Available online at www.ijournalse.org

Emerging Science Journal

(ISSN: 2610-9182)

Vol. 9, No. 6, December, 2025

Review Article

The Use of Eye-Tracking Technology in Mathematics Education: A Mapping Study with Bibliometric Analysis

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Abstract

This study aims to identify trends, domains, and research topics of eye-tracking methodology in mathematics education published in Scopus-indexed journals. A systematic mapping study with bibliometric was employed to investigate the field. The analysis identified 119 eye-tracking studies in mathematics education published between 2013 and 2023, reflecting fluctuating publication trends. In this period, 333 authors, 78 sources, 156 organizations, and 38 countries contributed to the field. Schindler authored the most documents, while Germany and the United States recorded the highest output. The most cited work was by Cortina et al., and the International Journal of Science and Mathematics Education was the most frequently cited journal. Collaborations analysis identified Brockmole and Hannula as the most collaborative authors, and the University of Helsinki as the most active institution. Topic and domain analysis showed that the studies primarily focused on numbers and arithmetic, problem-solving, reasoning, individual differences, mathematical anxiety, creativity, mathematical representation, multimedia in learning, embodied cognition, mathematics learning, learning difficulties, geometry, and preschool mathematics. The findings suggest that several mathematical domains remain underexplored, offering opportunities for further eye-tracking research in mathematics education.

Keywords:

Eye-Tracking;

Mathematics Education;

Bibliometric.

Article History:

Received:	21	July	2025
Revised:	26	October	2025
Accepted:	03	November	2025
Published:	01	December	2025

1- Introduction

Eye-tracking technology has gained increasing use in educational research in recent years. It is considered a valuable tool, particularly for studying visually presented cognitive tasks [1], as eye movements are associated with cognitive processes. Moreover, the link between cognitive processes and eye movements is grounded in the eye-mind hypothesis proposed by Just & Carpenter [2]. This hypothesis posits that what individuals see corresponds to what they think. Which may explain the wide application of eye-tracking across disciplines [3, 4], including mathematics education [5–9]. Eye tracking is widely used in mathematics research to examine cognitive and affective processes, track attention, and identify intentions without disrupting learning, problem-solving, or instruction [10]. It reveals cognitive processes more effectively than verbal reports [11, 12]. Eye tracking is advantageous as it evaluates processes rather than outcomes,

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DOI: http://dx.doi.org/10.28991/ESJ-2025-09-06-029

examines the link between reading and mathematical cognition, and uncovers cognitive processes that individuals cannot consciously report [4]. Despite its advantages, researchers in mathematics education face several challenges, including: (1) the need to monitor studies outside their domain, as similar methodologies may be applied for different purposes; (2) addressing new considerations in data collection and interpretation, which generate large volumes of data; (3) the need for researchers to possess advanced knowledge of eye tracking; and (4) the requirement for unique expertise to understand eye tracking processes in mathematics, as the domain employs distinct forms of text, symbols, visualizations, and representations [4].

Eye-tracking studies can provide valuable insights into students' attention and focus as they construct mathematical representations of abstract concepts [4]. Moreover, eye movement analysis enables examination of students' ability to shift between different representations of mathematical objects. In this context, eye tracking can examine how students learn and process information while solving mathematical problems, as their focus is closely tied to visual perception [5]. Several studies have demonstrated that eye tracking can identify learning difficulties [13, 14], mathematical anxiety [15, 16], problem-solving [17–19], and mathematical representation [20–22]. Recent applications include studies on children's arithmetic cognition [23], teacher-student interactions in learning and problem-solving [24], and the cognitive processes involved in mathematical problem posing [25]. This underscores the importance of eye-tracking in mathematics education. Consolidating existing literature is therefore essential to identify dominant trends, main themes, recurring patterns, and potential opportunities to advance the field in a more focused and sustainable way.

Further literature review on eye tracking is essential to strengthen its relevance in mathematics education. Our search found that several researchers have conducted reviews of eye tracking in this field [4, 8, 11, 26–29]. Strohmaier et al. [4] reviewed eye-tracking methodology in mathematics education from 1921 to 2018, using data from Scopus, Web of Science, ERIC, ScienceDirect, PsycARTICLES, Education Source, and MathEduc. Mock et al. [8] reviewed 45 studies on numerical cognition. Almfjord & Hallberg [11] synthesized 11 studies on mathematical difficulties published between 2002 and 2020 from PubMed, PsycNet, and LUBsearch. Perttula [26] reviewed 28 studies on mathematical representation [26]. Lilienthal & Schindler [27] reviewed 33 studies in proceedings from PME-34 to PME-42. Paskovske & Kliziene reviewed [28] 17 studies on children's mathematics education from Scopus, Web of Science, ScienceDirect, and ERIC. More recently, Schindler et al. [29] synthesized 116 eye-tracking studies in mathematics and statistics education, offering an updated view of methodological advances and future directions.

Existing reviews highlight the growing interest in eye tracking research in mathematics education, each offering insights into specific subfields such as numerical cognition, mathematical representation, and learning disabilities. However, the rapid growth of eye tracking studies highlights emerging topics and a broader range of research themes. This underscores the need for approaches that capture research dynamics more comprehensively and quantitatively. One such approach is bibliometric analysis, a systematic method for reviewing scientific literature to uncover patterns, trends, and impacts within a specific field [30, 31]. The process typically involves several stages: collecting data from relevant databases, cleaning and refining the dataset, and applying bibliometric techniques to generate insights that support research decision-making. In this context, bibliometrics serves as a valuable tool for examining the development and dynamics of scientific literature [31, 32], as it enables researchers to analyze large volumes of data, draw in-depth conclusions, and identify the most influential studies [33]. Bibliometric analysis facilitates a comprehensive and systematic understanding of research trends, collaborations among authors and institutions, influential journals, and the emergence or evolution of research themes. To date, no comprehensive bibliometric analysis has been conducted on eye tracking in mathematics education. Therefore, this study seeks to fill this gap by conducting a bibliometric analysis to provide an overview of the field.

This study aims to explore and identify research trends and themes covering several aspects: publication trends, author collaborations, citations, most influential journals, collaborating institutions, author country statistics, author keywords, domains, and mathematical topics explored using eye tracking. The findings will provide a comprehensive picture of the current research landscape, including identifying key themes, the most influential study contributions, and topics that remain open and promising for further exploration. By providing this perspective, this study aims to highlight significant research gaps and suggest promising directions. Furthermore, the analysis can serve as a strategic guide for researchers to position their studies, pursue new areas, and avoid duplication. The following research questions (RQ) were established to achieve the aim of this study:

- RQ1: What is the distribution of publication trends on the use of eye tracking in mathematics education research based on year, document type, author, sources, organizations, and countries in 2013-2023?
- RQ2: What domains and topics were used in mathematics education research with eye tracking from 2013 to 2023?

Through this bibliometric analysis, we aim to offer retrospective and prospective insights into the research trajectory of eye-tracking in mathematics education, including its recent progress and existing gaps. RQ1 aims to uncover research trends on eye-tracking in mathematics education by year, document type, author, source, organization, and country. It aims to identify the most productive authors, institutions, and countries in this field. In addition, this study identifies the sources most frequently utilized by researchers for their publications. Additionally, citations were considered to uncover important publications and future opportunities. Furthermore, RQ2 investigates the domains and topics of research on eye-tracking in mathematics education. This question analyses keyword associations to identify frequently studied domains and topics, as well as gaps that require further investigation. Collectively, this study is expected to provide insightful guidance and recommendations for advancing knowledge and directing future research in this field.

The structure of this paper comprises five main sections. The methodology section outlines the research design to ensure transparency in the study's conduct. The bibliometric results section presents the primary outcomes of the analysis, including publication trends, influential authors, highly cited works, collaborative networks, and thematic clusters in eye tracking in mathematics education. The discussion section interprets these results in relation to existing literature, emphasizing theoretical and practical implications while identifying gaps and opportunities for future research. Finally, the conclusion summarizes key findings, suggests directions for future research, and acknowledges the study's limitations.

2- Method

A systematic mapping study with a bibliometric design was employed to achieve the research aims. Bibliometric analysis was used to provide an overview of current studies on eye-tracking research in mathematics education. The research followed four stages: (1) defining the scope and objectives of the bibliometric study, (2) selecting bibliometric techniques, (3) searching and collecting data, and (4) conducting the analysis and reporting the findings [34].

2-1- Determine The Scope and Objectives of the Bibliometric Study

The scope of this research is limited to studies on the use of eye-tracking in mathematics education. The research objectives were presented previously in the introduction.

2-2- Select the Techniques for Bibliometric Analysis

The data analysis employed both descriptive methods and a comprehensive bibliometric analysis. Descriptive analysis method was used to examine the number of articles by years and document type. In the bibliometric analysis, a thorough co-authorship analysis was conducted, providing a comprehensive picture of collaboration in writing articles (author, institution, country). Citation analysis was conducted to show citation counts by document, author, institution, journal, and country. Co-occurrence analysis visualized keyword networks, with a number of co-occurrences indicating the frequency of keywords appearing together. The results were then mapped into several domains and topics based on keywords and clusters. In the counting method, complete counting was applied to assign each author a total weight score [35].

2-3- Search and Collect the Data

This research used the Scopus database through Publish or Perish (PoP) software. Scopus offers extensive global and regional coverage of scientific journals, conference proceedings, and scientific books, and is recognized for its best quality and rigorous selection process [36]. For this reason, Scopus was selected as the sole database. Titles and abstracts of each paper were reviewed before determining inclusion. Furthermore, inclusion and exclusion criteria were applied. The inclusion criteria were: (1) studies focusing on the use of eye tracking in mathematics education, (2) studies published between 2013 and 2023, and (3) studies written in English. A study was excluded if it met at least one of the following exclusion criteria: (1) the study presents material that has not been peer-reviewed, (2) written in a language other than English, (3) full-text access unavailable; (4) duplicate publication; and (5) published as a report.

The search process was systematically conducted to identify primary studies within the scope of eye tracking in mathematics education. The search was conducted on 18 November 2023. To construct the search string, we carefully identified relevant keywords. The search formula was: (eye OR gaze) AND (tracking* OR movement*) AND (math* OR "mathematical thinking" OR "numerical cognition"). The article selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) steps [37], as shown in Figure 1.

An initial keyword search in the database obtained 1482 articles. The identification results showed no duplicate, and screening was also conducted concurrently. During screening, 1356 articles were excluded for not aligning with the research objectives. After verification of the remaining 126 articles, 119 were deemed suitable, while seven were excluded for being written in languages other than English. Thus, 119 articles were included at this stage as they met the specified criteria.

2-4- Bibliometric Analysis and Report the Findings

We utilized the VOSviewer application, known for its clarity and precision, to conduct bibliometric analysis and visualize the results. VOSviewer (version 1.6.18) enables various analyses and visualizations of relationships among authors, journals, institutions, countries, and keywords [38, 39]. It was applied to nodes representing research items of interest, namely authors, institutions, countries, journals, and key terms. The relationship between two nodes indicates their connection, and the overall strength of these connections, expressed as a numerical value, is referred to as total link strength (TLS).

Furthermore, the nodes and links formed clusters on the bibliometric map. These clusters were based on the strength of relationships between nodes. Nodes with more links were grouped into clusters, each representing a distinct research area or a set of closely related items. Node size indicated the item's frequency of appearance, node color represented the network, line thickness displayed the strength of relationships, and distance between points indicated item relatedness [40]. Nodes with stronger associations were grouped into clusters [39, 41].

The synthesis of the bibliometric analysis represents the culmination of the mapping process, integrating patterns, trends, and key metrics to address the research questions. These synthesized findings are systematically presented in the results and discussion sections.

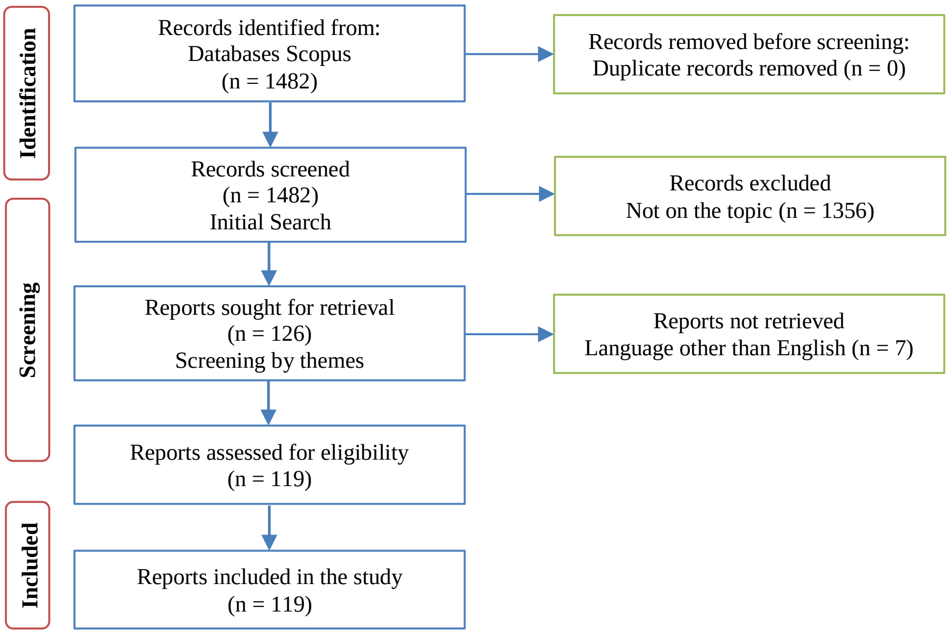

Figure 1. PRISMA flow diagram

3- Results

3-1- Publication Distribution Every Year

This study selected articles from the Scopus database based on inclusion and exclusion criteria. A total of 119 publications were identified during 2013–2023. The distribution of article publications is illustrated in Figure 2.

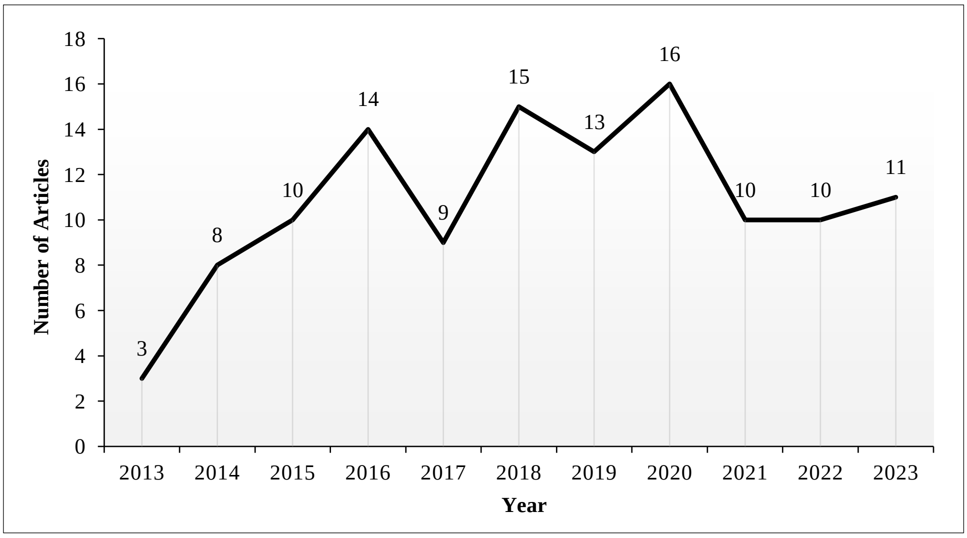

Figure 2. Distribution of article publications per year (n = 119)

Figure 2 shows an increase in studies on eye tracking from 2013 to 2016. However, publication numbers declined in 2016–2017, 2018–2019, and 2020–2021. In 2017, publications decreased by five compared to 2016, and in 2019, they fell by six compared to 2018. The highest number of publications was recorded in 2020, with 16 articles.

3-2- Distribution of Publications Based on Documents

The eye-tracking study in mathematics education retrieved from the Scopus database comprised five types of publications. As shown in Figure 3, most were articles, (88; 73.95%), followed by 25 conference papers (21.01%), three reviews (2.52%), two book chapters (1.68%), and one data paper (0.84%).

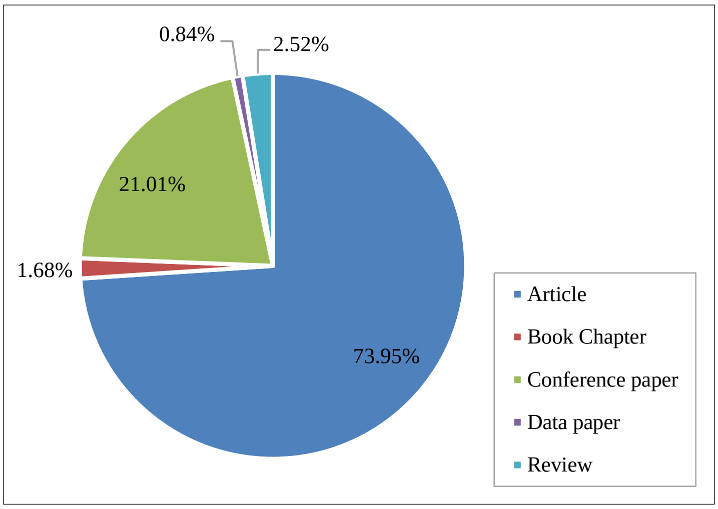

Figure 3. Distribution of publications by document

Furthermore, citation analysis was conducted to identify the most cited authors in the relevant literature. Table 1 presents the top 10 most cited documents (author and year of publication) in eye-tracking research in mathematics education.

Table 1. The distribution of the top 10 most cited studies

Rank	Authors	Year	Citations
1	Cortina et al. [42]	2015	77
2	Susac et al. [43]	2014	75
3	Schindler & Lilienthal [9]	2019	57
4	Wakefield et al. [44]	2018	49
5	Andrá et al. [5]	2015	46
6	Abrahamson et al. [45]	2016	46
7	Molina et al. [46]	2018	43
8	Obersteiner & Tumpek [1]	2016	41
9	Hurst & Cordes [47]	2016	40
10	Hartmann et al. [48]	2016	40

Table 1 illustrates that the article by Cortina et al. [42] is the most cited, with 77 citations. It is followed by Susac et al. [43] with 75 citations, Schindler & Lilienthal [9] with 57 citations, Wakefield et al. [44] with 49 citations, Andrá et al. [5] and Abrahamson et al. [45] with 46 citations, Molina et al. [46] with 43 citations, Obersteiner & Tumpek [1] with 41 citations, and Hurst & Cordes [47] and Hartmann et al. [48] with 40 citations. These high citation counts indicate the significant influence of these studies, either through methodological innovation or conceptual advancement. For instance, Cortina et al. [42] used mobile eye tracking to analyze classroom interactions in mathematics learning and found that experienced teachers were more effective than student teachers in classroom monitoring.

3-3- Distribution of Publications Based on Author

We used VOSviewer co-authorship analysis to examine author collaborations in the relevant literature. The analysis showed that 333 authors contributed to eye-tracking research in mathematics education. Table 2 presents the distribution of authors and co-authorship groups with at least two documents and their corresponding citation counts.

Table 2. **Authors and co-authorship groups with at least two documents**

Rank	Authors	Documents	Citations
1	Potgieter & Blignaut [49–52]	4	4
2	Schindler & Lilienthal [9, 12, 53]	3	78
3	da Silvab Soares et al. [54, 55]	2	5
4	Norqvist et al. [56, 57]	2	5
5	Kim et al. [17, 58]	2	6
6	Shvarts et al. [59, 60]	2	19
7	Hartmann [7, 61]	2	30
8	Shvarts & Abrahamson [62, 63]	2	36

The authors and co-authorship groups with the most eye-tracking research documents in mathematics education are Potgieter & Blignaut [49-52] with four documents (number of citations, NC = 4). They are followed by Schindler & Lilienthal [9], with three documents (NC = 78). da Silvab Soares et al. [54, 55] (NC=5), Norqvist et al. (NC=5) [56, 57], Kim et al. (NC = 6) [17, 58], Shvarts et al. (NC = 19) [59, 60], Shvarts & Abrahamson (NC = 36) [62, 63], and Hartmann (NC = 30) [7, 61], each produced two documents. In the co-authorship analysis at the author level (Figure 4), Hannula et al. [64] and Brockmole et al. [65] were the most active collaborators, each working with 13 other authors. They are followed by Schindler & Lilienthal [53], who collaborated with 11 authors during the study period.

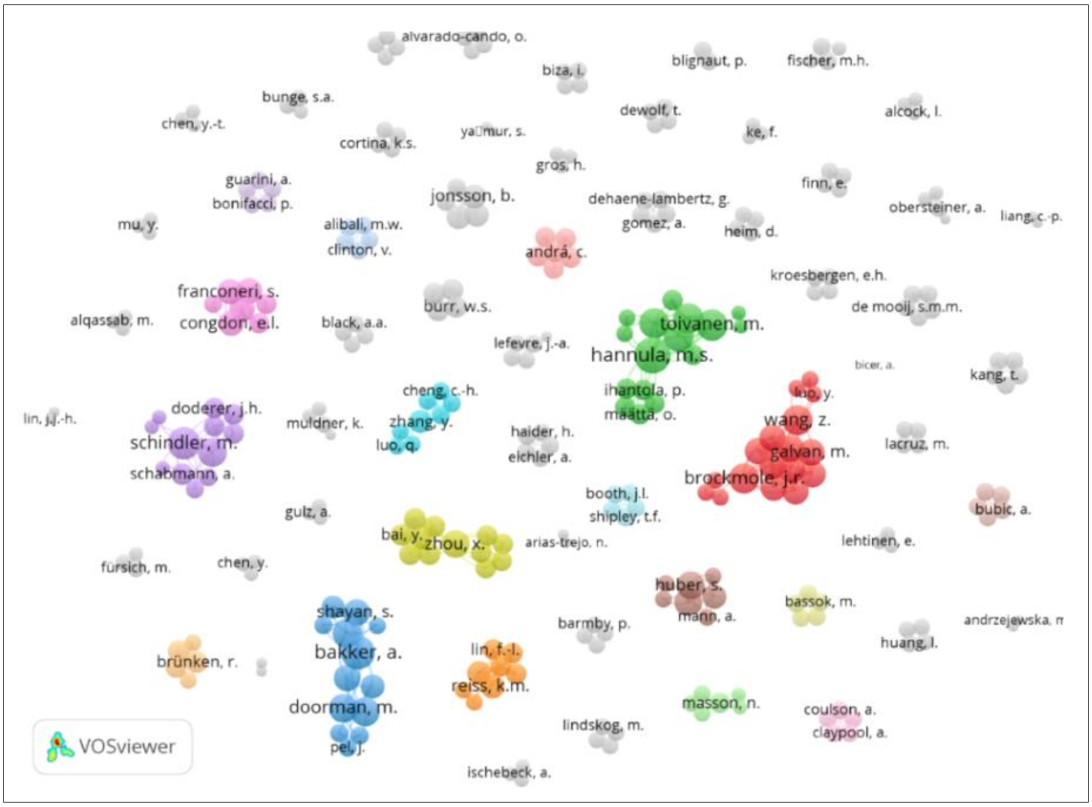

Figure 4. **Analysis of co-authors in the author unit**

Our citation analysis revealed that the most cited authors were Schindler & Lilienthal [9], with an impressive 78 citations (number of documents, ND = 3). They are followed by Cortina et al. [42] with 77 citations (ND = 1), Susac et al. [43] with 75 citations (ND = 1), Wakefield et al. [44] with 49 citations (ND = 1), Andrá et al. [5] and Abrahamson et al. [45] with 46 citations (ND = 1), Molina et al. [46] with 43 citations (ND = 1), Obersteiner & Tumpek [1] with 41 citations (ND = 1), and Hurst & Cordes [47] and Hartmann et al. [48] with 40 citations (ND = 1). The remaining authors in this category had fewer than 40 citations. Figure 5 presents a density visualization where the most cited authors are represented by the brightest areas, providing a clear depiction of their impact.

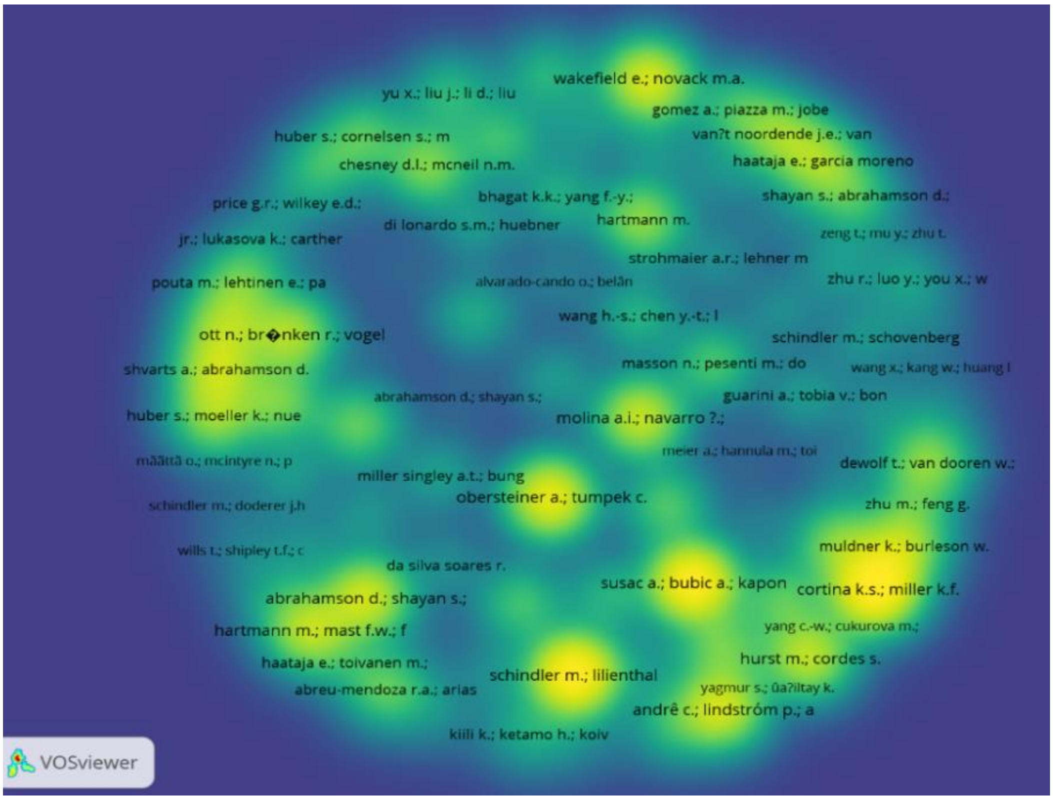

Figure 5. **Citation analysis in the author's unit**

3-4- Distribution of Publications Based on the Sources

The findings indicate that 78 sources published eye-tracking studies in mathematics from 2013 to 2023. Table 3 presents the distribution of publications by source.

Table 3. **The distribution of the top 10 sources.**

Rank	Source	Documents	Citations	Year
1	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	7	24	2014, 2017, 2018, 2020, 2022
2	International Journal of Science and Mathematics Education	6	241	2014, 2015, 2020
3	Psychological Research	6	156	2014, 2016, 2017
4	ZDM - Mathematics Education	5	57	2016, 2020, 2021, 2022
5	Quarterly Journal of Experimental Psychology	4	27	2016, 2018, 2020, 2021
6	Educational Studies in Mathematics	3	74	2019, 2021, 2023
7	Acta Psychologica	3	36	2014, 2017, 2022
8	Learning and Instruction	2	49	2018
9	Cognitive Processing	2	29	2015, 2021
10	Instructional Science	2	29	2015, 2023

Table 3 presents the top 10 journals that published the most articles on eye-tracking in mathematics education within the observed time period. Lecture Notes in Computer Science ranked first with seven publications, followed by the International Journal of Science and Mathematics Education and Psychological Research, each with six articles. Furthermore, ZDM-Mathematics Education published five articles, and the Quarterly Journal of Experimental Psychology published four articles. The next rankings are held by journals with fewer than 4 publications, Educational Studies in Mathematics (ND = 3), Acta Psychologica (ND = 3), Learning and Instruction (ND = 2), Cognitive Processing (ND = 2), and Instructional Science (ND = 2).

Based on citation counts, the International Journal of Science and Mathematics Education rank first with 241 citations, followed by Psychological Research with 156 citations, Educational Studies in Mathematics with 74 citations, and ZDM-Mathematics Education with 71 citations. Meanwhile, other journals have fewer than 50 citations. Notably, the International Journal of Science and Mathematics Education recorded the highest citations for a single article, written by Cortina et al. [42], demonstrating this study's significant impact in the field.

3-5- Distribution of Publications Based on Organizations/ Institutions

A total of 156 organizations and institutions participated in eye-tracking research in mathematics education. The bibliometric co-authorship analysis of "organizations" reveals institutional relationships. In this analysis, institutional and TLS connections were calculated. Node size was proportional to the number of publications, while the thickness represented collaboration frequency and connection strength. As shown in Figure 6, the University of Helsinki (n = 8), the University of Oslo (n = 3), the University of Oulu (n = 3), and Uppsala University (n = 3) were the most collaborative institutions.

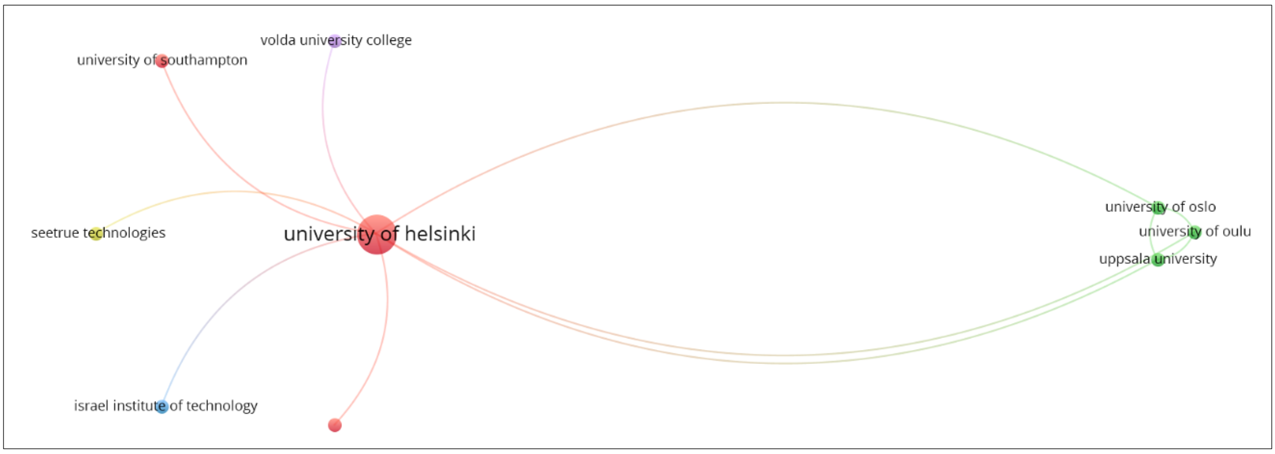

Figure 6. Co-authorship analysis for organizations

The citation analysis for organizations or universities contributing to eye-tracking research in mathematics education, as presented in Table 4, showcases the collective impact of leading institutions. Utrecht University leads with 116 citations (ND = 7), followed by the University of California with 99 citations (ND = 5), the University of Cologne with 91 citations (ND = 7), Orebro University with 84 citations (ND = 5), and the University of Michigan with 77 citations (ND = 1). The Knowledge Media Research Center has 76 citations (ND = 3), the University of Split and the University of Zagreb each have 75 citations (ND = 1), the University of Potsdam has 70 citations (ND = 3), and Eberhard Karls University has 57 citations (ND = 2). Collectively, these institutions represent a dynamic and influential community in eye-tracking research in mathematics education.

Table 4. The distribution of the top 10 Affiliates.

Rank	Affiliates	Citations	Documents
1	Utrecht University	116	7
2	University of California	99	5
3	University of Cologne	91	7
4	Orebro University	84	5
5	University of Michigan	77	1
6	Knowledge Media Research Center	76	3
7	University of Split	75	1
8	University of Zagreb	75	1
9	University of Potsdam	70	3
10	Eberhard Karls University	57	2

3-6- Distribution of Publications by Country

Co-authorship analysis at the country level shows that 38 countries published studies on eye tracking in mathematics between 2013 and 2023. Germany and the United States produced the most documents, with 24 each, followed by Finland and Sweden with 11 each; China and the Netherlands with nine each; the United Kingdom with eight; South Africa with six; and Canada and Taiwan with five each. Meanwhile, other countries contributed fewer than five documents. Figure 7 illustrates the mapping of interrelated countries based on the co-authorship analysis. The results highlight the interconnectedness of the global research community, with 18 clusters, 32 links, and a total strength of 34. The most collaborative countries were Finland (n = 7), Germany (n = 5), America (n = 5), the Netherlands (n = 4), and Sweden (n = 4).

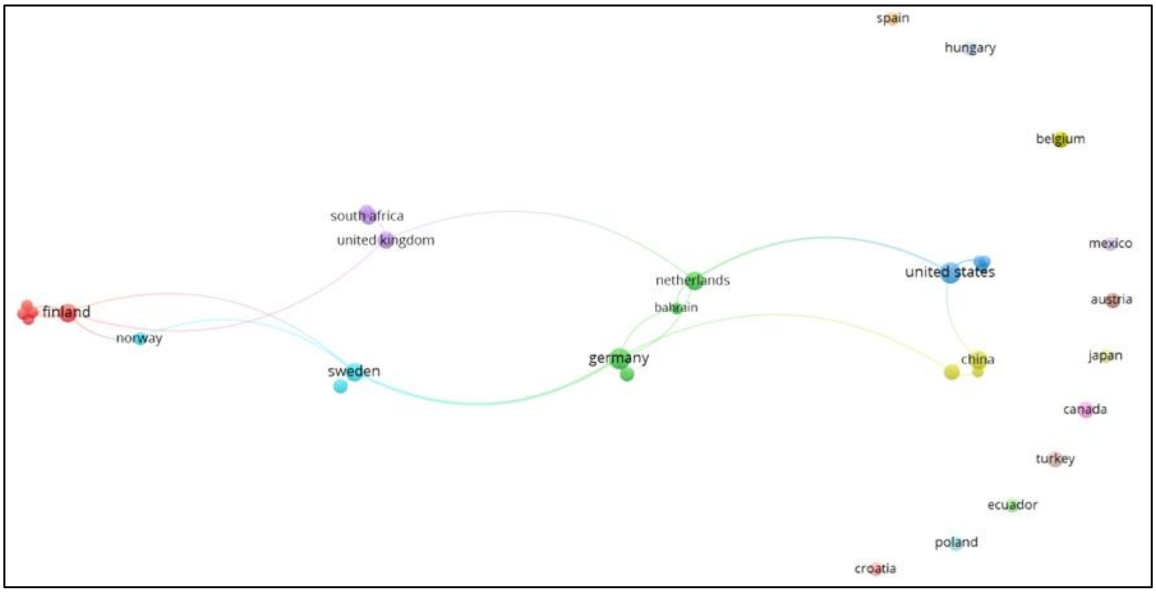

Figure 7. **Citation analysis in the author's unit**

Meanwhile, the citation analysis by country is presented in Figure 8, which includes only countries with at least 50 citations. Countries with fewer than 50 citations were excluded. The United States had the highest number of citations with 403 citations (ND = 24), followed by Germany with 399 (ND = 24), Sweden with 165 (ND = 11), and the Netherlands with 141 (ND = 9). Finland ranked next with 86 citations (ND = 11), followed by Croatia with 75 (ND = 1), the United Kingdom with 67 (ND = 8), Taiwan with 57 (ND = 5), Italy with 53 (ND = 3), and Belgium with 52 (ND = 3).

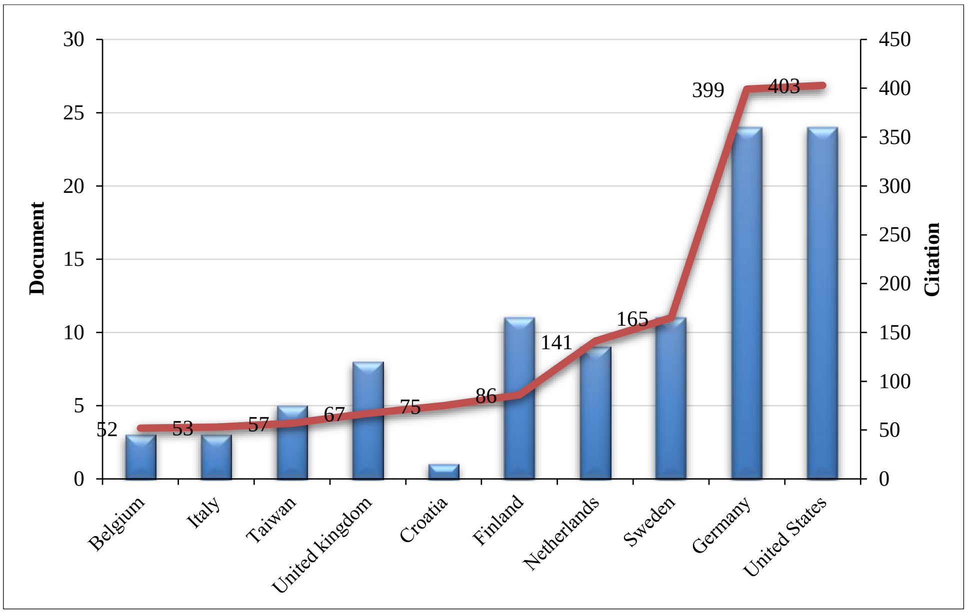

Figure 8. **Citation distribution by country**

3-7- Domain and Topic

This study employed VOSviewer co-occurrence analysis in the “authors’ keywords” area to identify the most frequently used keywords and terms in publications. A minimum threshold of two occurrences of keywords and terms was applied, resulting in 64 of the 325 most used keywords. To improve accuracy, the data were cleaned using a 'thesaurus file. To address plural/singular words (e.g., eye movements become eye movement; rational numbers become rational numbers; representations become representation), abbreviations (e.g., math becomes mathematics; math learning becomes mathematics learning; math anxiety becomes mathematics anxiety), hyphen variations (e.g., eye tracking becomes eye-tracking; collaborative problem solving becomes collaborative problem-solving; eye-movement becomes eye movement), and general or overlapping terms (e.g., fraction comparison and fraction processing into fractions; shared attention, spatial attention and split attention into attention). Irrelevant terms were also standardized (2340 cognitive processes into cognitive processes). After applying the 'thesaurus file', the number of keywords increases from 242. The ten most frequently used in publications are presented in Table 5.

Table 5. Top 10 keywords that occur most often used in publications.

Rank	Keyword	Occurrences	TLS
1	Eye tracking	71	155
2	Eye movement	19	49
3	Attention	14	39
4	Arithmetic	13	29
5	Mathematical problem-solving	12	29
6	Mathematics	10	22
7	Mathematics education	9	26
8	Mathematical word problems	8	18
9	Mathematics learning	8	21
10	Fractions	7	19

Based on the predetermined threshold, the initial analysis yielded 35 clusters with 955 links (TLS = 1070). To refine the results, the minimum cluster size was set to 7, producing 4 clusters in the primary analysis with 239 links (TLS=402). The co-occurrence map of the author's keywords is shown in Figure 9. The lines indicate the main relationships between terms, where thickness and distance represent the strength of association. Each cluster was color-coded for clarity: cluster 1 (red) with 27 items, cluster 2 (green) with 15 items, cluster 3 (blue) with 14 items, and cluster 4 (yellow) with 9 items.

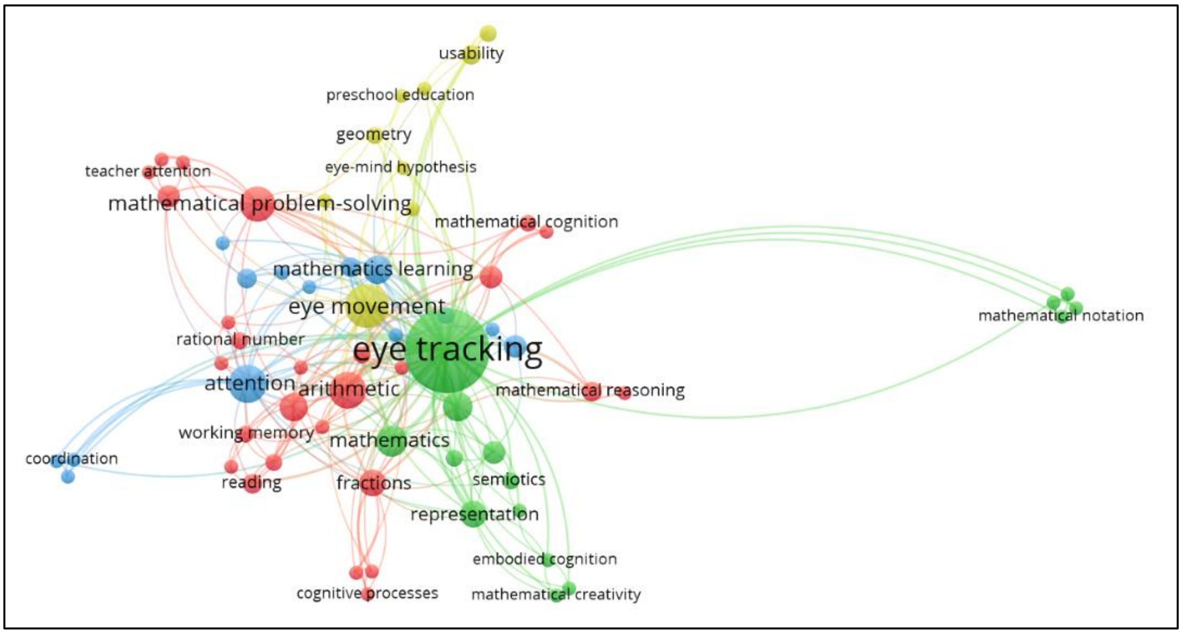

Figure 9. Co-occurrence map of authors' keywords

In a research article, several keywords are used to reflect the essence of the studied topic. As summarized in Table 5 and Figure 9, the most frequently used author's keywords with strong relationship in eye tracking research in mathematics were the term eye tracking from cluster 2, with 56 links and 71 occurrences. The second place is the term eye movement in cluster 4, with 25 links and 19 occurrences. Next, the third place is the term attention from cluster 3, with 22 links and 14 occurrences. The fourth place is occupied by arithmetic from cluster 1, with 12 links and 14 occurrences. The fifth place is mathematics problem solving from cluster 1, with 16 links and 12 occurrences. They were followed by mathematics from cluster 2, with ten links and ten occurrences. In seventh place is the term mathematics education from Cluster 2, with 17 links and nine occurrences. The eighth place is mathematics learning from cluster 3, with 14 links and eight occurrences. The ninth place is occupied by mathematical word problems from Cluster 1 with 11 links and eight occurrences. Lastly, the tenth place belongs to the fraction term from cluster 1 which has 13 links and seven occurrences.

The keyword and term analyses were performed on the article's to identify the domains and research topics of eye-tracking studies in mathematics education. A total of 65 terms and keywords in the network were grouped based on research similarities. Table 6 presents the research domains and topics of the most relevant keywords and terms.

Table 6. Relevant research domains and topics

Clusters	Label Clusters (Domain And Topic)	Representative Keyword	Number of Articles
Red	Numbers and Arithmetic	Number line, rational number, fraction, divisibility rules, and number comparison	27
	Problem-Solving	Mathematical problem-solving, mathematical word problem-solving, reading	13
	Reasoning	Mathematical reasoning	4
	Mathematical anxiety	Mathematical anxiety	3
	Individual differences	Individual differences, mathematical performance	4
Green	Mathematical creativity	Mathematical creativity	4
	Representation Mathematical	Representation mathematical, notation mathematics, symbolism	17
	Multimedia (Learning based technology)	Multimedia, mathematical software interfaces	7
	Embodied cognition and embodied interaction	Embodied cognition, semiotics	6
Blue	Learning Mathematics	Mathematics learning, visual attention, strategy, gaze, collaborative problem solving, attentional anchor, coordination, teacher and student competency assessments	13
	Learning difficulties	Mathematical difficulties	12
Yellow	Geometry and preschool	Geometry, GeoGebra, graph interpretation, preschool education	9

According to the analysis, the red cluster includes keywords related to numbers and arithmetic, such as number line, rational number, fraction, divisibility rules, and number comparison. It also contains the keywords mathematical reasoning, mathematical problem solving, mathematical anxiety, individual differences, and performance, which are crucial in understanding arithmetic in mathematics education. The green cluster includes mathematical creativity, mathematical representation, multimedia, embodied cognition, and semiotics. The blue cluster includes keywords related to mathematics learning, such as visual attention, strategy, teaching, coordination, and collaborative problem-solving, as well as mathematical difficulties and educational neuroscience. Lastly, the yellow cluster contains the geometry and preschool education.

4- Discussion

The development of eye-tracking technology extends beyond health, marketing, and engineering into education, including mathematics education. Consequently, eye-tracking has become a focus of interest for researchers and practitioners in the field. This study examines publications on the use of eye-tracking in mathematics education from 2013 to 2023, based on articles indexed in the Scopus database. It represents the first bibliometric analysis to specifically highlight the use of eye-tracking in mathematics education, drawing on Scopus data and providing a global perspective on research developments over the past 11 years. A total of 119 English-language documents, including articles, conference papers, review articles, proceedings, and book chapters. The analysis shows that scientific articles are the most dominant publication type. Furthermore, publication trends exhibit a fluctuating pattern, with a notable peak in 2020. This peak likely reflects methodological consolidation and new directions in mathematics education research rather than a mere temporal fluctuation. During this period, the eye-tracking research community in mathematics education began to mature, marked by systematic reviews that standardized protocols and mapped key research topics [4, 27]. Such consolidation typically increases publications output as research expands beyond exploratory studies to include replications, applications, and special issues in international journals. Concurrently, a shift in mathematics education research toward cognitive processes, representations, and affective factors such as anxiety made eye-tracking a highly relevant and appropriate method for addressing contemporary research needs [4].

The most cited document in eye-tracking studies on mathematics education is the article by Cortina et al. [42]. Its high citation count indicates its significant influence on subsequent research, as citations are often viewed as indicators of academic significance and scientific reputation [66-68]. Cortina et al. [42] demonstrated that mobile eye tracking is a valid, low-inference measure for assessing teacher expertise in mathematics teaching, confirming differences in attention distribution between novice and experienced teachers. Experienced teachers demonstrated a more balanced and strategic distribution of visual attention, whereas novice teachers showed a narrower focus. This supports the theory that cognitive and behavioral differences between experts and novices can be revealed through eye tracking, while also suggesting its potential as a tool for teacher reflection and professional development. Recent research further confirms that eye tracking is not only a methodological trend in academic studies but also provides new insights into the situational processes of teacher-student interactions in the classroom [69]. For example, eye-tracking data have been used to analyze teachers' multimodal interactions, including the integration of gaze, gesture, and language to enhance learning dynamics [70]. Chaudhuri et al. found that teachers' visual focus in the classroom was closely related to students' basic academic skills and the level of individual support provided [70]. These findings underscore the teachers' awareness of how they allocate visual attention, as it impacts student learning outcomes and the quality of support. Schindler's et al. [29] further confirmed that eye tracking can investigate interaction in authentic mathematics classrooms. In cooperative learning contexts, eye-tracking has been applied to observe teachers' visual attention patterns, which were closely related to their scaffolding strategies [71]. Thus, eye tracking systems enable more naturalistic educational research by observing problem-solving strategies, visual attention, and engagement in authentic classroom situations [55]. This technology warrants consideration in the instructional process due to its potential to support personalized learning and enhance learning outcomes [72]. Overall, these findings confirm that eye tracking is not merely a methodological trend, but a bridge between research and practice that helps teachers understand interactions, attention distribution, and effective learning strategies in mathematics education.

In the relational network map of authors, Hannula et al. [64] and Brockmole et al. [65] emerged as the most active collaborators. Meanwhile, Schindler & Lilienthal [9] were the most cited authors, with 78 citations across three documents. Regarding publication sources, 78 sources were identified as containing eye-tracking research in mathematics education, with Lecture Notes in Computer Science being the most productive, contributing seven documents. The International Journal of Science and Mathematics Education received the highest number of citations, with 241 citations across six articles. During the observed period, articles on eye tracking in mathematics were also published in psychology, cognition, and human behavior journals such as Psychological Research, European Journal of Social Psychology, Applied Cognitive Psychology, and Neuropsychologia. These findings suggest that eye-tracking research in mathematics education is positioned at the intersection of educational research, psychology, and cognitive science, while also gaining visibility in mathematics education–specific journals. This pattern reflects both the interdisciplinary nature of the method and its growing acceptance within the core field of mathematics education.

An institutional and country-level analysis shows that 156 organizations from 38 countries have contributed to research on eye-tracking in mathematics. Universities in Europe and America dominate these studies, while contributions from Asian and African countries remain limited. This finding aligns with Chytry et al. [73] who noted that European and American countries have conducted more studies on Using Eye-Tracking in Education than Asian and African countries. Such dominance is likely due to the fact that the early foundational studies in modern eye-tracking research originated in these regions. European and US countries have demonstrated a strong commitment through significant financial investments in this research field. In contrast, contributions from African countries and some lower-GDP Asian countries remain limited [73, 74]. However, their participation is strategically valuable, as it can enrich the diversity of global perspectives. Such contributions can be realized through active involvement in international research networks [4, 75]. Another contribution can be made using low-cost eye trackers, such as Eye Tribe, although their measurement accuracy is lower [76, 77]. However, these devices can be combined with interviews, think-aloud interviews, or stimulated recall interviews to gain detailed insights into students' engagement with mathematical tasks and processes [29].

In terms of collaboration, Finland was the most active country in global collaborative writing. Meanwhile, the United States has the highest significant number of cited articles. Among institutions, the University of Helsinki was the most active in collaborating on eye-tracking studies in mathematics education, maintaining strong connections with the University of Southampton, the University of Oslo, the University of Oulu, Uppsala University, Volda University College, Israel Institute of Technology, Queensland University of Technology, and SeeTrue Technologies. This suggests that research in this domain thrives on institutional collaboration, particularly among European universities with strong traditions in mathematics education and cognitive sciences. Such collaboration reflects the growing recognition of eye-tracking as a valuable methodology and the development of an evolving international research ecosystem. When viewed in terms of the number of citations, Utrecht University has the highest number of citations. Interestingly, while institutions such as Utrecht and Cologne are notable for their consistent productivity, universities like the University of Michigan demonstrate that even a single high-quality publication can exert substantial influence, as reflected in its relatively high citation count.

A co-occurrence analysis identified the most commonly used keywords in eye-tracking research in mathematics education, which represent the core concepts of the field [67]. The most common keywords were eye tracking, eye movement, mathematics, mathematics education, problem-solving, fractions, mobile eye tracking, mental arithmetic, learning, and mathematical difficulties. Figure 9 and Table 6 present the domains and topics investigated using eye tracking, including numbers and arithmetic, problem-solving, reasoning, individual differences, mathematical anxiety, mathematical creativity, mathematical representation, multimedia in learning, embodied cognition and embodied interaction, mathematics learning, mathematics difficulties, geometry, and preschool. Keyword analysis reveals that most eye-tracking studies in mathematics education have focused on numbers and arithmetic, including topics such as the number line, mental arithmetic, divisibility rules, fraction concepts, and comparison of rational numbers. These findings align with Strohmaier et al. [4] who observed that eye-tracking studies in mathematics education remain predominantly focused on numbers and arithmetic. Mock et al. [8] emphasized that numerical cognition, particularly the basic perception of number processing, is the most researched area. Furthermore, the topic of mathematical difficulties, also identified in the keyword analysis, is supported by Almfjord & Hallberg [11], who demonstrated that eye-tracking effectively identifies differences in strategies and elucidates the causes of errors and differences in response time. Furthermore, Paskovske & Kliziene [28] also highlight the potential of eye-tracking as a valuable tool for exploring students' problem-solving processes, consistent with the high frequency of related keywords in this study.

The bibliometric findings identified emerging topics in eye-tracking research, including mathematical anxiety, creative thinking, individual differences, and mathematical reasoning. Similarly, Schindler et al. observed that eye-tracking research is expanding beyond cognitive processes to include affective aspects and more complex learning domains [29]. Eye tracking has proven effective in understanding the dynamics of anxiety and learning difficulties in mathematics, as visual patterns reflect both students' affective load and cognitive constraints. Hunt et al. [15] found that students with high anxiety exhibited more fixations and saccades, indicating greater cognitive effort and difficulty in regulating attention. Li et al. [16] demonstrated that attentional control mediates the relationship between math anxiety and performance, with highly anxious students being more easily distracted by irrelevant information. Furthermore, eye-tracking technology has proven valuable in understanding early mathematics learning difficulties, such as recognizing geometric shapes in preschool children [78] and the enumeration process in students with numeracy difficulties [14]. Similarly, Soares et al. [72] emphasized that eye tracking increases interactivity, maintains student focus, provides immediate feedback, and helps identify learning difficulties often overlooked by traditional observation. This finding is important from an equity perspective, enabling teachers to recognize the unique needs of students, including those who struggle silently due to anxiety or cognitive barriers, and to design more equitably, personalized, and context-sensitive interventions. Thus, eye tracking serves not only as a technical innovation but also as a tool to promote equity in learning.

Furthermore, certain subtopics in the study's results only addressed specific mathematics topics to a certain extent. For instance, studies on creative thinking processes have only been conducted on primary school [6], high school [12], and postgraduate students [53]. Thus, future studies are suggested to investigate the creative process among prospective teachers or junior high school students to fill this gap.

The use of eye tracking in mathematics education is on an upward trajectory and is expected to continue growing. This field has attracted increasing attention over recent decades and is likely to inspire further exploration. Our research can guide future studies by highlighting unresolved issues in understanding mathematical thinking processes, abilities, and skills, as well as other mathematical domains, such as soft skills, through eye tracking. The potential for research in ASEAN countries, where eye-tracking studies in mathematics remain limited, is particularly promising and could open new avenues for exploration.

5- Conclusion

This research analyzed articles on the application of eye-tracking in mathematics education from 2013 to 2023, sourced from the Scopus database, and represents the first bibliometric analysis in this field. It provides a comprehensive global overview of developments in eye-tracking research over the past 11 years, highlighting fluctuating annual trends. During this period, contributions came from 333 authors, 78 sources, and 156 organizations across 38 countries. The most cited publication was by Cortina et al. [42], and the International Journal of Science and Mathematics Education was the most frequently cited journal. Researchers from Germany and the United States were the leading contributors, with notable participation from Asia and Africa. The University of Helsinki emerged as the most active collaborating institution. Topic and domain analysis revealed that eye-tracking studies in mathematics education primarily examined numbers and arithmetic, with other areas receiving less attention. These findings highlight opportunities for future research, particularly in mathematical anxiety, creative thinking processes, individual differences, and mathematical reasoning.

This research acknowledges several limitations that should be addressed in future studies. The analysis relied solely on the Scopus database, retrieved with Publish or Perish software, and examined using VOSviewer. While effective, future studies could benefit from incorporating alternative databases such as Web of Science, ERIC, or PubMed, each offering distinct advantages. Expanding the scope to include articles published in languages other than English would also enhance insights and coverage. With these considerations, future bibliometric studies can generate a more comprehensive understanding of the field. Despite these limitations, this study contributes to the development of future research, particularly in identifying topics and domains that require improvement in eye-tracking research in mathematics education.

6- Declarations

6-1- Author Contributions

Conceptualization, F., T.Y.E.S., and A.L.; methodology, F., A.L., and R.S.D.; software, F. and F.H.; validation, T.Y.E.S., A.L., and R.S.D.; formal analysis, F., T.Y.E.S., and H.; investigation, F. and R.S.D.; resources, F., F.H., and H.; data curation, F. and H.; writing—original draft preparation, F.; writing—review and editing, F., T.Y.E.S., and A.L.; visualization, F. and F.H.; supervision, T.Y.E.S, A.L., and R.S.D.; project administration, F.; funding acquisition, F., F.H., and H. All authors have read and agreed to the published version of the manuscript.

6-2- Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6-3- Funding and Acknowledgments

The authors would like to thank the Indonesian Education Scholarship (BPI), the Center for Higher Education Funding and Assessment (PPAPT Kemdiktisaintek) and the Indonesian Endowment Fund for Education (LPDP) for providing scholarships and funding for this paper.

6-4- Institutional Review Board Statement

Not applicable.

6-5- Informed Consent Statement

Not applicable.

6-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

7- References

[1] Obersteiner, A., & Tumpek, C. (2015). Measuring fraction comparison strategies with eye-tracking. ZDM, 48(3), 255–266. doi:10.1007/s11858-015-0742-z.

[2] Just, M. A., & Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. Psychological Review, 87(4), 329–354. doi:10.1037/0033-295X.87.4.329.

[3] Duchowski, A. T. (2017). Eye Tracking Methodology. Springer, Cham, Switzerland. doi:10.1007/978-3-319-57883-5.

[4] Strohmaier, A. R., MacKay, K. J., Obersteiner, A., & Reiss, K. M. (2020). Eye-tracking methodology in mathematics education research: A systematic literature review. Educational Studies in Mathematics, 104(2), 147–200. doi:10.1007/s10649-020-09948-1.

[5] Andrá, C., Lindström, P., Arzarello, F., Holmqvist, K., Robutti, O., & Sabena, C. (2015). Reading Mathematics Representations: An Eye-Tracking Study. International Journal of Science and Mathematics Education, 13(2), 237–259. doi:10.1007/s10763-013-9484-y.

[6] Bicer, A., & Bicer, A. (2023). Understanding young students' mathematical creative thinking processes through eye-tracking-stimulated recall interview. Mathematics Education Research Journal, 35(2), 361–399. doi:10.1007/s13394-022-00429-7.

[7] Hartmann, M. (2015). Numbers in the eye of the beholder: What do eye movements reveal about numerical cognition? Cognitive Processing, 16(1), 245–248. doi:10.1007/s10339-015-0716-7.

[8] Mock, J., Huber, S., Klein, E., & Moeller, K. (2016). Insights into numerical cognition: considering eye-fixations in number processing and arithmetic. Psychological Research, 80(3), 334–359. doi:10.1007/s00426-015-0739-9.

[9] Schindler, M., & Lilienthal, A. J. (2019). Domain-specific interpretation of eye tracking data: towards a refined use of the eye-mind hypothesis for the field of geometry. Educational Studies in Mathematics, 101(1), 123–139. doi:10.1007/s10649-019-9878-z.

[10] Schindler, M., Shvarts, A., & Lilienthal, A. J. (2025). Introduction to eye tracking in mathematics education: interpretation, potential, and challenges. Educational Studies in Mathematics, 118(3), 309–321. doi:10.1007/s10649-025-10393-1.

[11] Almfjord, J., & Hallberg, L. (2021). What eye tracking tells us about mathematical difficulties: A systematic review. Bachelor Degree, Ballerup, Denmark.

[12] Schindler, M., & Lilienthal, A. J. (2020). Students' Creative Process in Mathematics: Insights from Eye-Tracking-Stimulated Recall Interview on Students' Work on Multiple Solution Tasks. International Journal of Science and Mathematics Education, 18(8), 1565–1586. doi:10.1007/s10763-019-10033-0.

[13] van't Noordende, J. E., van Hoogmoed, A. H., Schot, W. D., & Kroesbergen, E. H. (2016). Number line estimation strategies in children with mathematical learning difficulties measured by eye tracking. Psychological Research, 80(3), 368–378. doi:10.1007/s00426-015-0736-z.

[14] Schindler, M., Schovenberg, V., & Schabmann, A. (2020). Enumeration Processes of Children with Mathematical Difficulties: An Explorative Eye-Tracking Study on Subitizing, Groupitizing, Counting, and Pattern Recognition. Learning Disabilities, 18(2), 193–211.

[15] Hunt, T. E., Clark-Carter, D., & Sheffield, D. (2015). Exploring the Relationship between Mathematics Anxiety and Performance: An Eye-Tracking Approach. Applied Cognitive Psychology, 29(2), 226–231. doi:10.1002/acp.3099.

[16] Li, T., Quintero, M., Galvan, M., Shanafelt, S., Hasty, L. M., Spangler, D. P., Lyons, I. M., Mazzocco, M. M. M., Brockmole, J. R., Hart, S. A., & Wang, Z. (2022). The Mediating Role of Attention in the Association between Math Anxiety and Math Performance: An Eye-Tracking Study. Journal of Educational Psychology, 115(2), 229–240. doi:10.1037/edu0000759.

[17] Kim, S., Pollanen, M., Reynolds, M. G., & Burr, W. S. (2020). Problem Solving as a Path to Comprehension: Mathematical Software and Structured Symbolism. Mathematics in Computer Science, 14(3), 607–621. doi:10.1007/s11786-020-00457-1.

[18] Wei, S., Xin, Y.P., Chen, Y. (2020). Visualizing Students' Eye Movement Data to Understand Their Math Problem-Solving Processes. Learning and Collaboration Technologies. Human and Technology Ecosystems. HCII 2020. Lecture Notes in Computer Science, Springer, Cham, Switzerland. doi:10.1007/978-3-030-50506-6_15.

[19] Türkoğlu, H., & Yalçınalp, S. (2024). Investigating problem-solving behaviours of university students through an eye-tracking system using GeoGebra in geometry: A case study. Education and Information Technologies, 29(12), 15761–15791. doi:10.1007/s10639-024-12452-1.

[20] Bolden, D., Barmby, P., Raine, S., & Gardner, M. (2015). How young children view mathematical representations: a study using eye-tracking technology. Educational Research, 57(1), 59–79. doi:10.1080/00131881.2014.983718.

[21] Lee, S., Ke, F., & Ryu, J. (2020). Engagement and effectiveness of symbolic and iconic learning support for math problem representation: an eye tracking study. Interactive Learning Environments, 31(3), 1514–1531. doi:10.1080/10494820.2020.1848877.

[22] Wills, T., Shipley, T., Chang, B., Cromley, J., & Booth, J. (2014). What gaze data reveal about coordinating multiple mathematical representations. Proceedings of the 36th Annual Meeting of the Cognitive Science Society, Quebec City, Canada.

[23] Porras, M. M., Campen, C. A. N. K., González-Rosa, J. J., Sánchez-Fernández, F. L., & Guzmán, J. I. N. (2024). Eye tracking study in children to assess mental calculation and eye movements. Scientific Reports, 14(1), 18901. doi:10.1038/s41598-024-69800-x.

[24] Haataja, E. S. H., Koskinen-Salmia, A., Salonen, V., Toivanen, M., & Hannula, M. S. (2024). Student visual attention during group instruction phases in collaborative geometry problem solving. Educational Studies in Mathematics, 118(3), 387–407. doi:10.1007/s10649-024-10337-1.

[25] Zhang, L., Song, N., Wu, G., & Cai, J. (2025). Understanding the cognitive processes of mathematical problem posing: evidence from eye movements. Educational Studies in Mathematics, 118(3), 449–478. doi:10.1007/s10649-023-10262-9.

[26] Perttula, A. (2017). Eye Tracking Studies Focusing on Mathematics: a Literature Review. INTED2017 Proceedings, 1, 2166–2173. doi:10.21125/inted.2017.0639.

[27] Lilienthal, A. J., & Schindler, M. (2019). Current trends in the use of eye tracking in mathematics education research: A PME survey. arXiv, Preprint arXiv:1904.12581. doi:10.48550/arXiv.1904.12581.

[28] Paskovske, A., & Kliziene, I. (2024). Eye tracking technology on children's mathematical education: systematic review. Frontiers in Education, 9, 1386487. doi:10.3389/feduc.2024.1386487.

[29] Schindler, M., Simon, A. L., Baumanns, L., & Lilienthal, A. J. (2025). Eye-tracking research in mathematics and statistics education: recent developments and future trends. A systematic literature review. ZDM - Mathematics Education, 57(4), 727–743. doi:10.1007/s11858-025-01699-8.

[30] Ninkov, A., Frank, J. R., & Maggio, L. A. (2022). Bibliometrics: Methods for studying academic publishing. Perspectives on Medical Education, 11(3), 173–176. doi:10.1007/s40037-021-00695-4.

[31] Passas, I. (2024). Bibliometric Analysis: The Main Steps. Encyclopedia, 4(2), 1014-1025. doi:10.3390/encyclopedia4020065.

[32] Khurshid, M. M., Rashid, A., Yusof, S., Ahmad, R. W., & Shehzad, H. M. F. (2024). Open Government Data Intention-Adoption Behavioural Model for Public Sector Organisations: A Technological Innovation Perspective. Emerging Science Journal, 8(5), 1732–1763. doi:10.28991/ESJ-2024-08-05-04.

[33] Akhmadieva, R. S., Udina, N. N., Kosheleva, Y. P., Zhdanov, S. P., Timofeeva, M. O., & Budkevich, R. L. (2023). Artificial intelligence in science education: A bibliometric review. Contemporary Educational Technology, 15(4), 460. doi:10.30935/cedtech/13587.

[34] Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research, 133, 285–296. doi:10.1016/j.jbusres.2021.04.070.

[35] Perianes-Rodriguez, A., Waltman, L., & van Eck, N. J. (2016). Constructing bibliometric networks: A comparison between full and fractional counting. Journal of Informetrics, 10(4), 1178–1195. doi:10.1016/j.joi.2016.10.006.

[36] Baas, J., Schotten, M., Plume, A., Côté, G., & Karimi, R. (2020). Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. Quantitative Science Studies, 1(1), 377–386. doi:10.1162/qss_a_00019.

[37] Haddaway, N. R., Page, M. J., Pritchard, C. C., & McGuinness, L. A. (2022). PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimised digital transparency and Open Synthesis. Campbell Systematic Reviews, 18(2), e1230. doi:10.1002/cl2.1230.

[38] Deveci, İ. (2022). Review of entrepreneurship education literature in educational contexts: Bibliometric analysis. Participatory Educational Research, 9(1), 214–232. doi:10.17275/per.22.12.9.1.

[39] Şahin, A., Karakaya, Y. E., & Dikmen, M. (2023). Mapping Tendencies in Curriculum Research on Physical Education and Sports: A Bibliometric Analysis. Participatory Educational Research, 10(3), 106–129. doi:10.17275/per.23.47.10.3.

[40] Hernández-Torrano, D., & Ibrayeva, L. (2020). Creativity and education: A bibliometric mapping of the research literature (1975–2019). Thinking Skills and Creativity, 35, 100625. doi:10.1016/j.tsc.2019.100625.

[41] Waltman, L., van Eck, N. J., & Noyons, E. C. M. (2010). A unified approach to mapping and clustering of bibliometric networks. Journal of Informetrics, 4(4), 629–635. doi:10.1016/j.joi.2010.07.002.

[42] Cortina, K. S., Miller, K. F., McKenzie, R., & Epstein, A. (2015). Where Low and High Inference Data Converge: Validation of CLASS Assessment of Mathematics Instruction Using Mobile Eye Tracking with Expert and Novice Teachers. International Journal of Science and Mathematics Education, 13(2), 389–403. doi:10.1007/s10763-014-9610-5.

[43] Susac, A., Bubic, A., Kaponja, J., Planinic, M., & Palmovic, M. (2014). Eye Movements Reveal Students' Strategies in Simple Equation Solving. International Journal of Science and Mathematics Education, 12(3), 555–577. doi:10.1007/s10763-014-9514-4.

[44] Wakefield, E., Novack, M. A., Congdon, E. L., Franconeri, S., & Goldin-Meadow, S. (2018). Gesture helps learners learn, but not merely by guiding their visual attention. Developmental Science, 21(6), e12664. doi:10.1111/desc.12664.

[45] Abrahamson, D., Shayan, S., Bakker, A., & Van Der Schaaf, M. (2016). Eye-Tracking Piaget: Capturing the Emergence of Attentional Anchors in the Coordination of Proportional Motor Action. Human Development, 58(4–5), 218–224. doi:10.1159/000443153.

[46] Molina, A. I., Navarro, Ó., Ortega, M., & Lacruz, M. (2018). Evaluating multimedia learning materials in primary education using eye tracking. Computer Standards & Interfaces, 59, 45–60. doi:10.1016/j.csi.2018.02.004.

[47] Hurst, M., & Cordes, S. (2016). Rational-number comparison across notation: Fractions, decimals, and Whole Numbers. Journal of Experimental Psychology: Human Perception and Performance, 42(2), 281–293. doi:10.1037/xhp0000140.

[48] Hartmann, M., Mast, F. W., & Fischer, M. H. (2016). Counting is a spatial process: evidence from eye movements. Psychological Research, 80(3), 399–409. doi:10.1007/s00426-015-0722-5.

[49] Potgieter, P., & Blignaut, P. (2017). Using eye-tracking to assess the application of divisibility rules when dividing a multi-digit dividend by a single digit divisor. Proceedings of the South African Institute of Computer Scientists and Information Technologists, 1–10. doi:10.1145/3129416.3129427.

[50] Potgieter, P., & Blignaut, P. (2018). The Effect of Learners' Knowledge of the Divisibility Rules on their Gaze Behaviour. African Journal of Research in Mathematics, Science and Technology Education, 22(3), 351–362. doi:10.1080/18117295.2018.1533611.

[51] Potgieter, P., & Blignaut, P. (2018). A system to determine if learners know the divisibility rules and apply them correctly. Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications, 1–8. doi:10.1145/3204493.3204526.

[52] Potgieter, P., & Blignaut, P. (2018). Setting Heuristics for Eye-Tracking Assessment on Divisibility Rules. 2018 International Conference on Intelligent and Innovative Computing Applications (ICONIC), 1–6. doi:10.1109/iconic.2018.8601297.

[53] Schindler, M., & Lilienthal, A. J. (2022). Students' collaborative creative process and its phases in mathematics: an explorative study using dual eye tracking and stimulated recall interviews. ZDM - Mathematics Education, 54(1), 163–178. doi:10.1007/s11858-022-01327-9.

[54] da Silva Soares, R., Lukasova, K., Carthery-Goulart, M. T., & Sato, J. R. (2021). Student's Perspective and Teachers' Metacognition: Applications of Eye-Tracking in Education and Scientific Research in Schools. Frontiers in Psychology, 12. doi:10.3389/fpsyg.2021.673615.

[55] da Silva Soares, R., Barreto, C., & Sato, J. R. (2023). Perspectives in eye-tracking technology for applications in education. South African Journal of Childhood Education, 13(1), 1204. doi:10.4102/sajce.v13i1.1204.

[56] Norqvist, M., Jonsson, B., & Lithner, J. (2023). Shifts in student attention on algorithmic and creative practice tasks. Educational Studies in Mathematics, 118(3), 409–428. doi:10.1007/s10649-023-10250-z.

[57] Norqvist, M., Jonsson, B., & Lithner, J. (2019). Eye-tracking data and mathematical tasks with focus on mathematical reasoning. Data in Brief, 25, 104216. doi:10.1016/j.dib.2019.104216.

[58] Kim, S., Pollanen, M., Reynolds, M.G., Burr, W.S. (2018). Identification of Errors in Mathematical Symbolism and Notation: Implications for Software Design. Mathematical Software – ICMS 2018. ICMS 2018. Lecture Notes in Computer Science, Springer, Cham, Switzerland. doi:10.1007/978-3-319-96418-8_35.

[59] Shvarts, A., Alberto, R., Bakker, A., Doorman, M., & Drijvers, P. (2019). Embodied collaboration to foster instrumental genesis in mathematics. A Wide Lens: Combining embodied, enactive, extended, and embedded learning in collaborative settings, 13^{th} International Conference on Computer Supported Collaborative Learning (CSCL), 17-21 June 2019, Lyon, France.

[60] Shvarts, A., Alberto, R., Bakker, A., Doorman, M., & Drijvers, P. (2021). Embodied instrumentation in learning mathematics as the genesis of a body-artifact functional system. Educational Studies in Mathematics, 107(3), 447–469. doi:10.1007/s10649-021-10053-0.

[61] Hartmann, M. (2022). Summing up: A functional role of eye movements along the mental number line for arithmetic. Acta Psychologica, 230, 103770. doi:10.1016/j.actpsy.2022.103770.

[62] Shvarts, A., & Abrahamson, D. (2019). Dual-eye-tracking Vygotsky: A microgenetic account of a teaching/learning collaboration in an embodied-interaction technological tutorial for mathematics. Learning, Culture and Social Interaction, 22, 100316. doi:10.1016/j.lcsi.2019.05.003.

[63] Shvarts, A., & Abrahamson, D. (2023). Coordination Dynamics of Semiotic mediation: A Functional Dynamic Systems Perspective on mathematics Teaching/Learning. Constructivist Foundations, 18(2), 220–234.

[64] Hannula, D. E., Althoff, R. R., Warren, D. E., Riggs, L., Cohen, N. J., & Ryan, J. D. (2010). Worth a glance: using eye movements to investigate the cognitive neuroscience of memory. Frontiers in human neuroscience, 4, 166. doi:10.3389/fnhum.2010.00166.

[65] Brockmole, J. R., & Henderson, J. M. (2008). Prioritizing new objects for eye fixation in real-world scenes: Effects of object–scene consistency. Visual Cognition, 16(2-3), 375-390. doi:10.1080/13506280701453623.

[66] Plummer, P., DeWolf, M., Bassok, M., Gordon, P. C., & Holyoak, K. J. (2017). Reasoning strategies with rational numbers revealed by eye tracking. Attention, Perception, and Psychophysics, 79(5), 1426–1437. doi:10.3758/s13414-017-1312-y.

[67] Julia, J., Afrianti, N., Soomro, K. A., Supriyadi, T., Dolifah, D., Isrokatun, I., Erhamwilda, E., & Ningrum, D. (2020). Flipped Classroom Educational Model (2010-2019): A Bibliometric Study. European Journal of Educational Research, 9(4), 1377–1392. doi:10.12973/eu-jer.9.4.1377.

[68] Qi, M., Zeng, A., Li, M., Fan, Y., & Di, Z. (2017). Standing on the shoulders of giants: the effect of outstanding scientists on young collaborators' careers. Scientometrics, 111(3), 1839–1850. doi:10.1007/s11192-017-2328-8.

[69] Haataja, E., Garcia Moreno-Esteva, E., Salonen, V., Laine, A., Toivanen, M., & Hannula, M. S. (2019). Teacher's visual attention when scaffolding collaborative mathematical problem solving. Teaching and Teacher Education, 86, 102877. doi:10.1016/j.tate.2019.102877.

[70] Chaudhuri, S., Muhonen, H., Pakarinen, E., & Lerkkanen, M. K. (2022). Teachers' visual focus of attention in relation to students' basic academic skills and teachers' individual support for students: An eye-tracking study. Learning and Individual Differences, 98, 102179. doi:10.1016/j.lindif.2022.102179.

[71] Li, R., Cao, Y., Tang, H., & Kaiser, G. (2023). Teachers' Scaffolding Behavior and Visual Perception during Cooperative Learning. International Journal of Science and Mathematics Education, 22(2), 333–352. doi:10.1007/s10763-023-10379-6.

[72] Soares, R. da S., Pinheiro, E. D., Oku, A. Y. A., Rizzo, M. B., Vieira, C. das N., & Sato, J. R. (2024). Integrating Students' Real-Time Gaze in Teacher–Student Interactions: Case Studies on the Benefits and Challenges of Eye Tracking in Primary Education. Applied Sciences (Switzerland), 14(23), 11007. doi:10.3390/app142311007.

[73] Chytry, V., Mundokova, N., & Kubiatko, M. (2025). Using Eye-Tracking in Education—A Review Study. Education Sciences, 15(7), 853. doi:10.3390/educsci15070853.

[74] Alemdag, E., & Cagiltay, K. (2018). A systematic review of eye tracking research on multimedia learning. Computers & Education, 125, 413–428. doi:10.1016/j.compedu.2018.06.023.

[75] Price, G. R., Wilkey, E. D., & Yeo, D. J. (2017). Eye-movement patterns during non-symbolic and symbolic numerical magnitude comparison and their relation to math calculation skills. Acta Psychologica, 176, 47–57. doi:10.1016/j.actpsy.2017.03.012.

[76] Ivanchenko, D., Rifai, K., Hafed, Z. M., & Schaeffel, F. (2021). A low-cost, high-performance video-based binocular eye tracker for psychophysical research. Journal of Eye Movement Research, 14(3), 1–21. doi:10.16910/JEMR.14.3.3.

[77] Dalmaijer, E. (2014). Is the Low-cost EyeTribe Eye Tracker any Good for Research? PeerJ PrePrints, 1-35. doi:10.7287/peerj.preprints.585v1.

[78] Nazaruk, S. (2020). Diagnosis of the Mathematical Skills of Children from Polish Kindergartens and Its Importance for Geometric Shape Recognition. Early Childhood Education Journal, 48(4), 463–472. doi:10.1007/s10643-019-01005-8.