ACTA DIDACTICA NAPOCENSIA
Volume 17, Number 1, 2024 - DOI: 10.24193/adn.17.1.4

BIBLIOMETRIC AND CONTENT ANALYSES OF DYSCALCULIA RESEARCH

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Abstract: Dyscalculia is a math learning difficulty that many researchers have studied. A bibliometric and content analysis was conducted using the Web of Science database to provide a comprehensive overview of existing research on dyscalculia. The study aimed to identify key themes, prevailing research trends, potential knowledge gaps, and influential authors and articles in the field. The analysis focused on several research questions related to the distribution of articles and their citation data over the years, the types and numerical distribution of publications on dyscalculia, collaborative networks between authors, institutions, and countries/regions, topical research foci, prominent journals publishing articles on dyscalculia, top authors and countries researching dyscalculia, disciplines comprising the foundation of dyscalculia research, topics covered, the sample studied, and methods preferred in highly cited articles on dyscalculia. The co-occurrence analysis of the keywords revealed that dyscalculia, mathematical difficulties, dyslexia, and developmental dyscalculia were the most frequently cited terms. The top ten most cited articles were subjected to content analysis, revealing the types of research and methodologies. This study paves the way for future research and emphasizes the importance of interdisciplinary collaboration in understanding the nature and underlying causes of mathematics learning disabilities.

Key words: Dyscalculia, mathematics learning difficulties, bibliometric analyses, content analyses

1. Introduction

Dyscalculia is a learning disorder characterized by difficulty understanding and manipulating numbers and mathematical concepts, despite age-appropriate education and no signs of impairment in general intelligence (Kosc, 1974; Geary, 2006; Raja & Kumar, 2012; Kucian, 2016). This manifests as a significant discrepancy between the mathematical performance of individuals with dyscalculia and their peers on standard arithmetic or numerical reasoning tests. The prevalence of developmental dyscalculia ranges from 3 to 6% among school-aged children (Badian, 1983; Barahmand, 2008; Desoete et al., 2004; Gross-Tsur et al., 1996; Kosc, 1974; Klauer, 1992; Koumoula et al., 2004; Landerl et al., 2010; Lewis et al., 1994; Ramaa et al., 2002; Reigosa-Crespo et al., 2012), with no significant gender differences (Lewis et al.,1994; Shalevet al., 2000; Keong et al., 2016).

Dyscalculia is common in children with certain medical conditions (e.g., epilepsy, premature birth, metabolic disorders) or genetic syndromes (e.g., fragile X syndrome, Williams-Beuren syndrome, velocardiofacial syndrome) (Shalev & Gross-Tsurn, 2001; Kaufmann & von Aster, 2012). Dyscalculia may be caused by dysfunctions or inadequacies in certain systems or skills, whether domain-specific or domain-general, that may interfere with one's ability to learn mathematics. However, the exact cause of dyscalculia remains unknown (Butterworth, 2000; Haberstroh & Schulte-Körne, 2022; Henik, Rubinstein & Ashkenazi, 2011; Passolunghi & Lanfranchi, 2012;). Therefore, there is a growing body of research on the cognitive characteristics of children with dyscalculia. Haberstroh and Schulte-Körne (2022) conducted a meta-analysis study to compare the cognitive profiles of children with mathematics learning disabilities (MLD) and those of children (8-12 years old) without MLD. They reported a distinct set of well-operationalized abilities that appeared to differentiate the two groups. These abilities include computation, fact retrieval, quantity processing, quantity/number relations, numerical relations, and visuospatial short-term memory. Agostini, Zoccolotti, and Casagrande (2022) reviewed 46 articles on domain-general cognitive skills in children with dyscalculia and found that

Received November 2023.

Cite as: Mutlu, Y. & Polat, K. (2024) Bibliometric and Content Analyses of Dyscalculia Research. *Acta Didactica Napocensia*, 17(1), 44-64, https://doi.org/10.24193/adn.17.1.4

children with mathematical difficulties have impairments in executive function, attention, and processing speed. Mishra and Khan (2022) documented that visuospatial working memory and symbolic number processing skills emerged as the best predictors of math ability in children with dyscalculia. To provide personalized interventions, we must assess these cognitive functions when diagnosing math difficulties.

The incidence and prevalence of common cognitive and behavioral characteristics among individuals with dyscalculia can vary (Desoete & Grégoire, 2006; Dowker, 2009, Gifford & Rockliffe, 2012). This variation may be influenced by environmental factors, cultural factors (e.g., length of education and characteristics of the counting system), pre- and post-natal illness, or socioemotional difficulties, such as math anxiety (Kaufmann et al., 2013).

Despite individual differences, some key characteristics are common in children with dyscalculia. They may have difficulty learning number concepts (Geary, 2004), understanding number relationships (Sharma, 2015), and performing simple arithmetic operations (Shalev et al., 2001). They may also have visuospatial memory deficits (Alloway & Passolunghi, 2011; Mammarella et al., 2018), leading to confusion with directions (Williams, 2013), difficulty reading maps, diagrams, tables, and charts (Tennant & Tennant, 2010), and difficulty with measurement, especially reading analog clocks (Anderson, 2008; Burny, Valcke & Desoete, 2012; Mutlu & Korkmaz, 2020). In addition, dyscalculic children may experience high levels of math anxiety (Mutlu, 2019), weak estimation skills (Olkun et al., 2017), slow processing speed (Ansari & Karmiloff-Smith, 2002; Geary, 2004), and intensive use of strategies that their peers have already abandoned, such as finger counting, even for very simple operations (Bender & Beller, 2012; Geary, 1990; Jordan et al., 2003; Mutlu et al., 2020).

Nelson and Powell (2018) conducted a systematic review of longitudinal studies of math difficulties to examine whether students with math difficulties exhibit comparable or stagnant growth compared to students without math difficulties and whether a diagnosis of math difficulties predicts math achievement in later grades and remains stable across grades. They found that students with math difficulties show growth on math measures but still perform worse than those without math difficulties. Math difficulty is strongly related to math achievement in later grades and is often persistent. Researchers have demonstrated that students with math difficulties struggle with math in later grades (Nelson and Powell, 2018). However, Iuculano et al. (2015) reported findings that are in marked contrast to those of longitudinal studies. They showed that the brain activity patterns of children with MLD can be distinguished from those of their neurotypical peers, particularly before remediation. However, these differences are no longer present after tutoring. This suggests that the improvement is not related to compensatory mechanisms. As can be seen, researchers have reported different results on dyscalculia.

Despite ongoing research, dyscalculia remains a complex and poorly understood condition. Studies have shown that there is still considerable uncertainty about the definition, diagnosis, causes, and treatment of dyscalculia. As a result, there is an ongoing debate among researchers and professionals.

A large number of meta-analyses and meta-synthesis studies have been conducted on the characteristics (Haberstroh & Schulte-Körne, 2022; Swanson & Jerman, 2006;), causes (Agostini, Zoccolotti & Casagrande, 2022; Glinik, 2022; Mishra and Khan, 2022), diagnosis (De Smedt, Noël, Gilmore, & Ansari, 2013; Guillaume & Van Rinsveld, 2018; Katzin, Cohen & Henik, 2019; Mulchay et al., 2022; Szűcs & Myers, 2017) and intervention methods (Khan et al., 2019; Lafay, Osana, & Valat, 2019; Monei & Pedro, 2017; Nelson & Powell, 2018; Thapliyal & Ahuja, 2021) of dyscalculia. In addition to meta-analysis and meta-synthesis, another method that can shed light on the cognitive structure and dynamics of a scientific field is bibliometric analysis (also known as scientific mapping). This method can provide a comprehensive view of a particular research area over a given period, allowing readers to identify the most important papers and the most influential researchers in the field (Gokhale et al., 2020). Bibliometric analysis provides valuable insight into quantitative aspects of scientific literature, such as publication and citation patterns and collaborations between authors and institutions. However, it provides only a partial view of the research environment, as it does not consider the content of publications. Content analysis provides a qualitative perspective on topics, concepts, and methods. Thus, combining bibliometric and content analysis can enrich our

understanding of a research field by revealing not only who is publishing and citing but also what they are saying. In addition, content analysis can help us identify gaps and overlaps in the literature, as well as emerging trends and debates. The primary purpose of this study is to conduct a bibliometric and content analysis of the existing literature on dyscalculia in the WOS database. The study aims to identify key themes, dominant research trends, and potential knowledge gaps by reviewing and synthesizing the literature. In addition, the analysis will focus on the most cited articles and influential authors in the field to provide a comprehensive overview of the current state of research on dyscalculia. In this context, the research questions are as follows:

1. How are the articles on dyscalculia and their citation data distributed over the years?
2. What are the types and numerical distributions of the publications on dyscalculia?
3. How are the collaborative networks between authors, institutions, and countries/regions?
4. What are the topical foci of research on dyscalculia?
5. What are the prominent journals that publish articles on dyscalculia?
6. What are the top authors and countries that conduct research on dyscalculia?
7. What are the disciplines that comprise the foundation of dyscalculia research?
8. What topics are covered by the most cited articles on dyscalculia?
9. What sample is studied by the most cited articles on dyscalculia?
10. Which methods are used by the most cited articles on dyscalculia?
11. What data collection tools are used by the most cited articles on dyscalculia?

2. Method

A mixed-methods systematic review is critical for determining a topic's knowledge base and evolution (Tlili et al., 2022). Studies integrating qualitative and quantitative methods are precious in this context. This study uses bibliometric analysis and content analysis to conduct a mixed-method systematic review of dyscalculia-related publications in the Web of Science database. Thus, a topic's knowledge base and evolution of the subject of dyscalculia has been tried to be determined.

2. 1. Publication Selection

When the literature on dyscalculia is examined, it is seen that many different expressions are used in place of the term dyscalculia. Indeed, terms such as mathematics learning difficulties, specific arithmetic learning difficulties, mathematical disabilities, arithmetic learning difficulties, developmental dyscalculia, learning difficulties in mathematics, and specific arithmetic skills disorder have been used to describe dyscalculia.

Therefore, all terms corresponding to dyscalculia were screened for bibliometric analysis. On January 23, 2023, Web of Science was screened using the keywords “dyscalculia, mathematics learning difficulties, or specific arithmetic learning difficulties, or mathematical disabilities, or arithmetic learning disabilities, or development dyscalculia, or learning disorder in mathematics, or specific disorder of arithmetical skills” for analysis. The search was limited to title, abstract, keywords, and subject heading to avoid unnecessary hits. The search resulted in 1406 publications. The search for 1406 publications was filtered according to the categories Education Special, Education, Educational Research, Educational Psychology, Educational Scientific Disciplines of Web of Science. The bibliometric analysis was performed on 340 publications obtained due to this filtering. In addition, a content analysis was performed on the ten most cited articles obtained due to the filtering. The publication selection process is shown in Figure 1.

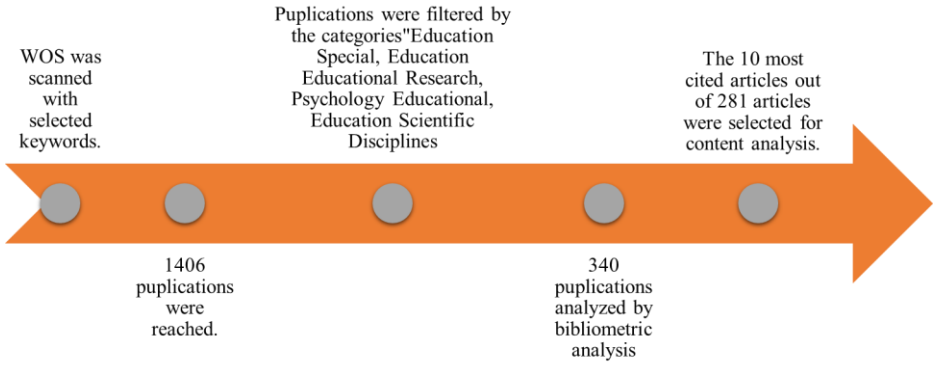

Figure 1. *Publication selection*

2. 2. Data Analysis

This systematic review employed descriptive analysis, bibliometric analysis, and content analysis. Descriptive analyses were used to determine the number and type of publications and the distribution of citations by year. The publications were analyzed by bibliometric analysis using VOSViewer software version 1.6.18 based on scientific collaboration, subject focus, prominent journals, top authors, and countries. The content analysis analyzed the ten articles' sample, topic, methodology, and data collection tools (Figure 2).

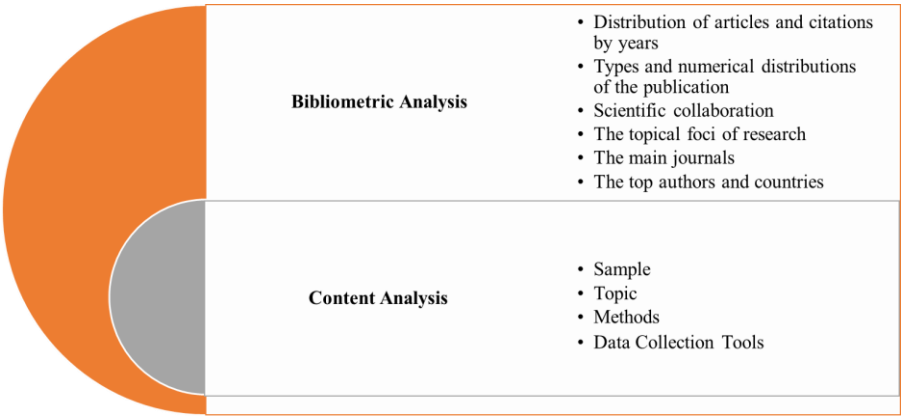

Figure 2. *Sub-titles in bibliometric and content analysis*

We used the open-access and free software VOSviewer to perform the bibliometric analysis. The VOSviewer software provides several visualization options for analysis, such as journal, researcher, or publication networks, bibliographic coupling, and publication co-citation. It is essential to understand the purpose of these analyses in order to interpret the data. Table 1 shows the VOSviewer analyses, the analysis units, and the purpose of the analyses:

Table 1. *Analysis by VOSviewer software*

Type of analysis	Unit of analysis	The aim of the analysis
Co-authorship	Authors Organizations Countries	Co-authorship analyses are performed to examine the scientific collaboration between authors, institutions, and countries. In these analyses, the node size represents the number of publications in a given author's, institution's, or country's record. The strength of collaboration between two nodes is indicated by the width of the nodes on the map and the distance of the line connecting them. The higher the network of co-authors, the closer the items appear on the map and the thicker the line connecting them. Strong connections are grouped into clusters. These clusters represent the collaborative networks of authors, institutions, or countries (Hernandez-Torrano & Ibrayev, 2020).

Co-occurrence	Author keywords	Keyword co-occurrence analysis is used to identify common themes or current research areas. All received documents are analyzed with their title, abstract, and keywords extracted from the keyword list. Co-occurrence analysis determines the frequency with which two keywords occur in a document. The co-occurrence relationship determines the frequency of occurrence of two keywords together in a document. The more often two keywords occur in a document, the stronger the relationship. Keywords frequently occurring together are organized into clusters representing general themes or research topics (Hernández-Torrano & Ibrayev, 2020).
Citation	Sources Authors Countries	However, a scientific article can be characterized by the journal in which it was published, but the references it contains direct readers to other articles and then to other authors and journals (Osca et al., 2009). In this respect, evaluating the citation links between authors, sources, and countries is necessary. Citation analysis helps to examine the links between citations attributed to studies.

3. Findings

The findings are presented in two parts: the findings from the bibliometric analysis and the content analysis.

3. 1. Findings of Bibliometric Analysis

Descriptive analyses were performed using the WOS system. Figure 1 shows the distribution of publications and citations by year, while Figure 2 shows the types and numerical distributions of publications.

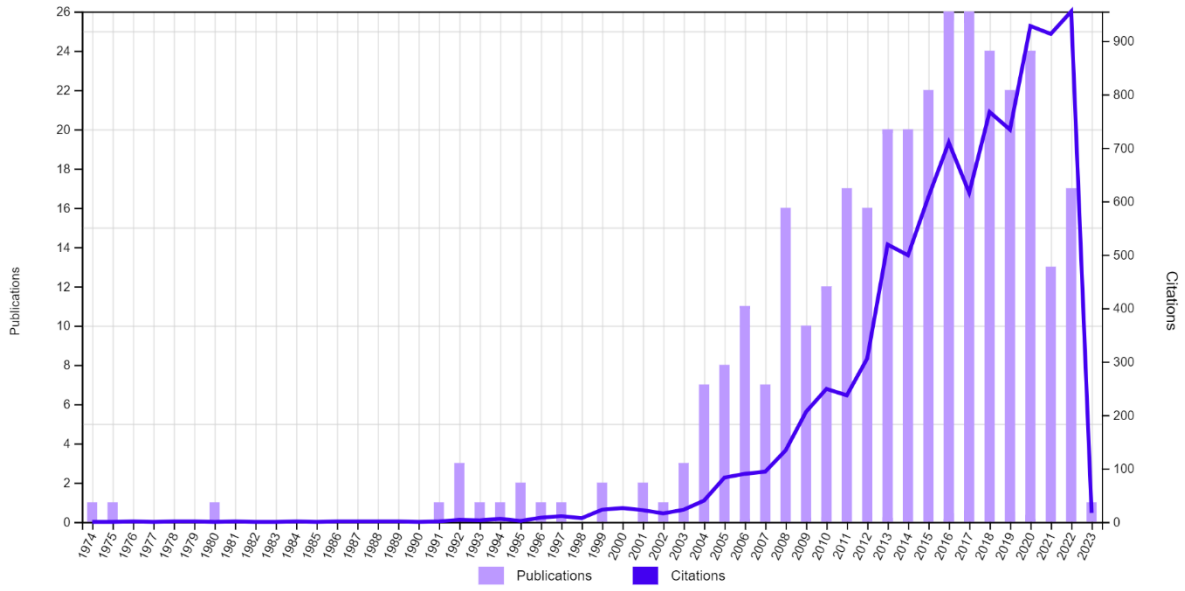

Figure 1. *The distribution of publications and citations by year*

Note. As the research was conducted at the beginning of 2023, only one publication from 2023 is shown in the figure.

The analysis of Figure 1 shows that the first publication dates back to 1974 when the psychologist Dr. Ladislav Kosc gave the first definition similar to the current one. According to Figure 1, the number of studies and references was low until 2004, so there were no publications on the topic in 1976, 1977, 1978, 1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, and 1990. Between 2004 and 2017, there has been an increase in studies and references, indicating a growing interest in the subject during this period. However, since 2017, there has been a certain decrease in the number of publications, especially in 2021, when the number of publications was only half of what was published in 2017.

Of 340 publications, 281 were articles, 30 were proceeding papers, 16 were book chapters, 13 were review articles, nine were editorial materials, eight were book reviews, six were early access, and one was a meeting abstract (Figure 2). Most publications are articles (77%), while 8% are proceeding papers, 4% are book chapters, 4% are review articles, 3% are editorial materials, 2% are book reviews, 2% are early access, and 1% are meeting abstracts. The abstract (2019) focused on multiple-choice tests to measure the mathematical skills of students with learning difficulties. Four early access publications are from 2022, and one each from 2021 and 2023. The book reviews were published in 1975, 1991, 2006, 2007, 2008, 2009, 2017, and 2019, focusing on the diagnosis and intervention methods for dyscalculia. The editorial materials were published in 2005, 2009, 2010, 2015, 2017, 2018, 2019, and 2021. Thirteen publications are review articles. In conclusion, the analysis reveals an increasing interest in the subject from 2004 to 2017, followed by a decrease in publications. Most publications are articles, while a few are related to book chapters, review articles, editorial materials, and meeting abstracts.

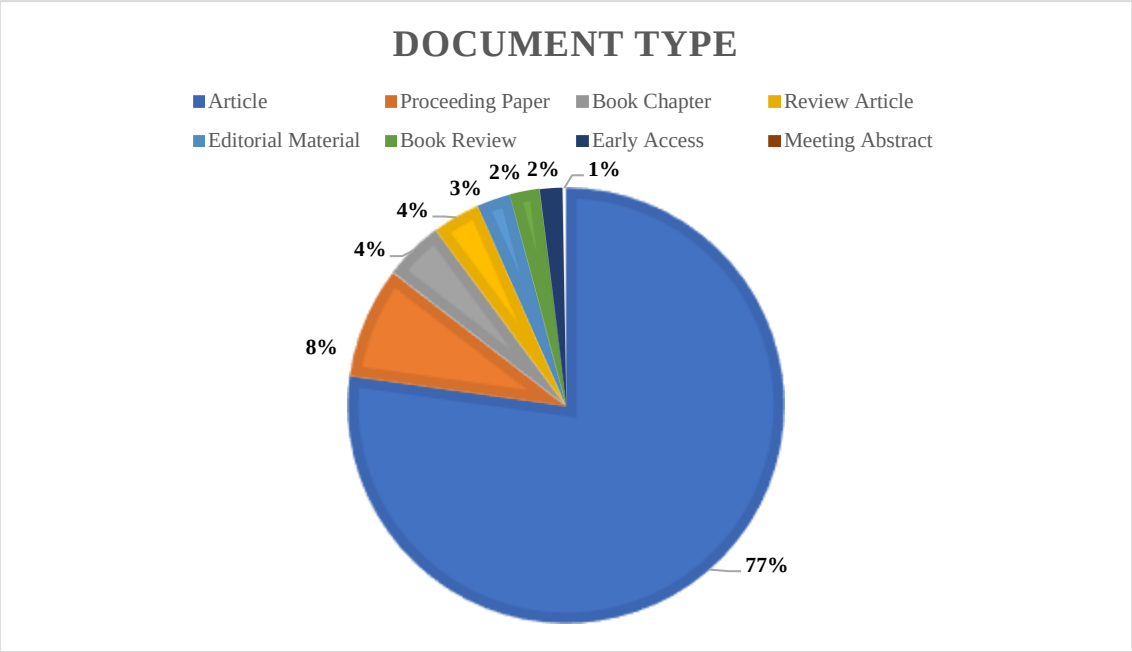

Figure 2. *The distribution of the document type of publications*

3.1.1. Scientific collaboration (Co-authorship analysis)

Bibliometric analysis can make inferences about future publications on a given subject. However, interpretations should be made by knowing the visuals on the maps revealed as a result of the analysis and the formed node, colors, or link. A bibliometric map consists of nodes of various colors and lines connecting the nodes. Nodes can have different sizes, and links can have different thicknesses. The node represents the occurrence of the items, the color represents the cluster, the thickness of the line connecting the node reveals the strength of the relationship between the clusters, and the distance between the nodes reveals the relationship between the clusters (Hernandez-Torrano & Ibrayeva, 2020).

Co-authorship analysis examines scientific collaboration in research in terms of authors, institutions, and countries. A series of co-authorship analyses were conducted to examine patterns of scientific collaboration between authors, institutions, and countries in dyscalculia studies. Figure 3 shows the co-authorship analysis performed using the author as the unit of analysis. This analysis reveals the collaborative networks between authors. For this analysis, authors with at least two publications in the dataset were restricted. In this case, 108 studies were included in the analysis. Independent publications were not included. Figure 3 shows different networks (i.e., clusters) of scientific collaboration among researchers. The red cluster is centrally located and connected to other networks on the map. This connection forms the basis for research collaborations in dyscalculia.

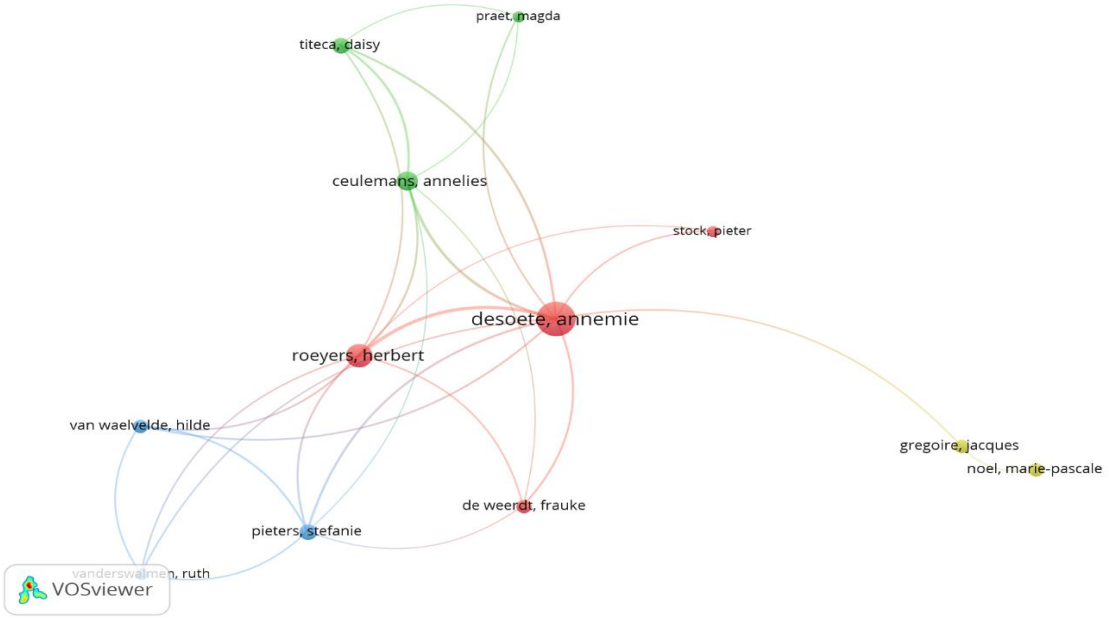

Figure 3. Collaborative research networks between authors

Note. Only authors with two or more publications were considered in the analysis (n = 108)

The co-authorship analysis, conducted by selecting institutions as the unit of analysis, included institutions with five or more publications among the 370 institutions. Thus, 18 institutions were included in the analysis. Unrelated institutions were not included (Figure 4).

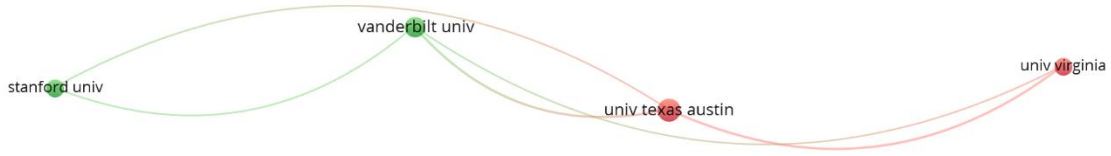

Figure 4. *Collaborative research networks between organizations*

Note. Only authors with five or more publications were considered in the analysis (n = 18)

As shown in Figure 4, the institutions fall into two clusters. The collaborating institutions are the University of Texas, the University of Virginia, Vanderbilt University, and Stanford University, all

located in the southern part of the United States. This suggests a network of collaboration between these universities in studying dyscalculia.

The co-authorship analysis by selecting country analysis units included countries with five or more publications out of 59 countries. Thus, 15 countries were included in the analysis (Figure 5). It is difficult to assume that a single country is the center of dyscalculia research (Figure 5). However, it can be said that the USA and Germany cooperate with other countries in dyscalculia research. The United States collaborates with Canada, Switzerland, Germany, the Netherlands, and China, while Germany collaborates with Israel, Belgium, Austria, Switzerland, the United Kingdom, and the United States. Finland, Spain, and Israel have ties with only one country and therefore have no ties with other countries.

Figure 5. *Collaborative research networks between countries*

Note. Only authors with five or more publications were considered in the analysis (n = 15)

3.1.2. Topical foci of research on dyscalculia (Co-occurrence analysis)

Co-occurrence analysis was used to identify common themes and current focus areas in dyscalculia research. In the analysis, the minimum number of repetitions of "keywords" was chosen to be two (n=15). The map is shown in Figure 6. The most frequently used keywords were dyscalculia (n=24), dyslexia (n=7), working memory (n=6), mathematical difficulties (n=8), comorbidity (n=5), learning difficulties (n=5), mathematics (n=5), specific learning difficulties (n=2), developmental dyscalculia (n=7), attention (n=2), reading difficulties (n=2), arithmetic (n=2), learning difficulties (n=2), mathematics difficulties (n=2), and numeracy (n=2). Figure 6 shows that studies on dyscalculia are grouped around four themes. Dyscalculia is the most frequently used keyword. In the green theme, the keywords dyscalculia, learning disabilities, learning difficulties, and mathematics difficulties are used together. In the red theme, the keywords working memory, mathematical disabilities, numerical competence, developmental dyscalculia, attention, and specific learning disabilities are used together. In the blue theme, the keywords dyslexia, mathematics, and arithmetic are used together. Finally, the keywords comorbidity and reading difficulties were used in the yellow theme.

In bibliometric analysis, maps offer three visualizations: network visualization, overlay visualization, and density visualization. To show the historical evolution of keywords used in the topic under study, the co-occurrence of keywords over time can be analyzed and interpreted through an overlay visualization map.

Figure 7 describes the evolution of current research on dyscalculia between 2008 and 2018. In the map shown in Figure 7, bluish nodes indicate keywords popular between 2008 and 2010, greenish nodes indicate keywords popular between 2010 and 2016, and yellowish nodes indicate keywords popular after 2016.

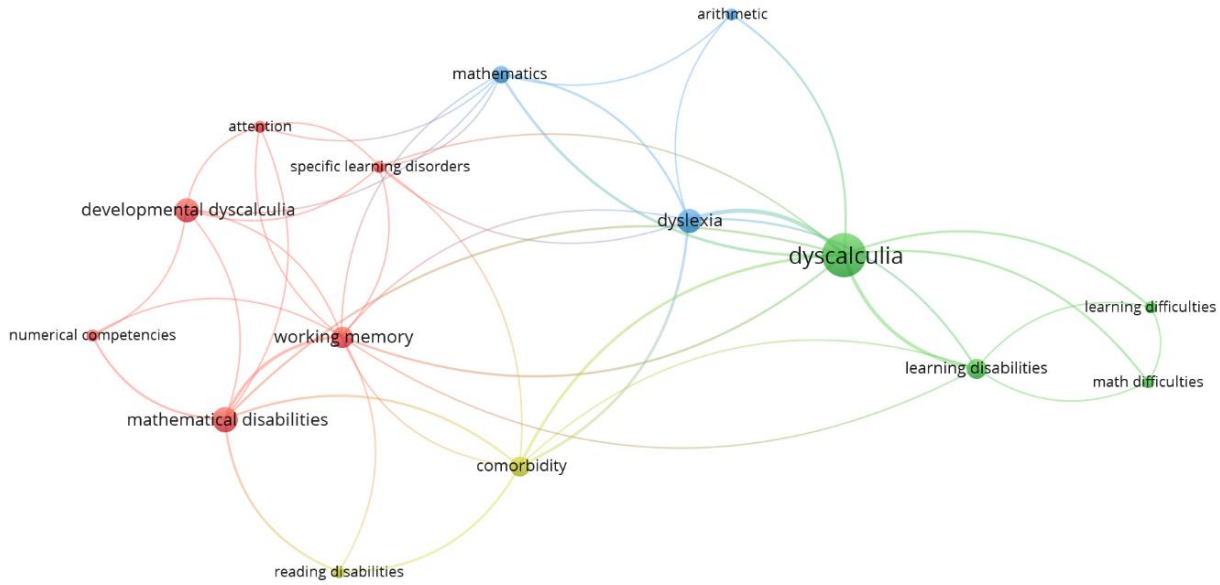

Figure 6. *Topical foci in creativity and education research*

Note. In this analysis, the keyword restriction is limited to at least 2 (n=15)

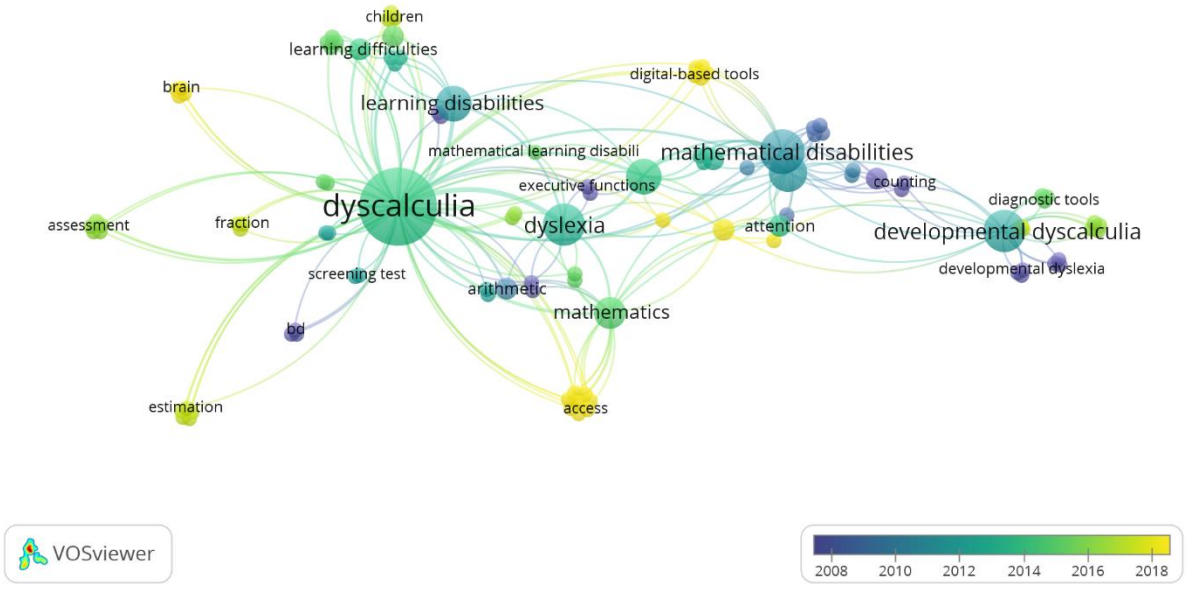

Figure 7. *Evolution of research themes in dyscalculia (2008–2018).*

Note. In this analysis, the keyword restriction is limited to at least 1 (n=107)

Figure 7 shows that between 2008 and 2010, publications on dyscalculia focused on behavioral disorders, mathematics difficulties, developmental dyslexia, dyscalculia in high school, counting, number concept, arithmetic, executive functioning, and mathematics difficulties. Between 2010 and 2016, the focus shifted to dyscalculia, mathematics, screening tests, diagnostic tools, assessments, dyslexia, comorbidity, mathematical learning disabilities, and learning disabilities. After 2016, the focus broadened to include concepts such as estimation, access, brain, fractions, children, and digital-based tools (Figure 7). The analysis shows that between 2008 and 2010, dyscalculia, i.e., other learning difficulties, arithmetic, counting, number concepts, and memory (executive function), were

the main themes. It is noteworthy that between 2010 and 2016, the concepts related to the diagnosis of dyscalculia were used. The use of digital-based tools is noteworthy in the concepts discussed after 2016. In addition, the relationship between dyscalculia and numbers, counting, arithmetic, and executive function was first investigated, and then diagnostic studies became popular.

3.1.3. Citation analysis

A citation analysis was performed to determine the journals with the highest number of articles published and cited, the most productive authors, and the countries with the highest number of articles.

Core journals on dyscalculia research

The minimum number of documents in a journal was selected as one, and the minimum number of citations was 30 (n=6). The number of publications and citations of the journals are presented in Table 2.

Table 2. *Core journals on dyscalculia research*

Journal name	Number of publications	Number of citations
Journal of Learning Disabilities	10	443
Research in Developmental Disabilities	4	38
Learning and Individual Differences	3	198
Learning Difficulties Quarterly	2	50
Dyslexia	1	146
Journal of Educational Psychology	1	63

Table 2 shows that some of the most cited journals in the area of dyscalculia research are the Journal of Learning Disabilities (443 citations in ten articles), Learning and Individual Differences (198 citations in three articles), Dyslexia (146 citations in one article), Research in Developmental Disabilities (38 citations in four articles), Journal of Educational Psychology (63 citations in one article), and Learning Difficulties Quarterly (50 citations in two articles). The analysis showed that a significant portion of the research on dyscalculia was published in journals specializing in learning disabilities. All journals but the Journal of Educational Psychology are related to learning disabilities.

Most productive authors

Table 3 shows the ranking of the authors with the most publications on dyscalculia. Looking at Table 3, we see that Desoete has the most publications on dyscalculia, with 19 publications.

Table 3. *Top authors ranked by number of publications*

Number	Authors	Number of Publications
1	Desoete A	19
2	De Smedt B	9
3	Powell SR	9
4	Roeyers H	9
5	Ghesquiere P	8
6	Schuchardt K	8
7	Hasselhorn M	7
8	Lucangeli D	7
9	Wong TTY	7
10	Ceulemans A	6
11	Swanson HL	6
12	Ansari D	5

13	Geary DC	5
14	Lewis KE	5
15	Mazzocco MMM	5
16	Berry KA	4
17	Brankaer C	4
18	Chan WWL	4
19	Mahler C	4

Countries that publish the most articles on dyscalculia

Table 4 shows the countries that published the most articles (i.e., three or more publications) on dyscalculia (n = 9). Table 4 shows the distribution of the number of articles and citations in Belgium (article 7, citation 121), England (article 6, citation 171), Germany (article 7, citation 256), Canada (article 3, citation 26), USA (article 4, citation 125), Italy (article 3, citation 87), Spain (article 4, citation 64), Greece (article 3, citation 15), Israel (article 3, citation 110). As a result of the analysis, it can be said that research on dyscalculia comes from different countries, but there is very little research on the subject. In this respect, it is difficult to define a leading country regarding publications and citations related to dyscalculia. However, it can be said that most of the countries in the ranking are in Europe.

Table 4. Top countries ranked by number of articles

Countries	Number of publications	Number of citations
Belgium	7	121
England	6	171
Germany	7	256
Canada	3	26
USA	4	125
Italy	3	87
Spain	4	64
Greece	3	15
Israel	3	110

Note. The minimum number of articles of a country was selected as three.

According to Figure 8, more studies were conducted in Germany, Spain, and the United States between 2008 and 2010, England and Belgium between 2011 and 2014, and Greece and Canada between 2015 and 2016.

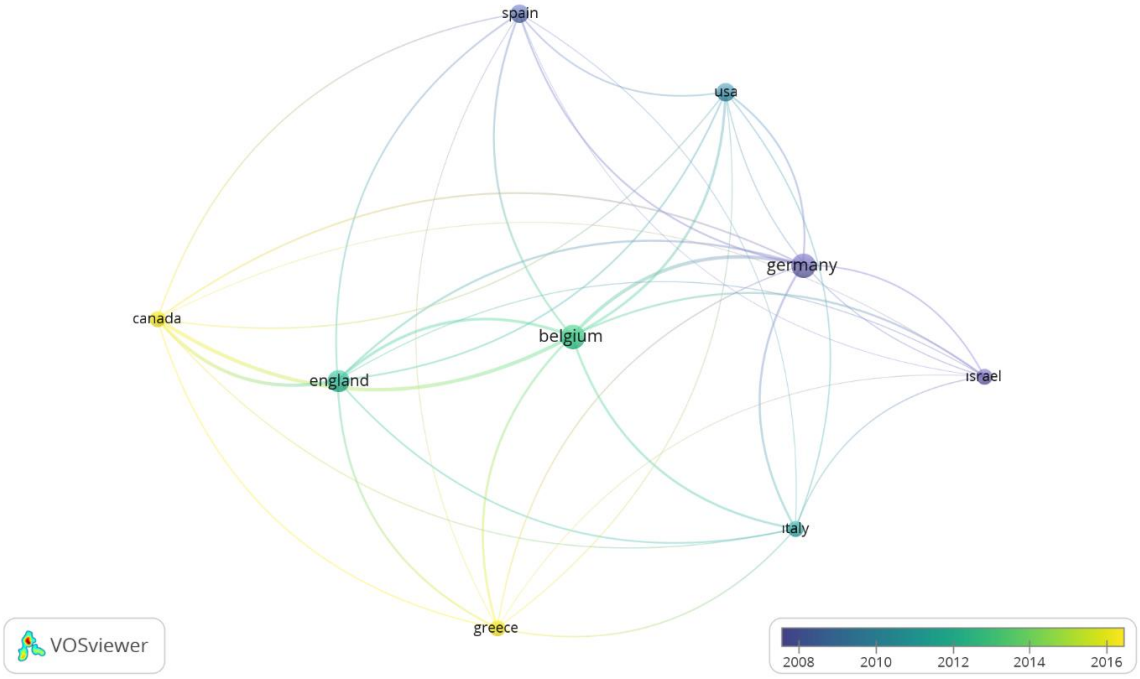

Figure 8. *Countries that publish the most articles*

Note. The minimum number of articles of a country was selected as three (n=9)

3.2. Content Analysis

The bibliometric analysis revealed the distribution of publications and citations by year, type of publications, scientific collaborations, topical foci, prominent journals, and the top authors and countries. Content analysis was conducted for the ten most cited articles. Figure 1 shows the publication selection process. Table 5 summarizes the titles, the journals in which they were published, the year of publication, and the number of citations received based on the content analysis.

Table 5. *Articles subjected to content analysis*

Title	Journal	Year	Total citation
Mathematics and learning disabilities (Geary, 2004)	JLD	2004	610
Impaired acuity of the approximate number system underlies mathematical learning difficulties (Dyscalculia) (Mazzocco et al., 2011).	CD	2011	338
Making sense of number sense: Implications for children with mathematical disabilities (Berch, 2005)	JLD	2005	224
Mathematical cognition deficits in children **w**ith learning disabilities and persistent low achievement: A five-year prospective study (Geary, et al., 2012)	JEP	2012	215
Complexities in identifying and defining mathematics learning difficulties in the primary school-age years (Mazzocco & Myers, 2003)	A.D.	2003	210
Number sense: Rethinking arithmetic instruction for students with mathematical disabilities (Gersten & Chard, 1999)	JSE	1999	206
Cognitive characteristics of children with a mathematics learning difficulties (MLD) vary as a function of the cutoff criterion used to define MLD. (Murphy et al., 2007)	JLD	2007	200
Comorbidity between reading difficulties and math difficulties: Concurrent psychopathology, functional impairment, and	JLD	2013	187

neuropsychological functioning (Willcuttet al., 2013)			
Early numerical development and the role of non-symbolic and symbolic skills (Kolkman et al., 2013).	LI	2013	161
Do weak phonological representations impact arithmetic development? A review of research into arithmetic and dyslexia (Simmons & Singleton, 2008)	Dyslexia	2008	146

Note. JLD= Journal of Learning Disabilities, CD= Child Development, JEP= Journal of Educational Psychology, AD= Annals of Dyslexia, JSE= Journal of Special Education, LI= Learning and Instruction

Table 5 shows the publication dates of the most cited articles between 2004 and 2013. In particular, the number of citations to the most cited article is 610, which is the number of citations to the most cited article. The citation numbers of the listed articles are 338, 224, 215, 215, 210, 210, 206, 200, 187, 161, and 146, respectively. Considering the number of citations of the most cited article and the second most cited article, the number of citations of the first article is about twice that of the second article. The fact that the first article received more citations than the others may be related to the fact that this article is a theoretical article about dyscalculia and its subtypes.

The content analysis of the top ten most cited articles was first analyzed by type of research. Four articles (1, 3, 6, and 10) dealt with mathematics learning disabilities or a topic related to mathematics learning disabilities from a theoretical perspective. These articles were analyzed regarding the year and the topic examined in the study (Table 6).

Table 6. *Articles reviewed in the review type*

Number	Year	Topic
1	2004	Mathematics learning difficulties and its subtypes
3	2005	Applications that can be implemented to improve the number sense in children with math learning difficulties
6	1999	The relationship between the concept of number sense and mathematics learning difficulties
10	2007	Relation of Weak Phonological Representations and Arithmetic Development

The articles were examined according to the method, research model, sample, data collection tools, and topics (Figure 2).

Table 7. *Articles reviewed in research article type*

No	Method	Research model	Sample	Data collection tools	Topic
2.	Quantitative	LCSM	Kindergarten-Grade 9	DST and DWT	Approximate number system
4	Quantitative	LCSM	Grade 1-2-3-4-5	DST and DWT	Mathematical cognition deficits in children with learning disabilities
5	Quantitative	LCSM	Kindergarten-Grade 1-2-3	DST and DWT	Identifying students with math learning difficulties

7	Quantitative	LCSM	Kindergarten-Grade 1-2-3	DST and DWT	Identifying students with math learning difficulties
8	Quantitative	CSM	Parents, Teachers, and Twins between 8-15 ages	DST and DWT	The relationship between reading difficulties and math learning difficulties
9	Quantitative	CSM	Children between 4-6 ages	DST and DWT	Early numerical development and the role of non-symbolic and symbolic skill

Note. LCSM= Longitudinal correlational screening model, CSM= Correlational screening model, Domain-specific tests and domain-general tests= DST and DWT

From a historical developmental perspective, the causes of dyscalculia have been examined in the context of domain-specific and domain-general deficit hypotheses (Can, 2020). Domain-general skills are related to cognitive functions that affect overall cognitive performance, such as intelligence, working memory, language skills, and attention control. On the other hand, domain-specific skills are related to numerical skills such as counting, number sense, and arithmetic operations. Different tests and tasks were used to test domain-general and domain-specific skills in the articles analyzed in the research article type. More information about the tests and tasks used in the reviewed articles is provided below.

In Article 2, the researchers used a variety of domain-specific and domain-general tests and examined the relationships between the results of those tests. To test domain-specific skills, they used an approximate number system test, the Early Mathematics Ability (Ginsburg & Baroody, 1990), the Woodcock-Johnson Revised Calculation subtest (Woodcock & Johnson, 1990), the Quick Math Task (Mazzocco et al., 2008), the Generating and Decomposing Numbers Task (Mazzocco & Hanich, 2010), and the Sorting Ratios Task (Mazzocco & Devlin, 2008). They used the Non-Word Reading Test (Wood-cock-Johnson-Revised Word Attack), Rapid Automatic Naming Test (Denckla & Rudel, 1976), Visual Closure Test (Hammill et al., 1993), Stanford Binet Intelligence Test (Digit Memory), Contingency Naming Test (Anderson et al., 2000), Memory Puzzle Test (Mazzocco et al., 2006) to test domain-general skills.

Article 4 used Raven's Colored Progressive Matrices (Raven et al., 1993), the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), The Working Memory Test Battery for Children (Pickering & Gathercole, 2001), The Strengths and Weaknesses of ADHD-Symptoms, and Normal-Behavior measure (Swanson et al., 2008) to test domain-specific skills. The researchers used the Wechsler Individual Achievement Test-II: Abbreviated (Wechsler, 2001), strategy choice tasks, and estimation tasks to test domain-general skills.

Article 5 focused on the Stanford Binet Fourth Edition (Thorndike, Hagen, & Sattler, 1986), the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), the Developmental Test of Visual Perception-second edition (Hammill et al., 1993), and the Woodcock-Johnson--Revised (Woodcock & Johnson, 1989) to test domain-specific skills. The researchers used the KeyMath--Revised Achievement Test (Connolly, 1998), the Test of Early Math Ability-second edition (Ginsburg & Baroody, 1990), and the Woodcock-Johnson-Revised (Woodcock & Johnson, 1989) Math Calculations tests to test domain-general skills.

Article 7 used the Word Attack subtest of the Woodcock-Johnson Psychoeducational Battery–Revised (Woodcock & Johnson, 1989), the Contingency Naming Test (Anderson et al., 2000; Taylor et al., 1987), Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999) tests to test domain-specific skills. The researchers used the second edition Test of Early Math Ability (Ginsburg & Baroody, 1990) tests to test domain-general skills.

Article 8 employed the Disruptive Behavior Rating Scale for parents and teachers (Barkley & Murphy, 1998), Diagnostic Interviews for Children and Adolescents (Reich, Welner, & Herjanic, 1997), Achenbach System of Empirically Based Assessment (Achenbach & Rescorla, 2001), Child Global

Assessment Scale (Setterberg et al., 1992), Colorado Learning Difficulties Questionnaire (Willcutt et al., 2011). For verbal comprehension skills, the researchers used the WISC-R Verbal Comprehension score, Gordon Diagnostic System (Gordon, 1983), to test working memory level Span Task (Siegel & Ryan, 1989), The Wisconsin Card Sorting Test (Heaton, 1981), Stroop Color and Word Test (Golden, 1978), The Rapid Automatized Naming Test (Denckla & Rudel, 1976).

In Article 9, the researchers used the number-to-position task (Laski & Siegler, 2007), the Number-naming task, The Early Numeracy Test-Revised (Van Luit & Van de Rijt, 2009), the Symbolic number-lines task, Symbolic comparison task, a standardized math test (Janssen et al., 2005) to test domain-specific skills.

4. Discussion

Dyscalculia is a learning difficulty that interferes with the normal development of arithmetic skills. We conducted a bibliometric and content analysis of the literature on dyscalculia in the Web of Science database. The aim was to identify key themes, prevailing research trends, potential knowledge gaps, and influential authors in dyscalculia.

The distribution of the results of the articles shows the history of publications on dyscalculia. The first publication on dyscalculia was in 1974, and it took some time for interest in the topic to grow. Until 2004, the number of studies and references on dyscalculia was relatively low; there were even some years with no publications. However, from 2004 to 2017, there was an increase in the number of studies and references on dyscalculia, indicating an increased interest in the topic during this period. Since 2017, however, there has been a decline in the number of publications, particularly in 2021, when there were only half as many publications as in 2017. Although a precise explanation for the decrease in 2017 is not possible from the information provided, it is reasonable to assume that the decrease in 2021 is due to the ongoing COVID-19 pandemic (Günay, 2021; Parlar, Kart, 2022).

The analysis revealed that the majority of publications related to dyscalculia were research articles, which accounted for 77% of all publications. In contrast, 8% of the publications were papers, 4% were book chapters, and 4% were review articles. The co-authorship analysis showed that the author network was centered around Anemie Desoete and Herbert Roeyers as prominent contributors in the field. On the other hand, when the co-authorship analysis is performed by selecting institution and country as the unit of analysis, it is difficult to position a single country as the center of dyscalculia research. However, it can be said that the USA and Germany collaborate with many other countries in dyscalculia research. This is evidenced by U.S. collaborations with Canada, Switzerland, Germany, the Netherlands, and China, and German collaborations with Israel, Belgium, Austria, Switzerland, the United Kingdom, and the United States. Finland, Spain, and Israel seem to depend on only one country and do not cooperate with other countries. It should be noted, however, that the lack of international cooperation does not imply a lack of research activity or innovation in these countries. However, scientific collaboration is a critical aspect of research publications. It can potentially solve complex scientific problems (Sonnenwald, 2007). Therefore, scientific collaboration in publications can be recommended to produce high-quality research results and address research questions related to dyscalculia.

A co-occurrence analysis was conducted to identify common themes and current focus areas in dyscalculia research. The results showed that dyscalculia was the most frequently used keyword, followed by mathematical difficulties, dyslexia and developmental dyscalculia, working memory, comorbid illness, learning difficulties, and mathematics. The analysis also showed that some related terms, such as specific learning disabilities, attention, reading difficulties, numeracy, learning disabilities, math difficulties, and numeracy competencies, appeared less frequently. An analysis of the keywords shows that there are keywords that belong to the domain-specific deficit hypothesis and keywords that belong to the domain-general deficit hypothesis. These terms provide further insight into different aspects of dyscalculia research and highlight potential areas for future research.

The distribution of the current focus of dyscalculia research over the years shows that between 2008 and 2010, the discourse surrounding dyscalculia focused primarily on its relationship to other learning

disabilities, such as conduct disorder, math difficulties, developmental dyslexia, arithmetic, counting, number sense, and executive function. From 2010 to 2016, the discussion shifted to include screening tests and diagnostic tools to identify dyscalculia and comorbidity with other learning disabilities and math learning disabilities. After 2016, the discourse expanded to include new concepts such as estimation, access, the brain, fractions, children, and digital-based tools. This indicates a growing interest in using technology to support dyscalculia interventions. There has also been a shift in focus toward investigating the relationship between dyscalculia and numbers, counting, arithmetic, and executive functioning. The results show that researchers in the field are exploring various topics and issues related to dyscalculia, which can be grouped as eliciting domain-specific and domain-general concepts, defining dyscalculia, intervening in dyscalculia, and investigating comorbidity.

Overall, this analysis highlights the evolving nature of dyscalculia research and the importance of keeping abreast of the latest developments in the field. Over time the focus has shifted from simply understanding the disorder to developing practical tools and interventions that can help individuals with dyscalculia overcome their difficulties and succeed in their academic and personal lives. A closer look reveals that some of the most cited journals in dyscalculia research are the Journal of Learning Disabilities, Learning and Individual Differences, Dyslexia, Research in Developmental Disabilities, Journal of Educational Psychology, and Learning Difficulties Quarterly. Remarkably, a significant proportion of dyscalculia research has been published in journals focusing specifically on learning disabilities. In fact, except for the Journal of Educational Psychology, all of the above journals specialize in learning disabilities. This observation underscores the importance of specialized journals in facilitating scientific discourse and promoting research in dyscalculia and related fields.

Authors who made significant contributions to the field of dyscalculia were ranked according to the number of publications attributed to them. The results show that Anemie Desoete has the highest number of publications on dyscalculia. After her, Bert De Smedt and Sarah R. Powell have the most publications. This ranking serves as a valuable resource for academics and practitioners who wish to identify key authors in the field of dyscalculia research. It also underscores the importance of publication output as a metric for measuring scientific impact and advancing our understanding of the condition. The contributions of these authors have significantly advanced our understanding of dyscalculia and paved the way for further research in the field.

Belgium, the United Kingdom, Germany, Canada, the United States, Italy, Spain, Greece, and Israel have contributed to research on dyscalculia. Thus, the analysis shows that research on dyscalculia is conducted in different countries, but there is limited research on the topic. As a result, it is difficult to identify a top country regarding publications and citations related to dyscalculia. However, it can be observed that most of the countries in the ranking are in Europe.

The results show that knowledge in the field of dyscalculia is limited to a small group of authors and countries. Therefore, cross-national comparative studies with researchers from other countries could be conducted to provide a more comprehensive view of dyscalculia research.

The top ten most cited articles were subjected to content analysis following the bibliometric analysis. First, the type of research was examined. The results showed that four articles approached the subject of mathematics learning disabilities or mathematics learning disabilities from a theoretical perspective. The remaining articles were mainly experimental studies. These studies were meticulously analyzed in terms of their methodologies, research designs, samples, data collection tools, and topics and presented in detail in the tables in the findings section.

This rigorous analysis provides valuable insights into the different research approaches to investigate mathematics learning disabilities. By identifying the types of research conducted and the methodologies used, this study can guide future researchers and practitioners who wish to investigate this complex topic further. Furthermore, this analysis highlights the need for interdisciplinary collaboration and to bring together theoretical frameworks to understand the nature and underlying causes of mathematics learning disabilities.

5. Conclusion

Bibliometric and content analyses shed light on the cognitive structure and dynamics of the dyscalculia research field. The results identified significant themes, dominant research trends, and potential knowledge gaps in dyscalculia research. The study also highlights the most cited articles and influential authors. Overall, the analysis provides a comprehensive overview of the current state of dyscalculia research and the field's future direction.

6. Limitations

While bibliometric reviews and content analysis are useful tools for conducting a comprehensive literature review, they inevitably fail to provide a complete picture of a field or discipline (Hernández-Torrano & Ibrayeva, 2020). This study has several limitations. First, we screened only the Web of Science (WOS) database. Therefore, we potentially excluded relevant publications from other databases or sources. Second, the search was restricted to the topic field, which may have omitted related publications from other fields of study. However, it is essential to note that the publications included in the sample were limited to education and educational research categories. Third, the study focused only on publications in English, thus potentially missing valuable literature published in other languages. Fourth, the study only considered publications published up to 23.01.2023; therefore, publications after this date were not included in the analysis. It is crucial to recognize that these limitations inevitably narrowed the scope of this study and did not provide a comprehensive overview of all research activities in the field of dyscalculia. However, despite these limitations, this study provides insights into dyscalculia research in its infancy.

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