five studied students with Math Disorder. Only one article investigated transversal skills (mathematical thinking, modeling, reasoning, etc.). There was a notable absence of research in many other mathematical fields, such as geometry, statistics and calculus. Like Lewis and Fisher (2016), we concluded that the majority of studies concerned arithmetic knowledge (including the specific topic of fractions), while there was a lack of research in advanced mathematics dealing with MLD in Mathematics Education. We underscored that the difficulties experienced by students with MLD were heterogeneous (Fias et al., 2013). That implies that research needs to expand into different areas of mathematics in mathematics education as in cognitive science.

4.4. Research interests addressed in mathematics education

In section 1.3, we identified three key areas of investigation: the identification of students with Math Disorder, Learning Disabilities or Severe Difficulties in Mathematics, (educational) interventions for these students, and their characteristics. We therefore classified the dataset papers as a function of these three areas, as shown in Fig. 5. Once again, we did not take into account the two overview articles (Lewis & Fisher, 2016; Scherer et al., 2016). All of the 17 papers addressed the identification of students with Math Disorder, Learning Disabilities or Severe Difficulties in Mathematics, interventions for such students or described the characteristics, skills and needs typical of such students. However, Fig. 5 shows that interventions were more investigated than the identification and students' characteristics.

The three articles that addressed "Identification" concerned students with Math Disorder and Learning Disabilities. Their identification was based on a medical model from the cognitive and neurocognitive domain. Only two articles appeared in both the identification and the intervention categories. This could be interpreted as a lack of interaction between educational and clinical domains and suggests that research is not as heterogeneous as some researchers working in mathematics education would like (Heyd-Metzuyanim, 2013; Karagiannakis et al., 2016).

Most studies addressed interventions (both case studies and larger samples) and concerned all three categories. This was consistent with the fact that our review concerned the mathematics education literature where the focus is on educational interventions. However, such interventions did not seem to fully exploit the information that could be drawn from diagnoses produced by clinicians.

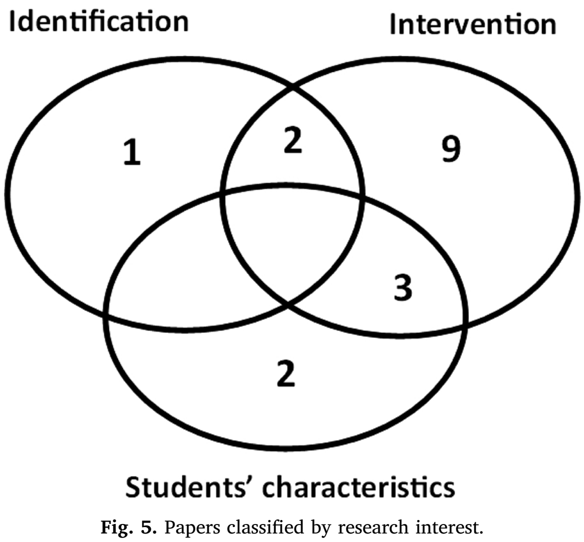

Fig. 5. Papers classified by research interest.

Very few articles addressed teacher training or teaching practices. Only two described the issue from the teacher's point of view. However, both articles only addressed Severe Difficulties in Mathematics. This could be interpreted as a weakness in teachers' education, especially the field of mathematics education for students with mathematical learning difficulties or disabilities. As Dias and Deruaz (2012) pointed out, improving the quality of teacher training could raise awareness and provide effective tools to be used in educational activities designed for students with Math Disorder.

5. Conclusions and future work

5.1. Conclusions

Our results offer new insights in the field of mathematics education:

- Our methodology (notably the identification of keywords) can be reused in literature reviews in connected fields, such as special education;
- We identified an exhaustive dataset of 17 articles and 2 overview articles linked with MLD in Mathematics Education in leading mathematics educational journals over the past ten years;
- We discussed the definition and characterization of MLD found in this dataset;
- We designed a tool to classify research into MLD in Mathematics Education (categories that can characterize students with Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics);
- Our results highlight various unexplored dimensions of MLD in Mathematics Education research.

We develop some of these results below.

5.1.1. Methodological aspects

The four selected keywords (*disab*, dyscalcul*, difficult**, and *inclus**) were efficient working criteria. The keyword selection was based on a preliminary scan of two leading congresses in mathematics education (PME and CERME) taking into account the literature review of Lewis and Fisher (2016). We checked the consistency of our list of keywords. All were found to be important, and enabled us to identify 449 papers in the *MathEduc* database (Toerner & Arzarello, 2012). Each keyword identified specific articles. Although the identification of articles with the keyword *difficult** was particularly time consuming, it was an essential step. The most efficient keyword was *disab**. Besides, we found that the word *dyscalculia*, which is very relevant in the cognitive domain, is not commonly used in mathematics education. This confirmed that the two fields – mathematics education and cognitive science – remain far removed from each other and do not share contents, vocabulary and purposes. Finally, the methodology developed in this article is reusable in other research fields.

5.1.2. The definition of MLD in Mathematics Education

Our introduction underscores the existence of several features of MLD in cognitive science. Our literature review shows that researchers in mathematics education have not yet agreed upon a definition of MLD (e.g. Scherer et al., 2016; Verschaffel et al., 2018). Our analysis highlights various characteristics of students: we defined three categories of students (based on descriptions of participants) i.e. Math Disorder, Learning Disabilities, and Severe Difficulties in Mathematics. An unexpected finding was that the articles we identified were equally distributed among these categorizations. Research in cognitive science seems to have impacted the features of MLD addressed by mathematics educators, for instance the new definitions included in DSM 5 in 2013 and the emphasis on diagnosis (cf. section 4.2).

5.1.3. MLD research in Mathematics Education

Research into MLD in the context of Mathematics Education has expanded since 2013, in particular in the US. Most studies addressed arithmetical content at the elementary school level. This result was consistent with the educational practices highlighted by Lewis and Fisher (2016) and the exploration of word problems (Fuchs et al., 2008). An in-depth analysis of the dataset of 17 articles (without the two overview articles) underlined the focus on educational interventions: in particular, it highlighted the need for didactic thinking about specific teaching approaches and specialized tools (cf. section 4.4). However, we noted that research in the field of mathematics education has failed to sufficiently explore both the characteristics and the identification of students with Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics.

5.1.4. Limitations

We can identify several methodological limitations.

Our journals were selected from the domain of mathematics education, and there is a possibility that the grading of the European Mathematical Society might be Europe-centric (in fact, Fig. 3 shows that this was not the case, but we have to be aware of such a phenomenon).

Other journals, in particular those focused on special education may also contain interesting studies of interventions dealing with learning difficulties or disabilities (not specifically in mathematics): that could contribute to the design of interventions for students with specific learning difficulties or disabilities in mathematics.

Our literature review was conducted in August 2018, and the *MathEduc* database did not include any articles published in

2017–2018. We will update our literature review in future years. Moreover, our findings, notably the analysis, should be viewed in light of the choices we made regarding the categorization and analysis of the dataset. Our categories were developed in order to answer our research question, and could be changed.

5.2. Future research

5.2.1. Characteristics of students in learning situations

Articles that addressed students with Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics in learning situations were mainly linked to interventions and the teaching sequence. Thus, they were not focused on such students (the exception is Van Garderen, Scheuermann, & Poch, 2014), while four articles only addressed certain features of learning difficulties or disabilities or students with MLD (Hunt, Tzur, & Westenskow, 2016; Lewis, 2014; Hunt, 2015; Gifford & Rockliffe, 2012). However, there appeared to be various research questions regarding educational interventions for students with Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics: as a first step, we can hypothesize that the impact of such interventions depends on the characteristics of such students, their age and the mathematical domain. There is vast scope for research that seeks to identify the benefits of such interventions for these students.

5.2.2. Remedial interventions, support and scaffolding

Our review found that interventions were the focus of mathematics education researchers. Most articles presented case studies concerning Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics. It should be noted that, as mentioned above, the object of the investigation was the characteristics and kinds of interventions. In other words, students were not the focus. In fact, remedial interventions did not seem to be designed around students' characteristics or abilities but on the difficulty inherent in specific mathematical content, such as fractions. Thus, remedial interventions (scaffolding) focused on teaching strategies (devices, tools, interactions) designed to help students progress, rather than students' cognitive abilities.

5.2.3. Identification

The identification of MLD in Mathematics Education is clearly the object of a plurality of paradigms, developed as a function of the scientific field and its theoretical background. Tools and devices are the object of a didactical study focused on mathematical knowledge. It is interesting to note that only one article in our dataset explicitly addressed the contribution of mathematics education to the identification of students with MLD (Ginsburg, Lee, & Pappas, 2016). This confirms the need, expressed in Lewis and Fisher (2016), to pursue research that focuses on ways to identify MLD in Mathematics Education.

The theme of tools used to identify MLD in Mathematics Education was absent from our literature review. Authors adopted different definitions and, therefore, used different ways to identify mathematical learning disabilities or difficulties. This finding underscored the importance of drawing up a full inventory of tools used to identify students (at different ages, in various mathematical domains) and the need for educational interpretation. This would make it possible to design specific devices for teachers and identify persistent difficulties experienced by students, as proposed by Peteers (2018) and Peteers and Ouvrier-Buffet (2019).

5.2.4. The need for collaboration between mathematics education, cognitive science and special education

Our literature review took into account the state of the art regarding MLD in the domain of cognitive science, which has sought to define and diagnose MLD for a long time. We identified differences between research in cognitive science and research in mathematics education, especially regarding the definition of MLD, the identification of students with MLD, and the type of research (identification *versus* intervention). We agree with Karagiannakis et al. (2016) that "it is a high priority that research on mathematical learning and teaching, including research on difficulties in learning mathematics, is approached in an interdisciplinary way" (p. 136) as this would enrich research results concerning MLD.

We argue that it would be advisable to foster collaboration among the different fields of research. It appears that a threefold focus is necessary, involving the domains of mathematics education, cognitive science and special education.

Better collaboration could identify pedagogical actions based on fundamental results, which could be tested in classrooms. As De Smedt and Grabner (2016) stated, "neuroscientific data do not immediately prescribe how interventions should look like; they can only offer suggestions that should be combined with pedagogical principles, the effects of which should be tested by means of rigorous educational intervention studies" (p. 251).

Collaboration between the fields of education and cognitive science could help in the early diagnosis of students with MLD. Remedial interventions in the classroom would benefit from existing intervention studies in mathematics education and special education (on the one hand) and identification studies in cognitive science (on the other hand). A threefold approach could help to develop effective interventions by exploiting both cognitive diagnosis techniques and knowledge of special needs.

Furthermore, there is a need to analyze the work and reasoning of students with Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics in the classroom: research in the domain of mathematics education has developed a significant body of theory and methodologies in all mathematical domains (not only arithmetic) and specific transversal skills such as proving, modeling, defining etc.

By adopting this approach, new research questions emerge that lie at the intersection of mathematics education, special education and cognitive sciences. They include:

- How can we design devices and tools that can identify students with Math Disorder, Learning Disabilities and Severe Difficulties in

Mathematics at an early stage in the classroom?
- How can we design learning environments that foster learning and enhance the potential of such students in an inclusive perspective?
- How can we improve teacher training, both in ordinary and special education contexts, regarding remedial interventions, support devices and scaffolding?

To conclude, our review provides evidence of the need for further research into students with Math Disorder, Learning Disabilities and Severe Difficulties in Mathematics in order to develop specific knowledge related to both pedagogy and mathematical content. Our findings suggest that we need to develop a fruitful cooperation with other research fields to improve the effectiveness of actions taken in mathematics education. We recommend that collaboration among different fields of research be enhanced.

Funding

This research was not funded by an agency in the public, commercial, or not-for-profit sectors.

CRediT authorship contribution statement

Michel Deruaz: Methodology, Formal analysis, Investigation, Validation, Writing - original draft, Writing - review & editing, Supervision. **Thierry Dias:** Conceptualization, Methodology, Investigation, Validation, Writing - original draft, Writing - review & editing, Supervision. **Marie-Line Gardes:** Conceptualization, Methodology, Investigation, Validation, Writing - original draft, Writing - review & editing, Supervision. **Francesca Gregorio:** Methodology, Formal analysis, Investigation, Validation, Writing - original draft, Writing - review & editing. **Cécile Ouvrier-Buffet:** Conceptualization, Methodology, Investigation, Validation, Writing - original draft, Writing - review & editing, Supervision. **Florence Peteers:** Methodology, Formal analysis, Investigation, Validation, Writing - original draft, Writing - review & editing. **Elisabetta Robotti:** Conceptualization, Methodology, Investigation, Validation, Writing - original draft, Writing - review & editing, Supervision.

Acknowledgements

We would like to thank the reviewers for their constructive comments and suggestions. We wish to thank Elena La Scala for her comments.[8]

References

American Psychiatric Association (2013). *Diagnostic and statistical manual of mental disorders*(5th ed.). Arlington, VA: American Psychiatric Publishing.
Assude, T., Perez, J. M., Suau, G., Tambone, J., & Vérillon, A. (2014). Accessibilité didactique et dynamique topogénétique: une étude de cas. *Recherches en didactique des mathématiques, 34*(1), 33–57.
Attridge, N., & Inglis, M. (2015). Increasing cognitive inhibition with a difficult prior task: implications for mathematical thinking. *ZDM Mathematics Education, 47*(5), 723–734.
Baroody, A. J., Lai, M. L., & Mix, K. S. (2006). The development of number and operation sense in early childhood. In O. Saracho, & B. Spodek (Eds.). *Handbook of research on the education of young children* (pp. 187–221). Mahwah, NJ: Erlbaum.
Berch, D. B., & Mazzocco, M. M. M. (Eds.). (2007). *Why Is Math So Hard for Some Children? The Nature and Origins of Mathematical Learning Difficulties and Disabilities*. Baltimore, MD: Brookes Publishing.
Blanton, M., Stephens, A., Knuth, E., Gardiner, A. M., Isler, I., & Kim, J. S. (2015). The development of children's algebraic thinking: The impact of a comprehensive early algebra intervention in third grade. *Journal for Research in Mathematics Education, 46*(1), 39–87.
Boesen, J., Lithner, J., & Palm, T. (2010). The relation between types of assessment tasks and the mathematical reasoning students use. *Educational studies in mathematics, 75*(1), 89–105.
*Bouck, E. C., Joshi, G. S., & Johnson, L. (2013). Examining calculator use among students with and without disabilities educated with different mathematical curricula. *Educational Studies in Mathematics, 83*(3), 369–385.
Broza, O., & Kolikant, Y. B.-D. (2015). Contingent teaching to low-achieving students in mathematics: Challenges and potential for scaffolding meaningful learning. *ZDM Mathematics Education, 47*(7), 1093–1105.
Butterworth, B. (2005). Developmental dyscalculia. In J. I. D. Campbell (Ed.). *Handbook of mathematical cognition* (pp. 455–468). New York: Psychology Press.
*Butterworth, B., & Laurillard, D. (2010). Low numeracy and dyscalculia: Identification and intervention. *ZDM Mathematics Education, 42*(6), 527–539.
Butterworth, B., Varma, S., & Laurillard, D. (2011). Dyscalculia: from brain to education. *Science, 332*, 1049–1053.
De Smedt, B., & Grabner, R. H. (2016). Potential applications of cognitive neuroscience to mathematics education. *ZDM Mathematics Education, 48*, 249–253.
De Smedt, B., Verschaffel, L., & Ghesquière, P. (2012). Mathematics Learning Disability. In N. M. Seel (Ed.). *Encyclopedia of the Sciences of Learning* (pp. 2121–2123). Boston, MA: Springer.
De Vleeschouwer, M. (2010). An institutional point of view of the secondary-university transition: The case of duality. *International Journal of Mathematical Education in Science and Technology, 41*(2), 155–171.
Dias, T. (2019). Difficultés d'apprentissage en mathématiques : un regard didactique. In J. Pilet, & C. Vendeira (Eds.). *Proceeding of séminaire de didactique des mathématiques* (pp. 80–88).
Dias, T., & Deruaz, M. (2012). Dyscalculie : et si les enseignants reprenaient la main? *Approche Neuropsychologique des Apprentissages chez l'Enfant (ANAE), 120-121*, 529–534.
Dowker, A. D. (2005). *Individual differences in arithmetic: Implications for psychology, neuroscience and education.* Hove: Psychology.
Ellis, A. B. (2007). Connections between generalizing and justifying: Students' reasoning with linear relationships. *Journal for Research in Mathematics Education, 38*(3), 194–229.

[8] References denoted with * indicate the studies that were included in the final list of our review.

Eriksson, G. (2008a). Arithmetical thinking in children attending special schools for the intellectually disabled. *Journal of Mathematical Behavior, 27*(1), 1–10.
Eriksson, G. (2008b). Supervision of teachers based on adjusted arithmetic learning in special education. *Journal of Mathematical Behavior, 27*(4), 264–276.
Fias, W., Menon, V., & Szűcs, D. (2013). Multiple components of developmental dyscalculia. *Trends in neuroscience and education, 2*(2), 43–47.
Fletcher, J. M., & Vaughn, S. (2009). Response to intervention: Preventing and remediating academic difficulties. *Child Development Perspectives, 3*(1), 30–37.
Fuchs, L. S., Fuchs, D., Hamlett, C. L., Lambert, W., Stuebing, K., & Fletcher, J. M. (2008). Problem Solving and Computational Skill: Are They Shared or Distinct Aspects of Mathematical Cognition? *Journal of Educational Psychology, 100*(1), 30–47.
Geary, D. C. (2010). Mathematical disabilities: Reflections on cognitive, neuropsychological, and genetic components. *Learning and individual differences, 20*(2), 130–133.
Geary, D. C., Hoard, M. K., Nugent, L., & Bailey, D. H. (2012). Mathematical cognition deficits in children with learning disabilities and persistent low achievement: a five-year prospective study. *Journal of educational psychology, 104*(1), 206.
Gifford, S. (2014). A good foundation for number learning for five-year-olds? An evaluation of the English Early Learning 'Numbers' Goal in the light of research. *Research in Mathematics Education, 16*(3), 219–233.
*Gifford, S., & Rockliffe, F. (2012). Mathematics difficulties: does one approach fit all? *Research in Mathematics Education, 14*(1), 1–15.
*Ginsburg, H. P., Lee, Y. S., & Pappas, S. (2016). Using the clinical interview and curriculum based measurement to examine risk levels. *ZDM Mathematics Education, 48*(7), 1031–1048.
Giroux, J. (2008). Conduites atypiques d'élèves du primaire en difficulté d'apprentissage. *Recherches en Didactique des Mathématiques, 28*(1), 9–62.
González, J. E. J., & Espínel, A. I. G. (1999). Is IQ-achievement discrepancy relevant in the definition of arithmetic learning disabilities? *Learning Disability Quarterly, 22*(4), 291–301.
Groth, R. (2007). Understanding teachers' resistance to the curricular inclusion of alternative algorithms. *Mathematics Education Research Journal, 19*(1), 3–28.
Gueudet, G. (2008). Investigating the secondary–tertiary transition. *Educational studies in mathematics, 67*(3), 237–254.
Harwell, M. R., Post, T. R., Medhanie, A., Dupuis, D. N., & LeBeau, B. (2013). A multi-institutional study of high school mathematics curricula and college mathematics achievement and course taking. *Journal for Research in Mathematics Education, 44*(5), 742–774.
Herbert, S., & Pierce, R. (2012). Revealing educationally critical aspects of rate. *Educational Studies in Mathematics, 81*(1), 85–101.
Herrera, A. N., Bruno, A., Gonzalez, C., Moreno, L., & Sanabria, H. (2011). Addition and subtraction by students with Down syndrome. *International Journal of Mathematical Education in Science and Technology, 42*(1), 13–35.
*Heyd-Metzuyanim, E. (2013). The co-construction of learning difficulties in mathematics—teacher—student interactions and their role in the development of a disabled mathematical identity. *Educational Studies in Mathematics, 83*(3), 341–368.
Heyd-Metzuyanim, E., & Graven, M. (2016). Between people-pleasing and mathematizing: South African learners' struggle for numeracy. *Educational Studies in Mathematics, 91*(3), 349–373.
*Holmes, W., & Dowker, A. (2013). Catch up numeracy: a targeted intervention for children who are low-attaining in mathematics. *Research in mathematics education, 15*(3), 249–265.
*Hord, C., Tzur, R., Xin, Y. P., Si, L., Kenney, R. H., & Woodward, J. (2016). Overcoming a 4th grader's challenges with working-memory via constructivist-based pedagogy and strategic scaffolds: Tia's solutions to challenging multiplicative tasks. *The Journal of Mathematical Behavior, 44*, 13–33.
*Hunt, J. H. (2015). Notions of equivalence through ratios: Students with and without learning disabilities. *The Journal of Mathematical Behavior, 37*, 94–105.
*Hunt, J. H., Tzur, R., & Westenskow, A. (2016). Evolution of unit fraction conceptions in two fifth-graders with a learning disability: An exploratory study. *Mathematical Thinking and Learning, 18*(3), 182–208.
*Hunt, J. H., Westenskow, A., Silva, J., & Welch-Ptak, J. (2016). Levels of participatory conception of fractional quantity along a purposefully sequenced series of equal sharing tasks: Stu's trajectory. *The Journal of Mathematical Behavior, 41*, 45–67.
*Jankvist, U. T., & Niss, M. (2015). A framework for designing a research-based "maths counsellor" teacher programme. *Educational Studies in Mathematics, 90*(3), 259–284.
Joklitschke, J., Rott, B., & Schindler, M. (2018). Theories about mathematical creativity in contemporary research: a literature review. In E. Bergqvist, M. Österholm, C. Granberg, & L. Sumpter (Vol. Eds.), *Proceedings of the 42nd Conference of the International Group for the Psychology of Mathematics Education: Vol. 3*, (pp. 171–178). Umeå, Sweden: PME.
Jordan, N. C., Hanich, L. B., & Kaplan, D. (2003). A longitudinal study of mathematical competencies in children with specific mathematics difficulties versus children with comorbid mathematics and reading difficulties. *Child Development, 74*, 834–850.
Jupri, A., Drijvers, P., & van den Heuvel-Panhuizen, M. (2014). Difficulties in initial algebra learning in Indonesia. *Mathematics Education Research Journal, 26*(4), 683–710.
Karagiannakis, G. N., Baccaglini-Frank, A. E., & Roussos, P. (2016). Detecting strengths and weaknesses in learning mathematics through a model classifying mathematical skills. *Australian J. of Learning Difficulties, 21*(2), 115–141.
Kaufmann, L., Mazzocco, M. M., Dowker, A., von Aster, M., Göbel, S. M., Grabner, R. H., et al. (2013). Dyscalculia from a developmental and differential perspective. *Frontiers in Psychology, 4*(516), 1–5. https://doi.org/10.3389/fpsyg.2013.00516.
Kilpatrick, J., & Sierpinska, A. (Eds.). (1998). *Mathematics education as a research domain: a search for identity: an ICMI study*. Kluwer Academic Publishers.
Kyriakides, A. O., & Houssart, J. (2016). Paraprofessionals in Cyprus and England: perceptions of their role in supporting primary school mathematics. *Research in Mathematics Education, 18*(3), 249–266.
*Lambert, R. (2015). Constructing and resisting disability in mathematics classrooms: a case study exploring the impact of different pedagogies. *Educational Studies in Mathematics, 89*(1), 1–18.
Landgraf, S., Van der Meer, E., & Krueger, F. (2010). Cognitive resource allocation for neural activity underlying mathematical cognition: A multi-method study. *ZDM Mathematics Education, 42*(6), 579–590.
Landerl, K., Bevan, A., & Butterworth, B. (2004). Developmental dyscalculia and basic numerical capacities: A study of 8–9-year-old students. *Cognition, 93*(2), 99–125.
*Lewis, K. E. (2014). Difference not deficit: Reconceptualizing mathematical learning disabilities. *Journal for Research in Mathematics Education, 45*(3), 351–396.
*Lewis, K. E., & Fisher, M. B. (2016). Taking stock of 40 years of research on mathematical learning disability: methodological issues and future direction. *Journal for Research in Mathematics Education, 47*(4), 338–371.
Mazzocco, M. M. M., & Myers, G. F. (2003). Complexities in identifying and defining mathematics learning disability in the primary school-age years. *Annals of Dyslexia, 53*, 218–253.
Mazzocco, M. M. M. (2007). Defining and differentiating mathematical learning disabilities and difficulties. In D. B. Berch, & M. M. M. Mazzocco (Eds.). *Why is math so hard for some children? The nature and origins of mathematical learning difficulties and disabilities* (pp. 29–48). Baltimore, MD: Brookes.
Nunes, T. (2014). Deaf Children, Special Needs, and Mathematics Learning. In S. Lerman (Ed.). *Encyclopedia of Mathematics Education*. Dordrecht: Springer.
Nunes, T., Bryant, P., Evans, D., & Barros, R. (2015). Assessing quantitative reasoning in young children. *Mathematical Thinking and Learning, 17*(2–3), 178–196.
Passelaigue, D., & Munier, V. (2015). School Teacher trainees' difficulties about the concepts of attribute and measurement. *Educational Studies in Mathematics, 89*(3), 307–336.
Penesetti, D. (2018). *What is specific learning disorder? [Physician review of The American Psychiatric Association]*. Retrieved fromhttps://www.psychiatry.org/patients-families/specific-learning-disorder/what-is-specific-learning-disorder.
Peteers, F. (2018). *Un trouble à l'interface entre différents champs disciplinaires (handicap, santé et formation): la dyscalculie - Une approche didactique (Doctoral dissertation)*. Retrieved fromUniversity of Reims Champagne-Ardennehttps://hal.archives-ouvertes.fr/tel-01944017.
Peteers, F., & Ouvrier-Buffet, C. (2019). Diagnosis tools of dyscalculia - Contribution of didactics of mathematics to numerical cognition. in press *Proceedings of the 11th Congress of the European Society for Research in Mathematics Education (CERME11, February 6–10, 2019)*.
*Pfister, M., Opitz, E. M., & Pauli, C. (2015). Scaffolding for mathematics teaching in inclusive primary classrooms: A video study. *ZDM Mathematics Education, 47*(7), 1079–1092.
*Salminen, J., Koponen, T., Räsänen, P., & Aro, M. (2015). Preventive support for kindergarteners most at-risk for mathematics difficulties: Computer-assisted

intervention. *Mathematical Thinking and Learning, 17*(4), 273–295.

*Scherer, P., Beswick, K., DeBlois, L., Healy, L., & Opitz, E. M. (2016). Assistance of students with mathematical learning difficulties: how can research support practice? *ZDM Mathematics Education, 48*, 633–649.

Sfard, A. (2017). Ritual for ritual, exploration for exploration or what the learners get is what you get from them in return. In J. Adler, & A. Sfard (Eds.). *Research for educational change: Transforming researchers' insights into improvement in mathematics teaching and learning* (pp. 39–63). London: Routledge.

Shalev, R. S., Manor, O., Kerem, B., Ayali, M., Badichi, N., Friedlander, Y., et al. (2001). Developmental dyscalculia is a familial learning disability. *Journal of Learning Disabilities, 34*(1), 59–65. https://doi.org/10.1177/002221940103400105.

Shepherd, M. D., Selden, A., & Selden, J. (2012). University students' reading of their first-year mathematics textbooks. *Mathematical Thinking and Learning, 14*(3), 226–256.

Sofronas, K. S., DeFranco, T. C., Vinsonhaler, C., Gorgievski, N., Schroeder, L., & Hamelin, C. (2011). What does it mean for a student to understand the first-year calculus? Perspectives of 24 experts. *The Journal of Mathematical Behavior, 30*(2), 131–148.

Solomon, Y., Radovic, D., & Black, L. (2016). "I can actually be very feminine here": contradiction and hybridity in becoming a female mathematician. *Educational Studies in Mathematics, 91*(1), 55–71.

Stavy, R., & Babai, R. (2010). Overcoming intuitive interference in mathematics: Insights from behavioral, brain imaging and intervention studies. *ZDM Mathematics Education, 42*(6), 621–633.

Szũcs, D. (2016). Subtypes and comorbidity in mathematical learning disabilities: multidimensional study of verbal and visual memory processes is key to understanding. *Progress in Brain Research, 227*, 277–304.

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

Tambonne, J. (2010). Un dispositif de recherche pour observer les pratiques enseignantes: L'observation des maîtres spécialisés en adaptation scolaire. *Recherche en Didactique des Mathématiques, 30*(3), 275–315.

Toerner, G., & Arzarello, F. (2012). *Grading mathematics education research journals*, *86*, Newsletter of the European Mathematical Society52–54.

Traoré, K., Lajoie, C., & Mura, R. (2007). Quelques erreurs pouvant être liées à une difficulté à concevoir un ensemble comme un objet distinct de ses éléments chez des étudiants et des étudiantes universitaires. *Educational Studies in Mathematics, 64*(3), 247–264.

Tropper, N., Leiss, D., & Hänze, M. (2015). Teachers' temporary support and worked-out examples as elements of scaffolding in mathematical modeling. *ZDM Mathematics Education, 47*(7), 1225–1240.

UN-United Nations (2006). *Convention of the Rights of Persons with Disabilities.* New York: United Nations.

*Van Garderen, D., Scheuermann, A., & Poch, A. (2014). *ZDM Mathematics Education, 46*(1), 135–149. https://doi.org/10.1007/s11858-013-0519-1.

Verschaffel, L., Baccaglini-Frank, A., Mulligan, J., van den Heuvel Panhuizen, M., Ping Xin, Y., & Butterworth, B. (2018). Special Needs in Research and Instruction in Whole Number Arithmetic. In M. G. Bartolini Bussi, & X. Sun (Eds.). *Building the Foundation: Whole Numbers in the Primary Grades* (pp. 375–397). Cham: Springer.

Vogel, S. E., Keller, C., Koschutnig, K., Reishofer, G., Ebner, F., Dohle, S., et al. (2016). The neural correlates of health risk perception in individuals with low and high numeracy. *ZDM Mathematics Education, 48*(3), 337–350.

WHO-World Health Organisation (2003). *International Statistical Classification of Diseases and Related Health Problems 2nd Revision.* Retrieved from:https://www.who.int/classifications/icd/icdonlineversions/en/.

Wischgoll, A., Pauli, C., & Reusser, K. (2015). Scaffolding—How can contingency lead to successful learning when dealing with errors? *ZDM Mathematics Education, 47*(7), 1147–1159.

Wu, Q., Lei, P. W., DiPerna, J. C., Morgan, P. L., & Reid, E. E. (2015). Identifying differences in early mathematical skills among children in Head Start. *International Journal of Science and Mathematics Education, 13*(6), 1403–1423.

*Xin, Y. P. (2008). The effect of schema-based instruction in solving mathematics word problems: An emphasis on prealgebraic conceptualization of multiplicative relations. *Journal for Research in Mathematics Education, 39*(5), 526–551.