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Digital Tools and Mathematics Learning Difficulties: A Bibliometric analysis (1988-2024)

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Students with dyscalculia or math disability experience difficulties in different mathematical areas. Assistive technology is often used to support their learning/ educational needs. As assistive technology is a broader term, the paper focuses on digital technology. The study examines the global research landscape on assistive technologies for students aged 12-18 with mathematical disabilities. It analyses the most commonly used assistive technologies and their evolution over time, identifying leading countries, prolific authors and citation trends. Factors influencing the use of AT by these students are also explored. A systematic literature review, including 624 papers from 1988 to 2024 included in the Scopus and Web of Science databases, was conducted using methods of bibliometric analysis facilitated by the software VOSviewer. The relationship between digital technology (for teaching and learning purposes) and students with math disability aged 12-18 was examined. Based on co co-occurrence analysis six thematic clusters were identified that are related to (1) barriers and different kinds of digital technology and frameworks that address barriers, (2) cognitive processes, psychological processes, and mathematical (dis)abilities, (3) mathematics contents and digital and non-digital resources that supports representation of mathematics concepts, (4) relates to mathematics self-beliefs, achievements, and factors related to achievements, (5) learning and teaching of mathematics, (6) affinity to mathematics and the willingness to learn it. Our analysis shows that there is an extensive body of research regarding the usage of new digital technology in teaching and supporting students with math disability, however, suggesting that more specific research is needed to establish the impact of different types of digital technologies on learning basic mathematical concepts, procedures, and problem-solving tasks.

Keywords: digital tools, dyscalculia, learning difficulties, mathematics, VOSviewer

INTRODUCTION

Dyscalculia (ICD-11 code MB4B.5) is a developmental learning disorder that is characterized by significant and persistent difficulties in learning academic skills, mostly arithmetic (Ziadat, 2022). It is reflected in mathematical difficulties as

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consequence of lack of understanding basic arithmetic operation (Deda et al., 2024) Dyscalculia is (also) defined as an educational problem, specifically a math disability (MD) that cannot be predicted by student's intellectual functioning (Reid et al., 2013), as they normally tend to be of average intelligence (Geary, 2013). The ICD-11 also defines it as a developmental learning disorder with impairment in math, taking into account some exclusion criteria such as intellectual development disorder, sensory impairment, neurological impairment, lack of good teaching practice, language barrier due to migration and psychological adversity. Given the importance of appropriate gradual intensive support that includes good teaching practice, the model response-to-intervention has been recognized as an appropriate approach in identifying dyscalculia in students. The main feature of this approach is the assessment of the students' response to the mathematical instructions (interventions), which become more intense the more the students struggle in learning or mathematical domain. Students who do not benefit from this type of instruction are identified as students with dyscalculia (Ouyang et al., 2024).

Students with MD represent a very heterogeneous group who can experience serious difficulties in two main cognitive domains, namely (1) domain-general abilities (for example working memory, executive functions, visuospatial processing and attention) and (2) (numerical) domain-specific abilities (for example magnitude representation) (Li et al., 2023; Ouyang et al., 2024). On the other hand, Geary (2013) and Reid et al. (2013) argue that there are three domain-specific areas in which students with dyscalculia have difficulties: automatization of basic mathematical facts (number representation, counting knowledge, arithmetic), procedural competencies, and problem solving. Difficulties may also occur in the psychological domain such as a deficit in working memory (Geary, 2013; Kroesbergen et al., 2023; Ouyang et al., 2024; Reid et al., 2013), processing speed or rapid automatized naming (Geary, 2013; Kroesbergen et al., 2023; Reid et al., 2013), fact retrieval (Geary, 2013; Reid et al., 2013) and number sense (Kroesbergen et al., 2023). Both areas, domain-specific and domain-general abilities, can be contributory to dyscalculia, although in different ways, by creating barriers to the development of mathematical knowledge. Li et al. (2023) conducted a two-year longitudinal study showing that students with dyscalculia differ from their peers in executive function and number sense. Difficulties may also arise in the area of specific mathematical skills, such as understanding abstract meaning of numbers, sequences, quantity relationships, but also using arithmetic knowledge to solve everyday problems (Deda et al., 2024). Poor number word comparison skill and performance in the number line rise the risk for of dyscalculia in students (Ouyang et al., 2024). Student with MD frequently use immature or inappropriate (learning) strategies (Wadlington & Wadlington, 2008), have difficulties with retrieving information from memory (Passolunghi & Siegel, 2004), and usually omit steps of mathematical procedure, or fail to perform the procedure in correct sequence (Gersten et al., 2009). For this reason, direct instruction focused on scaffolding is needed when constructing mathematical concepts (Hughes et al., 2023).

However, in response to identified learning difficulties of children with learning disorders, assistive technology (AT) is often used (Bryant et al., 2014; Perelmutter et al., 2017; Thapliyal & Ahuja, 2023). AT is a broader term for all assistive products and their related systems and services (WHO, 2022). The Assistive Technology Industry Association (ATIA) defines it as "any item, piece of equipment, software program, or product system that is used to increase, maintain, or improve the functional capabilities of persons with disabilities" (ATIA, n.d.). Therefore, AT encompasses the hardware and software devices used when executing physical or rational tasks in an efficient way (Thapliyal & Ahuja, 2023). The aim of AT is to support the individual's functioning in different areas such as cognition, communication, inclusion, participation, and similar (WHO, 2022). AT can be low-tech to high-tech, hardware or software, inclusive (learning materials and curriculum aid), or specialized curricular software (ATIA, n.d.). Thapliyal & Ahuja (2023) categorized AT into five types, based on several parameters: non-electronic products, low-tech products, mid-tech products, high-tech products, and educational software. Different types of AT, mostly mid-tech products and educational software are used in helping and supporting students with dyscalculia such as talking calculator, software for mathematic learning, and calculation applications (Dhingra et al., 2024; Thapliyal & Ahuja, 2023). However, using manipulative materials is suggested.

Research has shown that AT, specifically digital technology (DT), has beneficial effects on students' learning disability (Thapliyal & Ahuja, 2023), especially for those affected by MD (Dhingra et al., 2024; Miundy et al., 2017; Poobrasert & Gestubtim, 2013). In particular, DT provides a customized experience to students, therefore learners develop an interest in using digital tools (Dhingra et al., 2024). DT helps learners to work on their deficit areas, also in the initial stages of learning mathematics (Dhingra et al., 2024). With the aid of Artificial Intelligence, AT is able to adapt the tasks to the cognitive needs of the learners with Intelligent Tutoring Systems (Dutt et al., 2022; Miundy et al., 2017). Moreover, the possibility of manipulating objects with the aid of Augmented Reality (AR) leads to additional benefits (Miundy et al., 2017). In the latter case, the benefits include an increase in motivation, ease of interaction, the development of cognitive skills, the improvement of short-term memory, and increased enjoyment of the lessons (Ahuja et al., 2022). DT may be important for students' functioning in the domain-general abilities, but it may affect also the emotional domain represented by motivation and interest. Research has also shown that motivation can play a prominent role in predicting and influencing the achievement of students with or at risk of learning difficulties (Sideridis et al., 2006).

However, DT aimed at addressing dyscalculia-related difficulties include specific digital tools such as talking calculators, calculation apps, and math-learning software (cf. Dhingra et al., 2024; Rohizan et al., 2020; Kohn et al., 2020; Poobraset & Gestubtim, 2013). Furthermore, manipulative tools, pattern blocks, programmable building blocks, and communicating beads facilitate better comprehension and exploration of mathematical concepts, especially compared to abstract formal methods (Aprinastuti et al., 2020; Miundy et al., 2017). This suggests that DT may also support students with MD in (numerical) domain-specific abilities, helping them to perform arithmetic tasks and understand abstract mathematical concepts. For example, a study by Kohn at al. (2020) showed that introducing a computer-based learning program, specifically Calcularis 2.0, can help improve arithmetical abilities and mental number line representation in students with MD.

The integration of DT in education has become increasingly important, particularly for students with MD. These technologies offer significant potential to support and enhance learning outcomes for students in middle and high schools, where the challenges associated with learning mathematics can be particularly pronounced (cf. Powell et al., 2021). Understanding the current state of digital tool usage for these students is crucial for educators, policymakers, and researchers aiming to improve educational strategies and outcomes.

Given the vast and growing body of literature in this area, a comprehensive review is necessary to identify key trends, influential contributors, and the most effective tools and strategies. However, due to the extensive number of publications, a traditional literature review may be impractical. Instead, a bibliometric analysis, which is particularly suited for handling large datasets with over 200 references (Rogers et al., 2020), is employed to systematically explore the state of the art in this field.

This study focuses on students aged 12-18 and aims to answer several specific research questions. Firstly, we were interested in which country or geographic region has produced the highest number of papers in the field of AT and MD. Secondly, we aimed at understanding which author has published the most papers, and who is the most cited. Thirdly, we wanted to explore what are the most used ATs by students with MD, and how these trends have evolved over time. Finally, we wanted to explore what factors are associated with the usage of AT among students with MD. By addressing these questions, the study seeks to provide a detailed overview of the current landscape of digital technology usage in supporting students with specific learning difficulties in mathematics.

METHOD

Bibliometric analysis comprises several mathematical and statistical methods for assessing bibliometric data (Ellegaard, 2018). This technique aims at understanding the interrelationship among journals and it summarizes the current state of the art (Boonroungrut et al., 2022; Ellegaard & Wallin, 2015; Vázquez-Cano et al., 2022). The data utilized in a bibliometric analysis is retrieved from several databases, such as Scopus and Web of Science (WoS) Core Collection.

Scope of the research

The scope of the research is to analyze the state of the art about the usage of digital technology and tools with students with specific learning difficulties in mathematics in the age range 12-18 (i.e., in middle and high schools; cf. Powell et al., 2021). Bibliometric analysis is suitable to achieve this aim since the literature review might be too broad for a manual review. Bibliometric analysis is recommended with more than 200 references (Rogers et al., 2020).

As specific aims, we were interested in answering the following research questions:

RQ1: Which country or geographic region has produced the highest number of papers in the field of AT and MD?

RQ2: Which author has the highest number of papers published in this field? Which author was the most cited?

RQ3: Which AT is the most used by students with MD? Did the trend of using AT by students with MD change over time? If so, what is the current trend?

RQ4: Which factors are associated with the usage of AT with students with MD?

Collecting data

References for the research have been collected using two databases to extract data from the literature, i.e. the Scopus database and the WoS database. All data were retrieved in .csv or .txt format. Overall, 624 published articles were retrieved. These articles covered a period from 1988 to January 2024. In Table 1, the number of papers per year is presented. As it may be seen, more than half of the papers considered in the present research (61.5%) was published in 2020 and onwards, indicating that the interest in MD and AT has intensified in the last 5 years. The results can be explained by current trends in education systems, where curricula are being updated with digital competences. For example, the Eurydice report (2021) shows that almost half of European education systems include digital competences in their curricula (Bourgeois et al., 2019).

Table 1
The number of published papers in each year.

Year	Documents	Year	Documents
2024	18	2009	5
2023	109	2008	5
2022	109	2007	2
2021	89	2006	2
2020	59	2005	3
2019	42	2004	0
2018	25	2003	0
2017	38	2002	2
2016	29	2001	1
2015	16	2000	2
2014	13	1999	2
2013	21	1998	1
2012	14	1997-1989	0
2011	7	1988	1
2010	9		

Bibliometric data

On the Scopus and the WoS websites, the following keywords were searched in the engines: (“math” OR “maths” OR “mathematics”) AND (“dyscalculia” OR “specific learning dis*”) AND (“secondary school*” OR “high school*” OR “middle school*”) AND (“digital*” OR “technolog*” OR “ICT*” OR “assistive techn*”). The primary keywords were related to mathematics and learning difficulties. However, because we were interested in exploring the usage of technology associated with mathematics and learning difficulties, we also searched for digital tools that might be employed in the teaching and learning of mathematics. Additionally, we limited the research to secondary students solely. As an additional inclusion criterion, we considered solely published journal articles written in English. The database search was conducted on February 20, 2024. In total, 622 publications were retrieved from the Scopus database and 144 from the WoS database. Possible duplicates were automatically deduplicated by the software. Overall, 624 articles were processed.

Data analysis

The primary steps of the analysis involved (1) science mapping and (2) network analysis (Tamala et al., 2022). Science (or bibliometric) mapping is a way of analyzing the influences and the strengths of relationships among different article attributes. Those are presented in the item's co-occurrence weight and the total link strength. These results can be implemented with network analysis, which includes network metrics, clustering, and visualization. Science mapping and network analysis were performed with the computer software VOSviewer (version 1.6.20). This study was limited to keywords and title analyses.

The Visualization of Similarities (VOS) viewer is a software that has been gaining popularity in bibliometric research. It was developed in 2010 (van Eck & Waltman, 2010) to help researchers create and visualize bibliometric maps that are easier to interpret (Tamala et al., 2022). The software establishes similarities among publications and retrieves significant themes among the publications (Nobanee et al., 2021). The association strength is used as a similarity metric in a similarity matrix (Su et al., 2021). This matrix is created by normalizing the co-occurrence matrix. The similarity between two co-occurrence data, for instance, keywords, is computed as $s_{ij}=c_{ij}/(w_i\ w_j)$, where c_j represents the total number of occurrences of co-occurrences of the elements i and j, and where w_i and w_j are the total number of occurrences or co-occurrences of the elements i and j. The similarity matrix that is produced with the above method is then analyzed with the VOS approach, which aims at reducing the weighted sum of the squared Euclidean distances among all pairs of elements.

Furthermore, VOSviewer encompasses three visualization methods: network visualization, overlay, and density visualization. We specifically employed network visualization to cluster data, whether it pertained to word co-occurrences. This technique highlights interconnected keywords and published topics, with color coding indicating both clusters and the degree of similarity in studies. The lines connecting words undergo changes in contrast: a vibrant color denotes frequent usage across various studies, while a lighter color signifies a limited connection between them.

The analyses conducted in the present research were based on text data; the VOSviewer read data from bibliographic database files, namely the Scopus and WoS databases. The terms were extracted from the title and abstract fields. The software ignored the structured abstract labels and copyright statements. The full counting method was adopted. As a threshold level, the minimum number of occurrences of a term was set to 10. Of the 11,492 terms, 452 met the threshold. From them, the relevance score was calculated, and, from this score, 60% (271) more relevant terms were selected. The terms were manually verified, and 128 terms (47.2%) were considered for further analysis. The list of the excluded terms is reported in Appendix A. These terms were excluded mainly because they related to broad concepts that are not related to the study (e.g., "time", "children", "session"), were methodology-related (e.g., "intervention study", "control group", "min", "variance"), encompassed school levels out of the scope of this research (e.g., "college", "kindergarten", "elementary student"), were related to specific disorders (e.g., "adhd", "autism") although it may be a co-occurrence of disorders, or were not math-related (e.g., "reading", "predictor", "english"). The minimum cluster size was set to 3. As a normalization method, the association strength was used.

FINDINGS

Publication analysis

The papers that were considered in this analysis were published by authors from 81 countries; among them 31 had a minimum of 5 published papers (Table 1). As it might be noticed, the authors of most documents come from the United States of America (n = 273), and the total link strength is the highest (39). The second country with the most papers (n = 36) is United Kingdom, with a rather high link strength (36). The clustering of the authors' origin (see Figure 1 and Table 2) has shown a pseudo-geographical clustering: the states of the authors' origin are geographically, culturally, and socio-economically relatively close. Considering the continents' distribution, the majority of the authors (48.4%) was European, followed by Asian authors (32.3%), and North American countries (6.5%). All other continents were represented by only one paper.

Table 2
The countries of the authors of the papers

Country	Documents	Citations	Total link strength	Cluster
United States	273	6511	39	5
United Kingdom	36	950	36	6
Germany	25	395	22	1
China	32	641	14	3
Canada	18	288	13	8
Hong Kong	11	34	12	2
Italy	30	316	12	6
Finland	13	483	10	1
Australia	15	184	9	4
France	10	254	9	1
Singapore	7	53	9	3
Switzerland	5	63	9	1
Belgium	16	200	8	1
Greece	19	155	6	2
Norway	5	51	6	2
Sweden	11	69	6	2
Spain	16	99	5	5
Turkey	22	108	4	4
Austria	5	26	3	2
Indonesia	25	86	3	4
Ireland	5	71	3	8
Jordan	6	3	3	7
Saudi Arabia	14	82	3	7
Taiwan	8	286	3	3
Chile	5	26	2	5
The Netherlands	10	345	2	1
Portugal	5	57	2	5
India	7	55	1	7
Israel	15	143	1	6
Malaysia	8	6	1	4
South Africa	6	10	0	N.A.

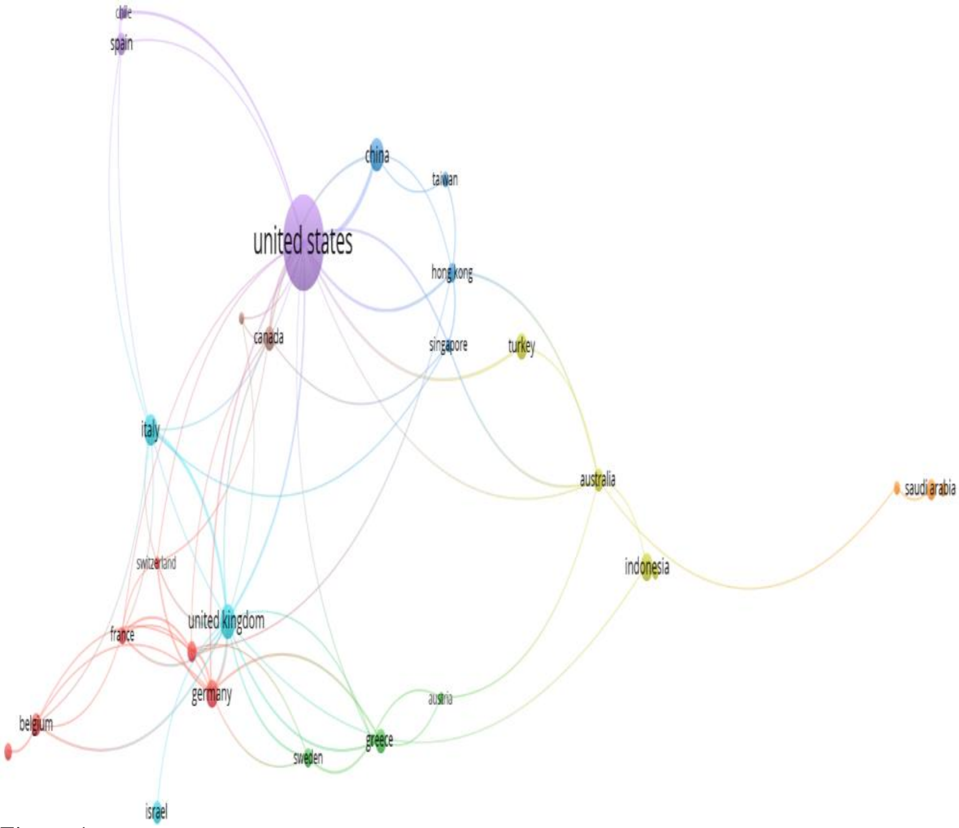

Figure 1
The network visualization of the authors of the papers

There were 1,922 different authors of the papers. In Table 3, the authors with 5 or more published articles on the topic are reported, as well as their link strength.

Table 3
The authors with 5 or more documents on the topic

Author	Documents	Citations	Total link strength
Brownell, Sara E.	5	88	5
Evmenova, Anya S.	6	115	5
Gin, Logan E.	5	88	5
Regan, Kelley	5	95	4
Nelson, Gena	5	85	1
Powell, Sarah R.	8	368	1
Satsangi, Rajiv	5	54	1
Bouck, Emily C.	7	72	0
Hughes, Elizabeth M.	5	37	0
Lucangeli, Daniela	5	90	0
Moeller, Korbinian	8	166	0
Zhou, Xinlin	7	135	0

Bibliometric mapping

The co-occurrence analysis was performed. It searched for relationships between keywords. In the co-occurrence mapping, all keywords were considered as units of analysis, aided by the full counting method. In the present study, we set some limitations. For instance, a minimum of 5 occurrences of a keyword was set as a limiting factor. Using the VOSviewer software, the (1) link, (2) link strength, and (3) co-occurrence of the keywords were computed. The link regards the co-occurrence between one item (keyword) to another, and the total link strength refers to the total cited references between one item and the other. The occurrences represent the number of articles in which the keyword was found.

In total, 128 items (keywords) were considered, which were grouped in 6 clusters (Figure 2), with a total of 2,129 links and the total link strength of 13,245. Details are presented in Appendix B. The highest occurrences were "learner" (n = 131), "math anxiety" (n = 124), "activity" (n = 97), and "computer" (n = 92). The keywords with the highest links are "teaching" (n = 82), "activity" (n = 75), "learner" (n = 74), and "curriculum" (n = 67). The items with the highest link strength are "math anxiety" (n = 1,175), "anxiety" (n = 1,009), "learner" (n = 910), and "self-efficacy" (n = 692).

The co-occurrences of the keywords are illustrated in the network visualization in Figure 2, where 6 clusters can be seen. The dimension of the circles and the texts within them represent the strength of their co-occurrence with other keywords; the distance of the items and the lines show the relatedness and linkages of the keywords respectively.

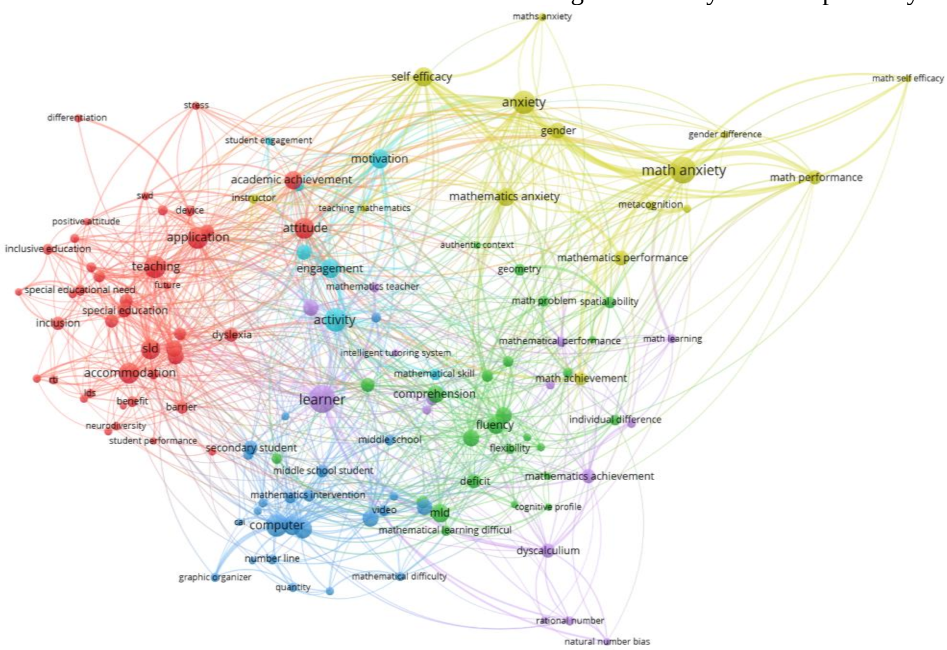

Figure 2
Network visualization

Keywords in each cluster were examined to establish the thematic distinction of the cluster based on the topic.

Cluster 1 (color red) is commonly related to barriers (e.g., “barrier”, “dyslexia”, “SLD” [Specific Learning Disability]) and different kinds of digital technology and frameworks that address barriers (e.g., “device”, “ICT” [Information Communication Technology], “inclusion”, “augmented reality”, “universal design”). The most common keywords are “teaching” (n = 91), “application” (n = 85), “accommodation” (n = 79), and “attitude” (n = 75).

Cluster 2 (color green) is related to cognitive processes (e.g., “cognitive skill”, “cognitive profile”), psychological processes (e.g., “memory”, “spatial ability”) and mathematical (dis)abilities (e.g., “MLD” [Math Learning Difficulties], “number sense”, “numerical cognition”). The most common keywords are “MLD” (n = 59), “fluency” (n = 56), “memory” (n = 52), and “reasoning” (n = 52).

Cluster 3 (color blue) is related to mathematics contents (e.g., “number line”, “quantity”, “fraction”, “functional relation”) and digital and non-digital resources that supports representation of mathematical concepts (e.g., “computer”, “representation”, “number line estimation”, “video”, “synthesis”, “virtual manipulative”, “graphic organizer”). The most common items are “computer” (n = 92), “fraction” (n = 67), “word problem” (n = 63), and “mathematics difficulty” (n = 50).

Cluster 4 (color yellow) relates to mathematics self-beliefs (e.g., “math self-efficacy” “self-efficacy”), achievements (e.g., “math achievement”, “math performance”), and factors related to achievements (e.g., “math anxiety”, “test anxiety”, “gender difference”). The most common keywords are “math anxiety” (n = 124), “anxiety” (n = 85), “self-efficacy” (n = 64), and “mathematics anxiety” (n = 58).

Cluster 5 (color violet) relates to the learning (e.g., “math learning”, “natural number bias”, “dragonbox” [a software used in math education]) and teaching of mathematics (e.g., “mathematics teaching”, “intelligent tutoring system”). The most common items are “learner” (n = 131), “belief” (n = 44), “dyscalculium” (n = 35), and mathematics achievement (n = 35).

Cluster 6 (color light blue) relates to the affinity to mathematics and the willingness to learn it (e.g., “activity”, “motivation”, “engagement”, “interest”). The most common keywords were “activity” (n = 97), “motivation” (n = 68), “engagement” (n = 64), and “interest” (n = 40).

Additionally, in Figure 3 we show the overlay visualization of the results, where results are colored based on the year of publication. As noticed, the most recent papers (published in 2022 or later) included terms related to cognitive and psychological factors associated with the learning of mathematics, namely “stress” (M = 2021.71), “belief” (M = 2021.77), “self-efficacy” (M = 2021.81); “math anxiety” (M = 2022.00); “neurodiversity” (M = 2022.46), and “math self-efficacy” (M = 2022.73), or new pieces of technology, e.g. “augmented reality” (M = 2022.07), and “dragonbox” (M = 2023.00). Older papers regarded classical pieces of technology, as “computer” (M =

2016.38), “assistive technology” (M = 2016.36), and “graphic organizer” (M = 2016.50), and learning disorders, such as “lds” (M = 2013.94).

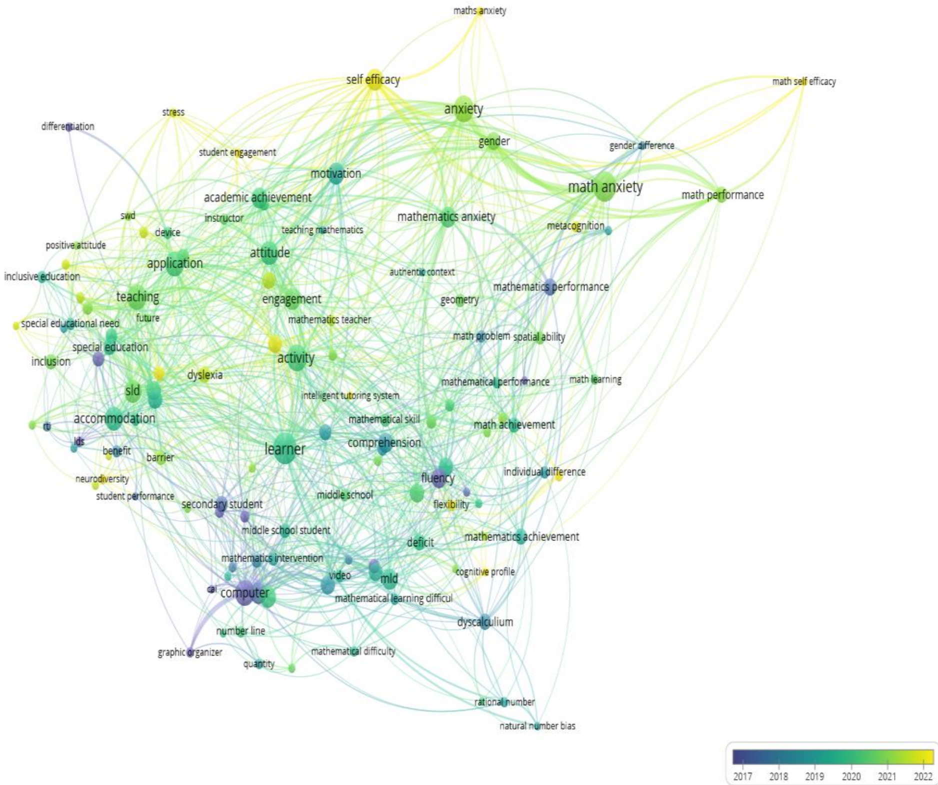

Figure 3
Overall visualization

DISCUSSION AND CONCLUSIONS

AT plays a pivotal role in supporting students with MD, enhancing their educational experiences and outcomes (Bryant et al., 2014; Perelmutter et al., 2017; Thapliyal & Ahuja, 2023). As the field of AT continues to evolve, there is a growing need to understand the trends, key contributors, and factors influencing the adoption and usage of these technologies. While previous research has explored various aspects of AT, there is limited comprehensive analysis of the global contributions, influential authors, and the changing patterns in AT usage over time. This study aimed to fill this gap by investigating several critical questions related to the field of AT and MD. Specifically, we seek to identify which countries or regions are leading in research output, the most prolific and cited authors, the most commonly used ATs by students with MD, the evolution of AT usage trends, and the factors associated with the adoption of AT in educational settings. By answering these questions, we aim to provide a clearer picture of the current landscape of AT for students with MD, offering valuable insights for researchers, educators, and policymakers working to improve educational practices and outcomes for this population.

Before addressing our research questions, it is important to highlight that the number of publications in the field of MD and AT has been rapidly increasing. Notably, an analysis of the distribution of publications over the last five years reveals that more than half of the papers were published between 2020 and 2024. Similar trends have been observed in other studies (cf. Chen et al., 2021; Karakus et al., 2019; Sinha et al., 2024). It is also important to note that the 2024 papers included in this research were only those published in January, so the total number of publications is expected to increase. These findings align with expectations and reflect the rapid pace of technological development, which recently includes the use of virtual reality (cf. Castro et al., 2014) and artificial intelligence (cf. Bhatti et al., 2024) to enhance the learning of mathematics among students with MD.

Regarding the country or geographic region that has produced the highest number of papers in the field of AT and MD, our research indicates that the United States leads in the number of publications, followed by the United Kingdom. However, when considering broader geographic macroregions, European authors produced nearly half of the papers in the field, followed by Asian authors, who collectively contributed almost a third of all publications. It was also observed that several geographic regions, such as Africa, South America, and Oceania, were underrepresented. Similar findings have been reported in studies on AT for people with disabilities (Chiew et al., 2024) and special needs (Omar & Ali, 2022). Moreover, clustering analysis revealed a strong connection between authors from countries with similar socio-economic and cultural backgrounds.

In terms of individual authorship, two researchers stand out for having the highest number of published papers in the field: Sarah R. Powell and Korbinian Moeller, each with eight publications. Sarah R. Powell also holds the distinction of having the highest number of citations (368). When considering link strength, the top authors were Sara E. Brownell (n = 5), Anya S. Evmenova (n = 5), and Logan E. Gin (n = 5).

Regarding the AT used by students with Multiple Disabilities (MulD), recent trends indicate that augmented reality and smartphone applications have become the most commonly used tools. Prior to 2020, computers, graphic organizers, and video-assisted learning were more prevalent. This shift in AT preferences reflects a growing interest in innovative and modern technological tools. In recent years, the use of smartphones and specialized applications to enhance students' mathematics knowledge has increased significantly (Bringula & Atienza, 2023; Weigand et al., 2024), with tools such as "Dragonbox" (Harrison & Lee, 2018) becoming popular. Additionally, the adoption of artificial and virtual reality (Cevikbas et al., 2023) has risen, indicating a current trend toward more sophisticated technological methods.

As for the factors associated with the use of AT among students with MD, cluster analysis reveals that AT usage is strongly linked to overcoming barriers and promoting inclusion (Fernández-Batanero et al., 2022). Furthermore, AT enhances cognitive processes (domain-general abilities) by assisting students with arithmetic and number fluency (Thapliyal & Ahuja, 2023), memory (Ok et al., 2020), and reasoning (Thapliyal & Ahuja, 2023). Specific tools, such as computers, number lines, videos, and virtual manipulatives, support the domain-specific abilities such as representation of mathematical concepts, enabling students to master various mathematical topics, including quantities, fractions, and functions (cf. Shin et al., 2021). Moreover, the use of AT fosters students' self-beliefs in mathematics, such as self-efficacy (Benavides-Varela et al., 2020), and improves their performance while reducing levels of mathematics and test anxiety (Nelson et al., 2022). By incorporating AT, students develop a greater affinity for mathematics and are more motivated and engaged in learning, which enhances their overall interest in the subject (Fernández-Batanero et al., 2022).

Overall, the results indicate that analyzed papers addressed DT in correlation with dyscalculia or math disabilities in a narrower sense, namely by using digital technologies for learning purposes or overcoming barriers. The barriers, such as difficulties in learning (basic) mathematical concepts because of the underlying specific learning disabilities, may be overcome with introducing digital technologies in teaching mathematics. This is consistent with the previous work that suggests digital technologies have beneficial effects on students with MD learning of mathematics (Dhingra et al., 2024; Miundy et al., 2017; Poobrasert & Gestubtim, 2013). Moreover, Artificial Intelligence facilitates the customizations of the task to students' cognitive needs (Dutt et al., 2022; Miundy et al., 2017), which is of crucial importance when taking into account the heterogeneity of educational needs for support of students with MD (Reid et al., 2013). On the other hand, augmented reality provides the experience of manipulating with object in virtual space (Miundy et al., 2017). Its importance in contribution to students' motivation and enjoyment of mathematical lessons is also recognized (Ahuja et al., 2022), considering the fact that students with learning disabilities (what MD is) often perceived themselves as learned-helpless (Gindrich, 2021) or unable to control the task when dealing with demanding problem-solving situations (Gacek, Smoleń & Pilecka, 2017). Furthermore, the co-occurrence analysis showed the existing relationship between mathematic contents and (digital) technologies that support learning those contents. The importance of DT is very well-known in supporting students with learning disabilities or MD. Namely, midtech products, especially digital tools and resources are used by students with dyscalculia in the learning process (Dhingra et al., 2024; Thapliyal & Ahuja, 2023).

The findings contribute a clearer understanding of the relationship between MD and the DT. While previous research has focused more on classical pieces of DT in relation with MD or learning disabilities, these results show that the recent papers are more focused on new DT, such as augmented reality. The latter suggests that further research is needed to establish the impact of new DT on supporting students with MD in different areas, such as basic mathematical facts, procedural competencies, and problem-solving.

LIMITATIONS

The present research comes with some limitations. Firstly, our study exclusively relied on papers indexed in Scopus and WoS, potentially excluding relevant research published in other databases or non-indexed sources. This limitation might have led to a partial representation of the literature available on the role of digital technologies in dyscalculia. Additionally, the search criteria and keywords employed might have inadvertently omitted pertinent studies, thus limiting the comprehensiveness of our review. Furthermore, as with any bibliographic analysis, the quality and rigor of the studies varied, which could impact the overall validity of our findings. Furthermore, the dynamic nature of technological advancements means that newer studies or emerging technologies may not have been captured in our search, thereby potentially overlooking recent developments in this field. These limitations underscore the need for future research to adopt a more expansive approach, encompassing diverse databases and methodologies to provide a comprehensive understanding of the topic.

The predominance of studies originating from the Global North in our bibliographic research on digital technologies in mathematics learning disabilities highlights several noteworthy implications and suggests potential avenues for future exploration. For instance, only one study from South America (namely, Chile), and one from Africa (namely, South Africa) were found by bibliometric research. Firstly, this geographic bias underscores the need for greater inclusivity and diversity in research endeavors. By predominantly focusing on regions from the Global North, there is a risk of neglecting the unique challenges and contextual factors shaping the experiences of individuals with mathematics learning disabilities in other parts of the world. Future research should strive to incorporate perspectives from a more diverse range of geographical locations to ensure a more holistic understanding of the subject matter. Furthermore, the overrepresentation of studies from the Global North may perpetuate disparities in access to resources and interventions for individuals with mathematics learning disabilities in other regions. It is crucial for researchers, policymakers, and practitioners to recognize and address these disparities to ensure equitable access to effective educational technologies and interventions worldwide.

In terms of future directions, efforts should be made to foster international collaboration and knowledge exchange in the field of mathematics learning disabilities and digital technologies. This could involve initiatives such as joint research projects, cross-cultural studies, and the adaptation of interventions to suit diverse cultural and linguistic contexts. Additionally, there is a pressing need for more research that specifically examines the effectiveness of digital technologies in addressing mathematics learning disabilities in underrepresented regions. This could involve conducting empirical studies, developing culturally sensitive interventions, and exploring the impact of socioeconomic factors on the implementation of digital technologies in educational settings.

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APPENDIX A

Due to over-generality and unsuitability, some terms were removed from the analysis, i.e.: school closure, cbgo, self advocacy, schema, word reading, expert, sentence, higher level, composition, girl, fifth grade student, dhh, chapter, boy, spelling, cognitive neuroscience, pandemic, turkey, semi, estimation, content analysis, pre service teacher, posttest, college, school year, covid, period, medium, note, high level, reading comprehension, autism, ebd, writing, word, mother, course, majority, systematic review, speed, elementary student, interview, higher education, autism spectrum disorder, career, right, step, phase, recommendation, asd, adhd, error, male, pretest, intellectual disability, healthy child, prevalence, publication, attention deficit hyperactivity disorder, framework, insight, college student, magnitude, element, trait anxiety, validation, month, female, peer, item, university, methodology, experimental study, young child, effect size, correlation, author, observation, beginning, issue, world, article, example, longitudinal study, challenge, measurement, parent, account, quality, suggestion, expectation, english, experience, person, perception, respect, survey, relevance, strength, meta analysis, min, struggle, trend, previous study, relation, case study, end, topic, grade level, light, rate, kindergarten, mechanism, adulthood, half, hand, feature, predictor, lesson, association, reading, home, experimental group, intervention study, session, variance, diagnosis, identification, possibility, dimension, importance, relationship, control group, time, current study, grade, children, age, child, task.

APPENDIX B

Item	Occurrence	Cluster	Links	Total link strength
Academic achievement	60	1	51	312
Academic performance	23	6	27	158
Accommodation	79	1	45	313
Active learning	14	1	11	93
Activity	97	6	75	596
Advanced mathematics	10	2	13	56
Anxiety	85	4	63	1,009
Application	85	1	64	397
Assistive technology	31	1	25	132
Attitude	75	1	54	539
Augmented reality	27	1	33	162
Authentic context	10	2	13	60
Barrier	26	1	49	218
Belief	44	5	54	371
Benefit	22	1	55	135
CAI	10	3	9	48
Calculation	25	5	40	156
Cognitive ability	23	2	36	176
Cognitive profile	10	2	16	86
Cognitive skill	11	2	17	88
Comprehension	44	2	42	265
Computer	92	3	60	430
Conceptual understanding	14	1	33	90
Curriculum	48	1	67	323
Deficit	37	2	46	250
Definition	22	2	33	130
Device	21	1	35	147
Differentiation	13	1	6	50
Dragonbox	15	5	8	111
Dyscalculium	35	5	36	328
Dyslexia	37	1	34	214
Educator	48	1	60	245
Engagement	64	6	52	392
Engineering	22	1	58	192
Executive function	12	2	33	117
Explicit instruction	22	3	36	99

Flexibility	18	2	21	135
Fluency	56	2	39	239
Fraction	67	3	47	315
Fraction concept	10	3	25	82
Functional relation	12	3	26	90
Future	11	1	27	73
Gender	44	4	56	510
Gender difference	11	4	16	167
Geometry	25	2	25	146
Graphic organizer	16	3	16	122
High school	31	1	40	181
ICT	14	1	26	83
IEP	10	1	8	12
Inclusion	32	1	42	147
Inclusive education	22	1	22	134
Individual difference	22	2	35	155
Instructional strategy	16	3	31	103
Instructor	19	4	31	199
Intelligent tutoring system	11	5	12	36
Interest	40	6	37	232
LDS	16	1	13	66
Learner	131	5	74	910
Learning process	26	1	39	202
Math achievement	34	4	32	271
Math anxiety	124	4	50	1,175
Math learning	17	5	28	182
Math performance	35	4	32	477
Math problem	22	2	37	181
Math self-efficacy	11	4	6	135
Mathematical achievement	26	2	34	262
Mathematical difficulty	16	3	23	113
Mathematical learning	16	5	35	117
Mathematical learning difficulty	20	2	31	151
Mathematical performance	19	5	40	203
Mathematical problem	18	3	38	115
Mathematical skill	26	6	41	242
Mathematics achievement	35	5	43	216
Mathematics anxiety	58	4	37	433
Mathematics difficulty	50	3	49	372
Mathematics education	38	2	46	234
Mathematics intervention	26	3	39	150
Mathematics performance	42	4	39	270
Mathematics teacher	18	5	31	153
Maths anxiety	14	4	9	96
Memory	52	2	59	376
Metacognition	18	4	26	128
Middle school	22	3	29	85
Middle school student	27	3	55	194
MLD	59	2	45	360
Motivation	68	6	48	529

Multiplication	13	3	27	92
Natural number	11	5	7	35
Natural number bias	10	5	7	84
Neurodiversity	13	1	9	60
Number line	19	3	20	84
Number line estimation	12	3	16	85
Number sense	27	2	19	57
Numerical cognition	12	2	14	46
Positive attitude	11	1	26	96
Positive effect	12	3	29	85
Quantity	16	3	24	85
Rational number	17	5	16	117
Reasoning	52	2	63	309
Representation	43	3	59	246
RTI	16	1	14	56
Science education	20	1	23	114
Secondary school student	15	5	34	85
Secondary student	37	3	45	184
Self-efficacy	64	4	37	692
SEN	11	1	10	81
SLD	70	1	55	476
Spatial ability	24	2	22	215
Special education	36	1	40	179
Special education teacher	18	1	31	172
Special Educational need	23	1	37	150
Special need	17	1	24	154
Specific learning disability	14	1	30	98
STEM	34	1	42	267
Stress	14	1	18	124
Student engagement	13	6	17	69
Student performance	11	1	25	66
SWD	13	1	13	76
Synthesis	24	3	28	143
Teaching	91	1	82	539
Teaching mathematics	10	4	26	106
Test anxiety	14	4	17	129
Universal design	12	1	24	59
Video	21	3	26	97
Virtual manipulative	13	3	22	86
Visualization	10	2	15	82
Word problem	63	3	48	327
Working memory	18	2	38	136