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Thematic bibliometric analysis of 37 specialized journals in mathematical education research indexed in *Scopus* or *Web of Science*

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Abstract
This bibliometric study examines the scientific production in mathematical education of 23,094 articles from 37 specialized mathematical education journals, indexed in *Scopus* and *Web of Science*, considering all records up to the year 2022. The analysis was conducted globally and regionally, including Latin America, Africa, Europe, the United States, and Canada. Articles were analyzed using *rhizomatic conceptual spaces*, which allow the representation of relationships between words present in the titles and keywords of articles through graphs, thereby identifying thematic nodes and connections, as well as visible and invisible peripheral elements. The results reveal the diversity of terms used in the field and the difficulties in capturing a disciplinary field using certain keywords. Common thematic nodes such as teaching, learning, knowledge, problem-solving, curriculum, assessment, and technology were observed, as well as regional differences in focus areas and theoretical currents. The study also highlights underexplored areas and suggests possible future research paths, including expanding searches in specialized sources, bibliometric analysis of specific topics, and temporal comparison of trends in the field.

Keywords: scientometrics, research networks, mathematical education, *Scopus*, *WoS*

INTRODUCTION

In recent years, numerous bibliometric studies have been carried out on scientific production in the field of mathematics education, exhibiting variability in the number of articles analyzed, the databases, and the methodologies employed. By conducting a search using the terms: *keywords*, *coword*[1], *co-words*, *bibliometr**, *scientometr**, *scopus*, *impact factor"*, *wos*, *web of science"*, *systematic review"*, *journal index"*, in conjunction with *educat**, and *math**, a result of just over 90 research articles between 2005 and 2023 is obtained, with two-thirds of these corresponding to the last three years.

The majority of these analyses address specific topics within mathematics education, with a large number of articles focused on technology. The bibliographic analyses of Borba et al. (2016) and Hwang et al. (2023) examine research trends on the use of technology in mathematics education. The former studies scientific production in mathematics education in 2,433 articles from *Web of Science* (*WoS*), ERIC, and PsycInfo databases, while the latter analyzes scientific production in mathematics education in articles from 14 specialized journals in the area. There are other articles, generally not exceeding 50 analyzed, that deal with more specific technology topics, such as the use of mobile devices (Bano et al., 2018), tablets (Svela et al., 2019), computational thinking (Gokce & Guner, 2022; Subramaniam et al., 2022; Ye et al., 2023; Yohannes & Chen, 2021), augmented reality (Jabar et al., 2022), and artificial intelligence (AI) (Hwang & Tu, 2021).

There are other bibliometric studies focusing on students or teachers, such as MacDonald and Murphy (2021), which is centered on the analysis of mathematics education articles related to children under four years old, or dos Santos de Oliveira Braga et al. (2022), who analyze academic production on youth and adult education, but only in Bolema [Bulletin] journal.

[1] Symbol * is used in search engines if you want to search for any term that starts with a specific word.

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Contribution to the literature

- This research offers a methodological contribution to the systematic literature review, being replicable for future research, especially in the field of mathematics education by using graphs to study the co-occurrence of words.
- A comparative bibliometric analysis was carried out using a database of 37 specialized journals in mathematics education, which is the most extensive database analyzed to date. These specialized journals provide relevant information on the subjects of study and the topics addressed in different geographical regions, such as Latin America, Africa, the United States and Canada, and Europe.
- The study highlights the importance of keywords in research articles and the possibility of developing strategies to systematize the selection process in order to increase the visibility of published research.

Regarding teachers, there are different bibliographic reviews. Mills et al. (2020) conducted a systematic literature review about expert disciplinary teachers in primary science and mathematics education. Shamim et al. (2022) analyze articles on the pedagogical beliefs of technical education teachers in science, technology, engineering, and mathematics (STEM). Linder and Simpson (2018) focus on the analysis of early childhood mathematics education and its empirical research, concentrating on the practice of teachers and teachers in training. Stahnke et al. (2016) carry out a systematic review of empirical research on mathematics teachers' situational skills, including perception, interpretation, and decision-making. With the exception of Linder and Simpson (2018), which analyzes around 1,200 articles, the rest of the reviews cover from a dozen to a hundred analyzed articles.

Additionally, there are bibliometric analyses focused on specific topics in mathematics education, such as instrumental approach (Drijvers et al., 2020), mathematical modeling (Hidayat et al., 2022), problem-solving (Suseelan et al., 2022), realistic mathematics (Phan et al., 2022), and pedagogical content knowledge (Depaepe et al., 2013). These studies analyze a range of 60 to 300 articles, mainly from *Scopus* and *WoS* databases.

Furthermore, there is another group of articles focused on academic production in a specific location, specific documentary sources, or with a global approach. The work of Castro et al. (2020) examines nearly 3,500 open-access articles produced in Colombia from various sources, such as conference proceedings, theses, articles in national and international journals on mathematics education, among others. Meanwhile, Bracho-López et al. (2012, 2014) conduct an analysis of Spanish scientific production, analyzing 774 and 959 articles in Spanish journals specializing in mathematics education. Other analyzed locations include Turkey, with the works of Dede and Ozdemir (2022), who analyzed 441 articles in *WoS*, and Kaya (2022), who analyzed 904 articles in the field from the TR database in the same country. Finally, within this subgroup is the work of Torres-Alfonso et al. (2014), who analyzed 1,357 articles registered in ALME (Acta Latinoamericana de Matemática Educativa [Latin American Educational Mathematics Act]) during the period from 2000 to 2009.

In relation to global analyses, only three were found: the first by Gokce and Guner (2021), who analyzed 1,021 articles from *WoS* database from 1980 to 2019; with almost five times more articles (5,633 to be precise). Ramirez and Devesa (2019) examined articles indexed in *Scopus* from 1978 to 2017 in the area. Julius et al. (2021) carried out the analysis using the largest number of articles in mathematics education, examining the production in *Scopus* between 1980 and 2020, which involved the analysis of 12,670 articles. In the last three mentioned works, as well as in several of the analyses that included a significant number of articles, VOSviewer tool was used (van Eck & Waltman, 2010), which allowed obtaining information about productivity, impact, and thematic axes in academic production.

In summary, it is observed that there are few reviews focused on broader regions and that, moreover, although the last-mentioned articles carry out a review of a large number of articles, they do not consider the majority of specialized journals in the subject. In addition, they present a significant discrepancy in the number of articles analyzed. Based on these antecedents, we pose the following research questions:

1. What are the relevant topics produced in specialized mathematics education journals in *Scopus* and *WoS*?
2. What is the citation impact of articles by region?
3. What are the relevant topics in scientific production in mathematics education according to geographical region? In particular, in Latin America, Africa, the United States along with Canada, and Europe.

CONCEPTUAL & METHODOLOGICAL FRAMEWORK

In our study, we address knowledge from a rhizomatic perspective (Deleuze & Guattari, 1980). According to this approach, knowledge is heterogeneous and connects with other knowledge in a horizontal and fluid way. To map this knowledge, a

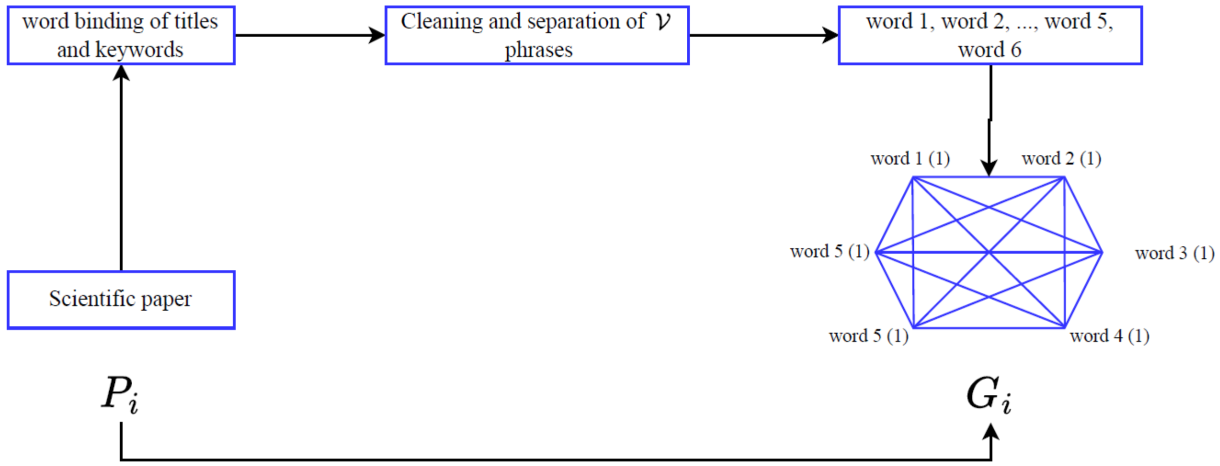

Figure 1. Assignment of a complete graph to a scientific article (P_i) with six words in V_i (extracted & adapted from Gaona & Manríquez, 2023)

rhizomatic graph can be employed in which words are nodes and the co-occurrence between words defines the relationships between nodes. The rhizomatic approach to knowledge can be useful for obtaining a global view of scientific production. Furthermore, it allows, among other operations, to perform a significant rupture, that is, to prune nodes, without the rhizome completely disappearing, but transforming and allowing new interpretations.

Building on the work of Gaona and Manríquez (2023), the *conceptual rhizomatic space* (*CRS*) is developed by creating graphs that connect the words of an article (**Figure 1**). Using the algorithm defined in the aforementioned article, a quantitative measure of the frequency of words and relationships can be obtained.

To interpret this *CRS*, one must not only consider an isolated word and its repetition but also the relationship between words and the differences that occur Deleuze (2002). From this perspective, we are interested in examining, through word frequency, the relevant topics of scientific production in mathematics education, both globally and in some regions of the world, without focusing on other metrics such as the number of published articles or citations received, which, although useful for certain analyses, do not reflect the accumulated knowledge of a community of researchers in indexed journals, which currently function as philosophical stones of scientific production Andrade-Molina et al. (2020).

The regional approach will allow us to identify the emphases that each community, sharing a common and close geographical space, has, although like any list, this can be questioned (Eco & Bouzaher, 2009). To this end, four regions were chosen, and a certain number of countries were selected in each region, according to the following list:

1. **Latin America:** Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, Guatemala, Honduras, Mexico, Panama, Peru, Puerto Rico, Uruguay, and Venezuela.
2. **Africa:** Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cape Verde, Cameroon, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Republic of the Congo, Ivory Coast, Djibouti, Egypt, Equatorial Guinea, Eritrea, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, São Tomé ve Príncipe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, South Sudan, Sudan, Tanzania, Togo, Tunisia, Uganda, Zambia, and Zimbabwe.
3. **North America:** The United States and Canada.
4. **Europe:** Albania, Andorra, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kosovo, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Moldova, Monaco, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Russia, San Marino, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom, and Vatican City.

Preferred reporting items for systematic reviews and meta-analyses or PRISMA methodology was used (Yepes-Nuñez et al., 2021). The methodological decisions employed in this work are described below.

Eligibility Criteria

Delimiting a disciplinary field is not an easy task. In the review carried out, the articles that were analyzed conducted a search based on some keywords related to education and others related to mathematics, which, based on the work of Castro and Gómez (2021), seems clearly insufficient. Instead, in this article, we chose articles from specialized journals indexed in *Scopus* or

WoS, trying to conduct a search that accounts for the core of scientific production in mathematics education. To select the journals, three criteria were used:

1. Journals whose name contains the words or strings of characters: *mathematic*, *matemática*, and *math*, in *education* or *developmental and educational psychology* categories of *Scopus*.
2. Journals whose name contains the words or strings of characters: *mathematic**, *matemática**, and *math**, in *education & educational research*, *education, scientific disciplines*, or *education*, special categories of *WoS*.
3. Specialized journals that do not contain the aforementioned words but are reported in articles dealing with the analysis of specialized journals Andrade-Molina et al. (2020) and in Nivens and Otten (2017), and are indexed in *Scopus* or *WoS*, such as Acta Scientiae [Journal of Science], PRIMUS, or LUMAT, among others.

Inclusion & Exclusion Criteria

The search was conducted considering only research articles (*articles*) and reviews (*review*). Only articles up to the year 2022 were considered. The search was conducted at the beginning of March 2023. This resulted in the list shown in **Table 1**.

Data Extraction Process

The data extraction process was carried out following the work of Gaona and Manríquez (2023). Keywords and title words were separated into individual words, and "stopwords" or *stopwords*, such as connectives, articles, prepositions, and others, were removed. Next, common word roots or lemmas were searched for. Subsequently, the lists of words were merged. Finally, repeated words were removed, i.e., if a word appears in both the title and keywords, it is counted as a single occurrence.

To carry out the first process, Python's split method was used. For the second and third processes, natural language toolkit (NLTK) (https://www.nltk.org/) was employed. To remove words, the stop words method in English was used. To join words according to a common root, the lemmatize method was used, which seeks to preserve the meaning of words.

From this, a graph was defined for each article. Each word represents a node, which we call v_i. Furthermore, two words, denoted by v_i and v_j, being in the same article are related by an edge called e_{ij} (**Figure 1**).

If the database has n scientific articles and we denote each of them by $P_1, P_2, \ldots, P_n$. Observe that each P_i corresponds to a list or set of words obtained from the titles and keywords. Thus, we can write $V=(V_1, V_2, \ldots, V_n)$, where each V_i is a list of words corresponding to P_i.

To identify the relationships between the words that are in each V_i, we associate a complete graph to each P_i, where the set of vertices is V_i. We denote this complete graph by G_i. In summary, we associate a complete graph to each scientific article whose vertices are the words found in the titles and keywords of the analyzed articles.

Once the previous assignment has been made for each P_i, we define the graph G as the union of all graphs G_i. The union of graphs corresponds to the union of nodes and edges. In other words, $G=G_1+G_2+\cdots+G_n$.

It is possible and recurrent that a word in V_i is also in V_j with $i\neq j$, that is, a node of the graph G_i is also a node of the graph G_j. Similarly, we could have two or more nodes repeated in two different graphs, implying that the edges connecting them are also repeated. We quantify these repetitions in weight functions for nodes and edges of the graph G weighted by the total number of analyzed articles: $w_{node}(v)$=*Number of* V_i *to which* v *belongs/Number of analyzed articles* and $wedge(e_{ij})$=*Number of* G_i *in which* e_{ij} *is/ Number of analyzed articles*.

As a result, according to these elements, *CRS* is defined as the weighted graph G. Since the goal is to visualize *CRS* within a screen or a sheet of paper, the number of nodes and edges is limited in such a way that the most relevant relationships can be observed. Therefore, we consider the parameters η and a for visualization, where η will be the parameter regulating the display of nodes and a the parameter regulating the display of edges. We denote by $G_{\eta,a}$ the graph obtained from G according to the parameters η and a. Formally: $G_{\eta,a}=(V_{\eta,a}, E_{\eta,a})$ is a graph such that $V_{\eta,a}=\{v\in V: w_{nodo}(v)\geq\eta\}$ and $E\eta,a=\{e_{ij}\in E: w_{arista}(e_{ij})\geq a\}$.

Based on this, *CRS* $G_{\eta,a}$ is defined, which will be displayed in different figures. In $G_{\eta,a}$, some nodes can be **pruned** arbitrarily to facilitate the visualization of the remaining nodes. When this occurs, the pruned nodes and the reason for such pruning will be indicated.

Within $G_{\eta,a}$, the **visible periphery** of *CRS* is identified as those words or relationships that are on the edges, remaining on the fringes, disconnected, or weakly connected. Although in G, by definition, all nodes are connected, they are not in $G_{\eta,a}$, as what is seen is a part of the whole, leaving out weaker relationships and nodes. However, there is an **invisible periphery** corresponding to all nodes and relationships not shown.

The algorithm operationalizing all these concepts is detailed in Gaona and Manríquez (2023, p. 16).

For citation analysis, data from *Scopus* will be used since all the consulted journals are from *Scopus*, while not all are from *WoS*. Moreover, even for journals appearing in both databases, the number of citations is higher in *Scopus* than in *WoS*. To analyze the distribution of citations in scientific articles, five different geographical regions were used: Latin America, Africa, the United States, and Canada, Europe, as well as Global. It is worth noting that articles can be repeated in two different regions if the affiliations belong to two countries from different regions. The region called

Table 1. List of journals, number of articles analyzed, & years considered in indexing

No	Journal	Abbreviation	Country	Q-2021		n	YI
				Scopus	WoS		
1	Acta Scientiae [Journal of Science]	ACTA	Brazil	Q4		296	2018-2022
2	African Journal of Research in Mathematics, Science & Technology Education	AJRMSTE	South Africa	Q3		509	1997-2022
3	Annales Universitatis Paedagogicae Cracoviensis | Studia ad Didacticam Mathematicae Pertinentia [Annals of Pedagogical University of Cracow | Studies for Didactics of Mathematics]	AUPC-SDMP	Poland	Q4		25	2019-2021
4	Avances de Investigación en Educación Matemática [Research Advances in Mathematics Education]	AIEM	Spain	Q4		59	2018-2022
5	Bolema: Mathematics Education Bulletin	BOLEMA	Brazil	Q3		740	2010-2022
6	British Journal for History of Mathematics	BJHM	UK	Q4		47	2019-2022
7	Canadian Journal of Science, Mathematics, & Technology Education	CJSMT	Canada	Q2		694	2001-2022
8	Educacion Matematica [Mathematics Education]	EM	Mexico	Q4		120	2018-2022
9	Educational Studies in Mathematics	ESM	Netherlands	Q1	Q2	2,095	1968-2022
10	EURASIA Journal of Mathematics, Science, & Technology Education	EJMSTE	UK	Q1		2,037	2006-2022
11	European Journal of Science and Mathematics Education	EJSME	Cyprus	Q3		64	2020-2022
12	For Learning of Mathematics	FLM	Canada	Q3		159	2011-2022
13	International Journal of Education in Mathematics, Science, & Technology	IJEMST	Türkiye	Q3		158	2018-2022
14	International Journal of Innovation in Science & Mathematics Education	IJISME	Australia	Q3		315	2010-2022
15	International Journal of Mathematical Education in Science & Technology	IJMEST	UK	Q2		4,751	1970-2022
16	International Journal of Science & Mathematics Education	IJSME	Netherlands	Q1	Q3	1,278	2003-2022
17	International Journal of Science, Mathematics, & Technology Learning	IJSMTP	USA	Q4		146	2012-2022
18	Investigations in Mathematics Learning	IML	USA	Q3		196	2008-2022
19	Journal for Research in Mathematics Education	JRME	USA	Q1	Q3	409	1996-2020
20	Journal fur Mathematik-Didaktik [Journal for Mathematics-Didactics]	JMD	Germany	Q3	Q3	671	1980-2022
21	Journal of Mathematical Behavior	JMB	USA	Q2		938	1994-2022
22	Journal of Mathematics Teacher Education	JMTE	Netherlands	Q1	Q3	466	2005-2022
23	Journal of Urban Mathematics Education	JUME	USA	Q4		17	2020-2022
24	Journal on Mathematics Education	JME	Indonesia	Q1		251	2010-2022
25	LUMAT	LUMAT	Finland	Q4		117	2016-2022
26	Mathematical Thinking & Learning	MT&L	USA	Q1	Q4	227	2009-2022
27	Mathematics Education Research Journal	MERJ	Netherlands	Q1		675	1989-2023
28	Mathematics Student	MS	India	Q4		112	2019-2022
29	Mathematics Teaching-Research Journal	MTRJ	USA	Q4		268	2006-2022
30	PRIMUS	PRIMUS	UK	Q3		1.507	1991-2022
31	Research in Mathematics Education	RME	USA	Q3		436	2000-2022
32	Revista Latinoamericana de Investigacion en Matematica Educativa [Latin American Journal of Research in Educational Mathematics]	RELIME	Mexico	Q3		189	2009-2022
33	School Science & Mathematics	SSM	USA	Q4	Q3	139	1973-2022
34	Teaching Mathematics and its Applications	TMA	UK	Q2		1,092	1982-2022
35	Teaching of Mathematics	TOM	Serbia	Q4	Q4	211	1998-2022
36	Turkish Journal of Computer & Mathematics Education	TJMCE	Türkiye	Q4		73	2018-2020
37	ZDM-International Journal on Mathematics Education	ZDM	Germany	Q1	Q2	1,623	1997-2022

Note. UK: United Kingdom; USA: United States; Q: Quarter; n: Number of articles; YI: Years indexed; & Total articles: 23,110

"Global" contains the previous regions and articles with affiliations from countries outside the analyzed regions.

The data were graphically represented using a boxplot, where the horizontal axis displays the regions, and the vertical axis shows the number of citations of the articles.

RESULTS

Global Analysis

Citation distribution by region

The distribution of citations across different geographical regions, as shown in **Table 2** and **Figure 2**

Table 2. Statistics of citations by geographical region

Region	n	Mean	SD	Minimum	Q1	Q2	Q3	Q4	Maximum
Latin America	1,530	3.79	8.69	0	0	1	4	10	106
Africa	1,136	5.94	12.80	0	1	2	6	13	162
USA & Canada	7,619	11.63	29.22	0	1	3	11	26	877
Europe	7,708	8.58	20.85	0	0	2	9	22	764
Global	23,110	9.05	22.69	0	0	2	9	22	877

Note. n: Number of articles; SD: Standard deviation; & Q: Quarter

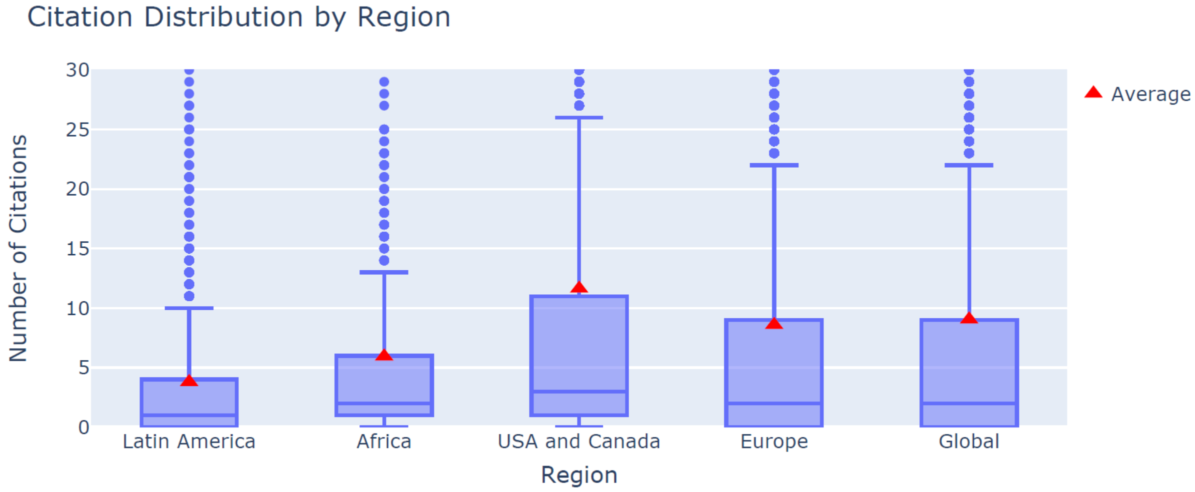

Figure 2. Graph depicting distribution of citations received in *Scopus* for publications in five different geographical regions (boxes show median, 1st & 3rd quartiles [Q1, Q3]; whiskers represent minimum & maximum values within 1.5 times interquartile range [1.5×(Q3-Q1)]; individual outlier values are displayed as circles; & vertical axis is limited between 0 & 30 for better visualization) (Source: Authors' own elaboration)

reveals a significant discrepancy in the number of citations between northern regions (Europe, the United States, and Canada) and southern regions (Latin America and Africa).

Latin America is the region with the lowest impact in terms of citations, both in quartile comparison and average.

A more in-depth analysis of the data indicates that there are a large number of uncited publications in all regions, which could be the result of various factors, such as lack of visibility, the quality of research, or the relevance of the studied subjects.

The absence of whiskers in the plot for Latin America, Europe, and the global set suggests that there is a wide range of publications that have not been cited, leading us to reflect on the reason for this low impact and for whom the writing is intended.

Additionally, it can be observed that the mean is located near the third quartile in all regions. This phenomenon is due to the presence of outliers, that is, those articles that receive an exceptionally high number of citations. These outliers "push" the mean upwards, which could give a distorted impression of the actual impact of publications in each region.

This discrepancy in the citation impact between the northern and southern regions could be the result of differences in resources and support for research, the quantity and quality of international collaborations, and access to publications. It could also be due to a concentration of research topics in areas that are more relevant or popular in the northern regions, resulting in a higher number of citations for those publications.

In summary, the citation distribution displays a clear disparity between geographical regions, and a more detailed analysis is needed to identify the underlying causes of these differences.

Moreover, it is essential to consider the role of outliers and their effect on the means, and to reflect on the possible reasons behind the high proportion of uncited publications in all regions.

Main topics of interest at global level

Regarding the thematic analysis, by calculating the $G_{230,461}$ *Global CRS* or $G_{230,461}$ *complete ERC-Global* based on the articles from the 37 analyzed mathematical education journals, the image shown in **Figure 3** is obtained. Words were classified into five major groups: words associated with disciplinary content (mathematics and sciences), words associated with mathematical education, words associated with education in general, words associated with socio-cultural concepts, and a fifth category containing all words not included in previous categories.

Regional Analysis

Latin America

The principal journals in which articles affiliated with Latin America are published are presented in **Table 3**. It

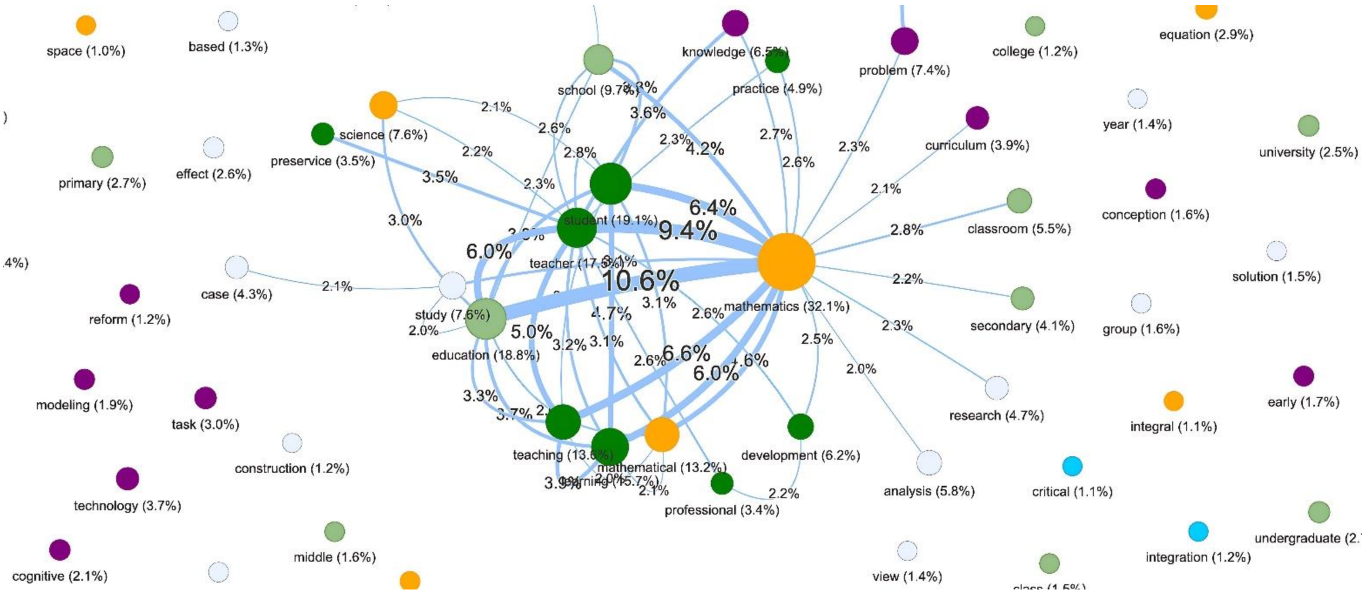

Figure 3. *G230,461 CRS* weighted for 23,110 articles (color code: • Mathematical education concepts; • Disciplinary mathematical concepts; • & • Generic education concepts; • Concepts on social issues; • Concepts not included in other categories; & for a more detailed view of $G_{230,461,}$ see https://datoseducativos.cl/rev_biblio_37_rev_ed_mat_hasta_2022/grafo_podado_GLOBAL_POND_title_key_metodo_met_lemmatize23094_n_23094_f_nodo_230_f_edge_461.html) (Source: Authors' own elaboration)

Table 3. Top-5 journals featuring articles affiliated with Latin American countries (percentage is calculated on 100% corresponding to 1,530 articles affiliated with these countries)

Journal	n	P (%)	AP (%)
Bolema-Mathematics Education Bulletin	589	38.5	38.5
Acta Scientiae [Journal of Science]	205	13.4	51.9
International Journal of Mathematical Education in Science & Technology	119	7.8	59.7
Revista Latinoamericana de Investigación en Matemática Educativa [Latin American Journal of Research in Educational Mathematics]	101	6.6	66.3
Educación Matemática [Mathematics Education]	93	6.1	72.4

Note. n: Number of articles; P: Percentage; & AP: Accumulated percentage

is important to highlight that nearly three-quarters of the articles are concentrated in these journals, four of which belong to the region.

On the other hand, **Figure 4** shows the $G_{15,30}$ *ERC-Latin America*. In this graph, it can be observed that the terms associated with *teacher* (27.8%) and *teaching* (21.6%) are more frequent than the terms associated with *student* (14.8%) and their *learning* (14.2%).

The terms linked to teaching mainly relate to words associated with the various stages of a teacher's professional life, such as *training* (6.5%), *development* (6.5%), *professional* (4.8%), or *preservice* (2.8%). Similarly, there are terms connected with multiple words, both from the teaching and learning process, like *knowledge* (9.7%) or *school* (16.4%).

In the **visible periphery** of $G_{15,30}$ *ERC-Latin America*, words related to **cognitive processes** can be seen, such as *understanding* (3.8%) or *reasoning* (3.0%). Regarding terms linked to **mathematical education**, the following pairs are observed: *problem* (6.9%) and *solving* (4.6%); *technology* (5.2%) and *digital* (3.5%). Additionally, there are isolated nodes like *curriculum* (4.4%), *task* (4.1%), *textbook* (4.0%), *representation* (3.9%), *modeling* (3.7%), *modelling* (3.7%), and *assessment* (2.7%), among others.

Also, words that are not present in the global scope but are in Latin American articles appear, such as *apos* (2.5%), *ethnomathematics* (2.2%), *onto-semiotic* (2.2%), and *socio-epistemology* (1.1%). These words are related to **specific theories of mathematics education** of which ethno-mathematics and socio-epistemology are theoretical perspectives that were initially developed in Brazil and Mexico, respectively.

The main terms associated with **mathematics or disciplinary** are *function* (5.4%), *geometry* (4.0%), *math* (3.9%), *algebra* (3.7%), *calculus* (3.6%), *statistic* (3.5%), *number* (3.3%), *science* (3.2%), *equation* (3.0%), *statistical* (2.8%), *engineering* (2.7%), *algebraic* (2.5%), *differential* (2.5%), *linear* (2.2%), *probability* (2.2%), *derivative* (2.2%), and *geometric* (2.0%), among others.

In summary, the analysis of $G_{15,30}$ *ERC-Latin America* provides an overview of the terms and concepts that prevail in mathematics education research in the Latin American region. It highlights the presence of terms related to teaching and learning, as well as specific

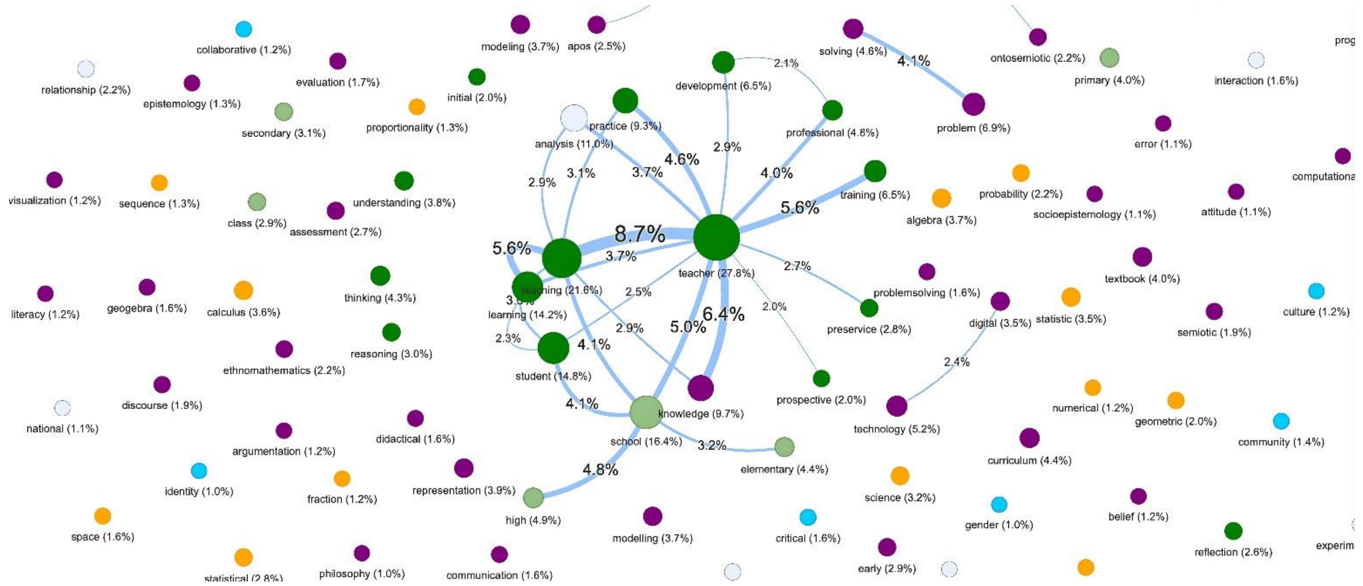

Figure 4. Extract from $G_{15,30}$ pruned *CRS* for 1,530 articles affiliated with **Latin American** countries (pruned words are *education*, *mathematics*, & *mathematical*; color coding: • Mathematical education concepts; • Disciplinary mathematical concepts; • & • Generic education concepts; • Concepts on social themes, & • Concepts not found in other categories; &for a more detailed view of $G_{15,30}$, see https://datoseducativos.cl/rev_biblio_37_rev_ed_mat_hasta_2022/grafo_podado_LATAM_POND_title_key_metodo_met_lemmatize1530_n_1530_f_nodo_15_f_edge_30.html) (Source: Authors' own elaboration)

Table 4. Top-5 journals featuring articles affiliated with African countries (percentage is calculated on 100% corresponding to 1,136 articles affiliated with these countries)

Journal	n	P (%)	AP (%)
African Journal of Research in Mathematics, Science, & Technology	459	40.4	40.4
International Journal of Mathematical Education in Science & Technology	229	20.2	60.6
EURASIA Journal of Mathematics, Science, & Technology Education	159	14.0	74.6
Educational Studies in Mathematics	55	4.8	79.4
ZDM-Mathematics Education	31	2.7	82.1

Note. n: Number of articles; P: Percentage; & AP: Accumulated percentage

concepts of mathematics didactics and disciplinary terms.

Moreover, the influence of theories and perspectives inherent to the region, such as Ethnomathematics and Socio-epistemology, is observed. This analysis can be useful for identifying areas of research interest in mathematics education in Latin America and better understanding the region's peculiarities compared to the global sphere.

Africa

In articles affiliated with African countries, a little over 40.0% of the articles are found in the *African Journal of Research in Mathematics, Science and Technology* from South Africa. The remaining 40.0% is distributed among four journals that are outside African Region (**Table 4**).

On the other hand, **Figure 5** displays $G_{11,22}$ *ERC-Africa*. Here it can be seen that there are more studies focusing on *teacher* (27.6%) and *teaching* (18.3%) than on *student* (22.0%) and their *learning* (20.4%), *learner* (10.1%).

The nodes associated with teachers and teaching are linked with terms related to the **stages of a teacher's professional life** (*development* [7.3%], *practice* [6.8%], *pre-service* [5.9%], *professional* [3.7%], and *in-service* [2.2%]).

Nodes associated with students and their learning are connected with terms related to **educational levels** such as *school* (16.0%), and *high* (2.9%), *secondary* (8.0%), *university* (4.9%), and *primary* (4.0%).

Additionally, there are several nodes connected to both teaching and learning, some of which are **territorial** terms from the continent like South Africa (*south* [11.4%]), *African* (7.0%), and *Africa* (6.3%), other nodes are related to topics inherent to mathematics education (*knowledge* [9.3%] or *curriculum* [7.2%]), disciplinary ones (*science* [17.1%] and *physical* [2.7%]), and about cognitive processes (*understanding* [7.2%]).

In the **visible periphery**, terms related to **cognitive processes** like *thinking* (2.9%) or *reasoning* (1.7%); to **mathematics education**, such as the pair *problem* (5.6%) and *solving* (3.4%) or the unimodal islands *assessment* (5.2%), *strategy* (4.6%), *technology* (3.8%), *perception* (3.1%) and *attitude* (2.6%), among others.

Mathematical or disciplinary terms are seen as main nodes to some terms of basic sciences and school

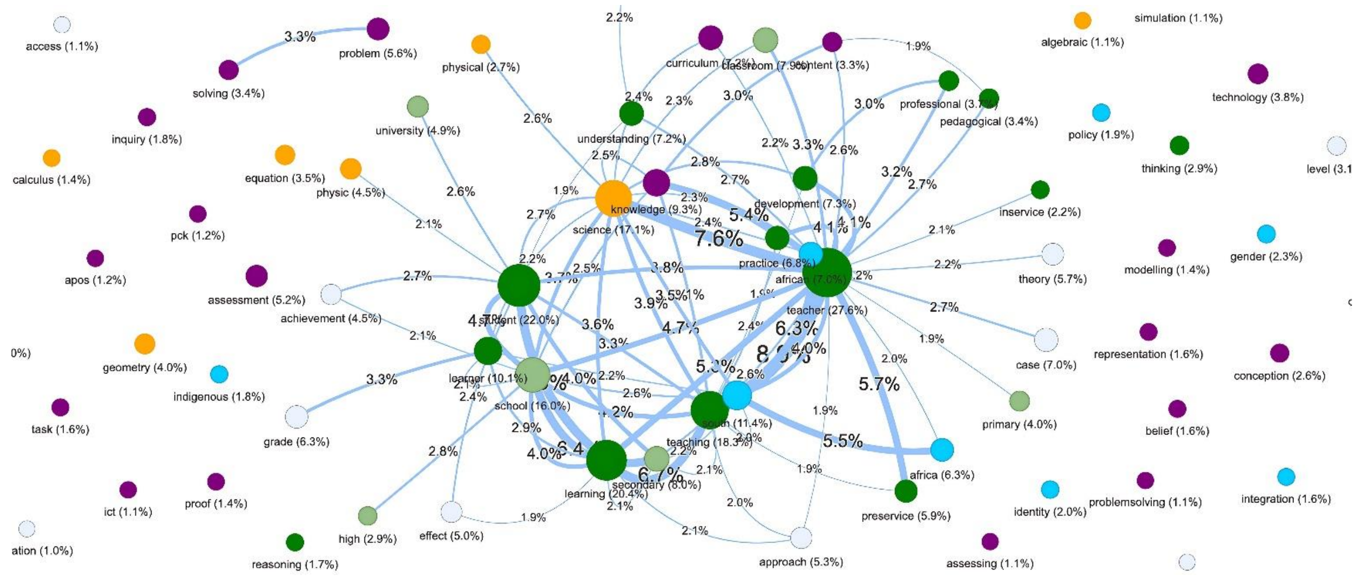

Figure 5. Extract from $G_{11,22}$ pruned *CRS* for 1,136 articles affiliated with **African** countries (pruned words are *education*, *mathematics*, & *mathematical*; color coding: • Mathematical education concepts; • Disciplinary mathematical concepts; • & • Generic education concepts; • Concepts on social themes, & • Concepts not found in other categories; &for a more detailed view of $G_{11,22}$, see https://datoseducativos.cl/rev_biblio_37_rev_ed_mat_hasta_2022/grafo_podado_AFR_POND_title_key_metodo_met_lemmatize1136_n_1136_f_nodo_11_f_edge_22.html) (Source: Authors' own elaboration)

Table 5. Top-5 journals featuring articles affiliated with **the United States & Canada** (percentage is calculated on 100% corresponding to 7,619 articles affiliated with these countries)

Journal	n	P (%)	AP (%)
International Journal of Mathematical Education in Science & Technology	1,455	19.1	19.1
PRIMUS	1,466	19.2	38.3
Educational Studies in Mathematics	648	8.5	46.8
Journal of Mathematical Behavior	638	8.4	55.2
Canadian Journal of Science, Mathematics, & Technology Education	487	6.4	61.6

Note. n: Number of articles; P: Percentage; & AP: Accumulated percentage

curriculum terms such as more advanced topics in mathematics, such as, *physics* (4.5%), *geometry* (4.0%), *equation* (3.5%), *chemistry* (3.0%), *number* (2.6%), *function* (2.6%), *biology* (2.5%), *engineering* (2.2%), *scientific* (2.1%), *linear* (1.5%), *calculus* (1.4%) and *algebra* (1.3%), among others.

In addition, some **social** terms such as *gender* (2.3%), *community* (2.1%), *identity* (2.0%), *policy* (1.9%), and *indigenous* (1.8%), among others, are observed.

In summary, articles affiliated with African countries are concentrated in a few journals, primarily in *African Journal of Research in Mathematics, Science and Technology*. Studies in Africa focus more on teachers and teaching than on students and their learning. The terms associated with teaching are related to stages of a teacher's professional life, whereas terms associated with learning are linked to educational levels. In addition, territorial, mathematics education-related, disciplinary, cognitive processes, and social terms are found in the *ERC-Africa* analysis.

The United States & Canada

In this region of the globe, 60.0% of the publications in the analyzed group of journals are produced in five journals of which the first three are from Europe, and the last two are from the United States and Canada, respectively (**Table 5**).

Upon calculating the $G_{76,152}$ *ERC-US-Canada*, the **Figure 6** is obtained. This reveals a slight predominance of articles related to *student* (19.6%) and *learning* (15.9%) over articles about *teacher* (18.9%) and their *teaching* (13.4%).

In the teaching pole, it is connected with **stages of professional life of the teaching staff** such as *development* (6.5%) and *professional* (3.9%); *practice* (6.0%) and *preservice* (4.4%), as well as with **teaching levels**, specifically *elementary* (6.3%) and *secondary* (3.6%), and in the **disciplinary** aspect with *science* (7.7%).

The student pole is connected with words associated with **cognitive perspectives** such as *reasoning* (5.6%) and *understanding* (5.3%), and with *calculus* (7.9%) in the **disciplinary** aspect.

Moreover, both teaching and learning are connected with school (*school* [7.4%] and *high* [2.5%]) and with knowledge (*knowledge* [6.8%]).

In the **visible periphery** of $G_{76,152}$ *ERC-USA-Canada*, words associated with **mathematical education** are observed, such as the pair *problem* (7.5%) and *solving*

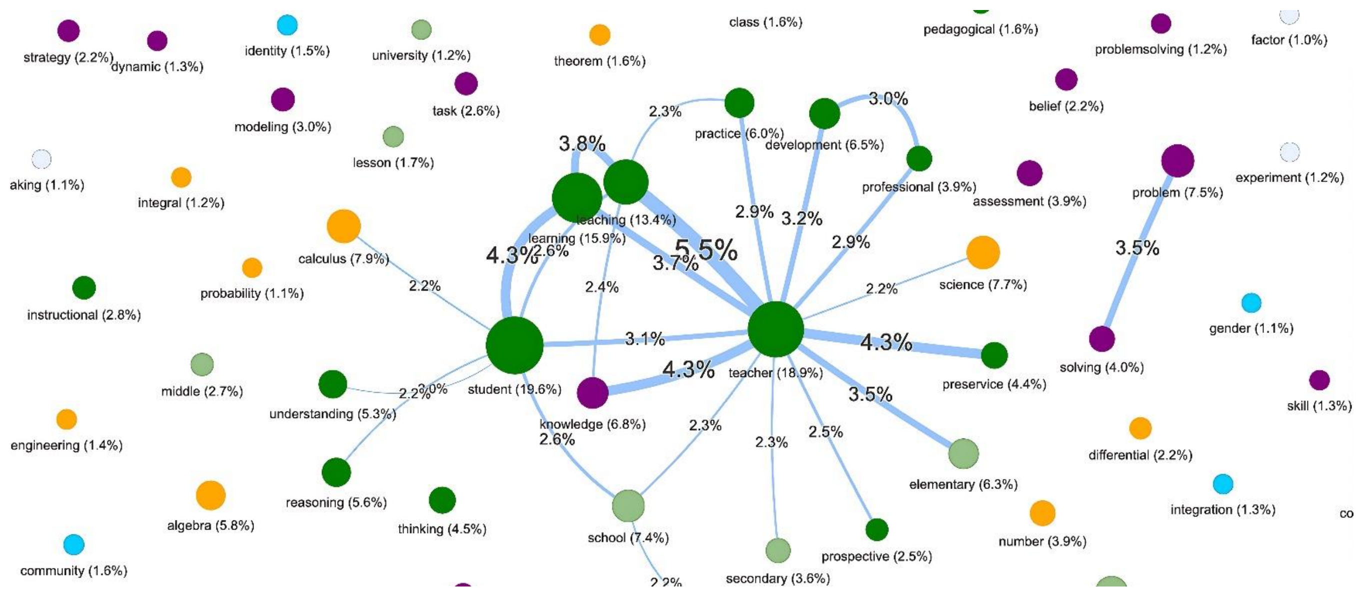

Figure 6. Extract from $G_{76,152}$ pruned *CRS* for 7,619 articles affiliated with **the United States & Canada** (pruned words are *education*, *mathematics*, & *mathematical*; color coding: • Mathematical education concepts; • Disciplinary mathematical concepts; • & • Generic education concepts; • Concepts on social themes, & • Concepts not found in other categories; &for a more detailed view of $G_{76,152}$, see https://datoseducativos.cl/rev_biblio_37_rev_ed_mat_hasta_2022/grafo_podado_USA_CAN_POND_title_key_metodo_met_lemmatize7619_n_7619_f_nodo_76_f_edge_152.html) (Source: Authors' own elaboration)

Table 6. Top-5 journals featuring articles affiliated with **European** countries (percentage is calculated on 100% corresponding to 7,716 articles affiliated with these countries)

Journal	n	P (%)	AP (%)
International Journal of Mathematical Education in Science & Technology	1,740	22.6	22.6
Educational Studies in Mathematics	863	11.2	33.8
ZDM-Mathematics Education	852	11.1	44.9
Teaching Mathematics & Its Applications	796	10.3	55.2
EURASIA Journal of Mathematics, Science, & Technology Education	457	5.9	61.1

Note. n: Number of articles; P: Percentage; & AP: Accumulated percentage

(4.0%), in addition to *curriculum* (5.0%), *proof* (4.1%), *assessment* (3.9%), *technology* (3.5%), *modeling* (3.0%), *representation* (2.9%), *task* (2.6%), *discourse* (2.2%), *reform* (2.2%), *belief* (2.2%), and *STEM* (2.2%), among others.

In the **mathematical or disciplinary** terms, there appear *algebra* (5.8%), *function* (4.2%), *number* (3.9%), *equation* (3.7%), *geometry* (3.3%), *linear* (2.7%), *fraction* (2.3%), *differential* (2.2%), *statistic* (1.9%), *theorem* (1.6%), and *algebraic* (1.4%), among others.

Also, more discreetly, some terms related to social themes appear such as *social* (1.8%), *community* (1.6%), *identity* (1.5%), and *equity* (1.2%).

In summary, the analysis of *ERC-USA-Canada* reveals a greater focus on issues related to students and learning, compared to teaching staff and teaching. An emphasis on cognitive aspects, different levels of teaching and specific disciplinary areas is also evident. Words related to mathematical education and mathematical topics occupy a prominent position, while terms linked to social issues appear more discreetly.

Europe

Similar to Latin America, the United States, and Canada, a little over 60.0% of the publications affiliated with European countries are found in five journals, four of which belong to the same region, as shown in **Table 6**.

Upon analyzing $G_{77,154}$ *ERC-Europe*, a slight predominance of themes related to *student* (15.4%) and their *learning* (12.2%) is observed, compared to themes about *teacher* (14.1%), and *teaching* (12.1%).

In relation to the teacher node, following the trend observed in other *ERCs*, the related nodes correspond to the stages of a teacher's career (*development* [5.6%] and *professional* [3.1%]), in addition to knowledge (*knowledge* [6.0%]).

As for the student node, it is connected with the **school and its levels**: *school* (8.8%), *secondary* (4.3%), and *primary* (4.2%).

In the **visible periphery** of $G_{77,154}$ *ERC-Europe*, words associated with **mathematical education** are found, such as the pair *problem* (7.2%) and *solving* (3.9%); along with other terms, like *modelling* (3.9%), *task* (3.3%), *assessment* (3.2%), *representation* (2.6%), *technology* (2.6%), *curriculum*

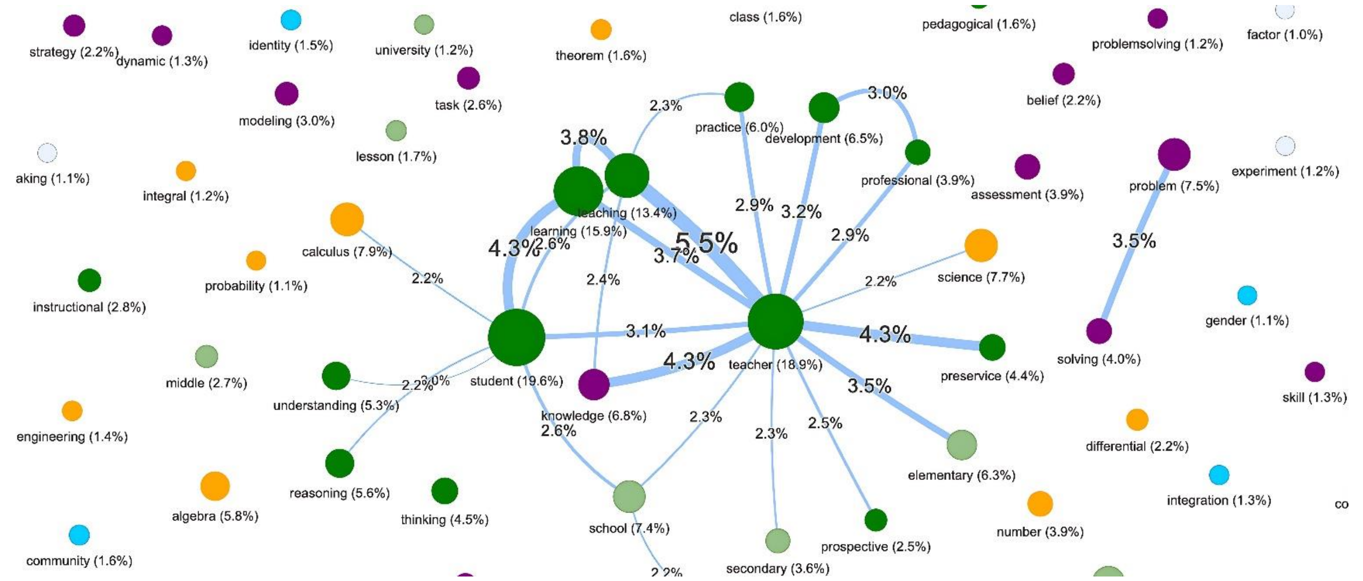

Figure 7. Extract from $G_{77,154}$ pruned *CRS* for 7,619 articles affiliated with **the European** (pruned words are *education*, *mathematics*, & *mathematical*; color coding: • Mathematical education concepts; • Disciplinary mathematical concepts; • & • Generic education concepts; • Concepts on social themes, & • Concepts not found in other categories; &for a more detailed view of $G_{77,154}$, see https://datoseducativos.cl/rev_biblio_37_rev_ed_mat_hasta_2022/grafo_podado_EUR_POND_title_key_metodo_met_lemmatize7708_n_7708_f_nodo_77_f_edge_154.html) (Source: Authors' own elaboration)

(2.5%), *proof* (2.5%), *computer* (2.5%), *strategy* (2.2%), and *belief* (1.9%), among others.

In terms of **mathematical or disciplinary** terms, *science* (4.9%), *number* (3.4%), *geometry* (3.0%), *function* (2.8%), *algebra* (2.5%), *equation* (2.2%), *engineering* (1.6%), *linear* (1.5%), *arithmetic* (1.5%), *calculus* (1.4%), *statistic* (1.4%), *physic* (1.4%), *algebraic* (1.3%), and *differential* (1.2%), among other terms, appear. Words with low frequency related to **social** aspects are observed.

The analysis of *ERC-Europe* reveals a slight prevalence of topics related to students and their learning compared to topics on teachers and teaching. Disciplinary or mathematical terms are also present, and words with low frequency linked to social aspects are observed (**Figure 7**).

CONCLUSIONS & DISCUSSION

In the introduction of this work, extensive literature on bibliographic reviews in mathematics education was mentioned. Globally, the study by Julius et al. (2021) stands out for having analyzed 12,670 articles. In contrast, this work reviewed more than 23,000 articles, showing a significant difference. It is important to point out that this discrepancy is not due to the two years not covered in the cited study, since in 2021 and 2022, the specialized journals examined in this work published around 3,000 articles. The disparity primarily lies in how the field of mathematics education is delimited in this and other bibliometric review works, which consists of associating the disciplinary field with a few keywords. In fact, according to Julius et al. (2021, p. 3), the search was based on the terms: TITLEABS-KEY(mathematics AND (edu* OR teach* OR learn* OR train* OR pedagogy OR student* OR curricul*)), meaning that only a minimum part of the words that encompass research in specialized journals were used, as observed in the different *ERCs* analyzed in this work.

To be more precise, when searching for the intersection of these words with the specialized journals of this article, just over 9,000 articles are obtained, that is, less than half. This situation not only occurs in global searches but also in searches for specific topics, as many articles are often excluded due to the limited use of keywords in the search.

Another interesting result is the asymmetry observed in the large number of articles of bibliographic reviews of technology, which in both the global and regional analysis, does not exceed 6.0%, in contrast to the few bibliographic reviews focused on the teacher or the student, which are the most recurring nodes in each of *ERCs* analyzed.

In relation to the global and regional *ERCs*, it was observed that, in addition to the student and the teacher, the topics on cognitive processes are the most frequent nodes. On the contrary, studies involving embodied, inactive, or emotional perspectives are part of the invisible periphery, that is, they appear well below 1.0%.

Although there are differences between regional emphases, this thematic difference seems much more attenuated than the difference in the impact of articles. Large number of uncited articles is also observed, which would require specific analysis, as they are invisible and this could be for a number of reasons, from how recent these could be, to the themes analyzed, among many other reasons. Writing an article seems to be throwing a bottle with a message into the sea that may reach someone, however, it is observed that many of these messages do not reach anywhere, at least as far as *Scopus* metrics are concerned.

In terms of regional analysis, on one hand, there is some convergence on the big nodes: teachers and students. However, the emphases and denominations vary, especially in relation to the initial training of teachers. In the countries of the global south, there is an emphasis on studies focused on teachers, while in the countries of the north, there is a greater focus, although slight, on students. In addition, some words are observed in the visible periphery both in Latin America and in Africa that do not appear either in the global analysis or in the other regions. In the case of Latin America, we refer to words that refer to theoretical currents developed in the region, such as Ethnomathematics or Socio-epistemology, in addition to other theoretical currents that appear frequently. In the case of Africa, what is distinctive.

Like all studies, this one has its limitations. The most obvious limitation is that, although this review is larger than all those described in the problem, this work only considers specialized journals, leaving out all the mathematics education research present in related journals, such as Enseñanza de las Ciencias [Science Teaching], Computer Applications in Engineering Education or Computer & Education, among many others. Also left out are articles on mathematics education that appear in journals that are neither in the area nor related, but that accept articles related to the subject, for example, Estudios Pedagógicos [Pedagogical Studies] or Education Policy Analysis Archives, among many other journals. This is without considering that there are a series of specialized journals, related journals, and articles in the area outside *Scopus* and *WoS*, which were the search universes in this case.

This study, together with the limitations just stated, has theoretical implications when it comes to delimiting research in a field of study or a subfield. In our particular case in mathematics education. In the literature review, several articles are presented as a global review of the field, but only by a numerical comparison we see that they are far from being comprehensive reviews. We should question more deeply how we can find all the articles that correspond to mathematics education or another topic of interest.

Another theoretical implication of this work has to do with making an analysis using the multiple relationships offered by graph theory. Dichotomous classifications are difficult to sustain, except in very coarse analyses. On the other hand, the multiplicity of meanings that words can have shown the importance of metadata, particularly keywords. It also shows their limitations. For a more precise classification of articles, current systems have the ability to store words according to specific parts of a paper. For example, if an author could place keywords according to subject matter, theoretical aspects and methodological aspects, among others, the analysis of large numbers of articles would be more accurate. In practical terms, this forces us to change and combine techniques and perspectives to delimit the field, for example, complementing the search in specialized journals with word searches, by authors in the field and combining them with AI analysis techniques, to establish with some degree of certainty those articles that really belong to the field.

These complementary techniques, together with an analysis of the literature using graphs (among other possible techniques) open up a series of possibilities for systematic literature reviews. This work sought to give a glimpse of the field of mathematics education through the analysis of 37 specialized journals, however, in the near future we want to deepen and extend this search in at least two directions. The first is to try to extend this search to the entire field of mathematics education, considering the limitations mentioned above. The second is to try to extend and deepen the analysis of more thematic reviews, for example, analyzing the scientific production of the field in a particular region, such as Latin America, or of some subtopic of the area, such as technology, among many others.

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Ethical statement: The authors stated that the study did not require an ethics committee. The study did not involve human or animal research. Additionally, data that is available through public domains were used during the study.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: All data from this study can be found in the following public repository: https://github.com/jorgegaonap/37_journal_math_education/blob/main/df_final.csv

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