Mapping the Intellectual Landscape of Critical Mathematics Education: A Systematic Retrospective (2000-2025)

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Abstract

Critical Mathematics Education (CME) positions mathematics classrooms as sites where learners develop critical consciousness, democratic agency, and engagement with the socio-political dimensions of mathematical knowledge. CME draws on the Freirean and Frankfurt School traditions to assert that mathematics education is not a politically neutral enterprise, but a site where structures of oppression are either reproduced or contested. Despite the theoretical richness of its foundations, the intellectual structure of CME scholarship has not been comprehensively mapped. This study addresses that gap through a systematic bibliometric analysis of 160 indexed scholarly publications from 2000 to 2025, drawn from the Web of Science and Scopus databases. A science mapping approach was employed, incorporating network and temporal analyses to trace the field's conceptual evolution. The analysis is framed reflexively: citation databases are treated as commercial infrastructures whose coverage encodes linguistic and economic hierarchies that CME itself sets out to critique. Educational Studies in Mathematics emerged as the leading publication outlet, while Ole Skovsmose was the central foundational figure in the co-citation structure. Fourteen thematic groupings, read alongside timeline and time-zone visualisations, supported three broad phases: an epistemological formation phase (2000-2009), a pedagogical and teacher-oriented *expansion phase (2010-2018), and a socio-political diversification phase (2019-2025) marked by climate change, decolonial perspectives, translanguaging and critical citizenship. Despite CME's dialogic commitments, collaboration networks remained fragmented. The study offers a reflexive map of the indexed CME literature and identifies both its emerging directions and the exclusions produced by the infrastructures through which that literature becomes visible.*

Keywords: *critical mathematics education; social justice; neoliberal critique; science mapping; emancipatory pedagogy*

Introduction

This article situates itself within the tradition of critical education policy studies (Aguilar & Zavaleta, 2012; Apple, 1992, 2013; Giroux, 2007, 2020). Mapping the intellectual structure of CME is not merely a bibliometric exercise. It is a political intervention. Understanding how CME scholarship has been produced, by whom, in which institutional centres, and in response to which policy contexts, is essential for building CME as a coherent force for educational transformation (Ghosh, 2018; Gonzalez, 2009; Gutstein, 2008). As neoliberal education reform continues to reduce mathematics to a tool for labour market competitiveness, the urgency of tracing and strengthening CME's emancipatory project grows ever more pressing (Balliester Reis & Yoon, 2025).

In an era defined by algorithmic governance, ecological crisis, and deepening socioeconomic inequality, the question of whose mathematical knowledge counts has become a matter of democratic urgency (Skovsmose, 1985, 1992). Credit scoring systems, predictive policing algorithms, and automated judicial platforms increasingly deploy mathematics as a black box, encoding social bias

as objective truth while reproducing the very inequalities they purport to measure. In this context, mathematical literacy, or what Skovsmose (1994b) terms mathemacy, is no longer simply a school subject; it is a fundamental matter of human rights and democratic citizenship. It is precisely within this contemporary landscape that Critical Mathematics Education (CME) has developed as a field of democratic resistance. While mainstream mathematics education often operates within an authoritarian and banking framework, CME provides a philosophical and practical orientation towards emancipation (Avcı, 2022; Skovsmose, 2000, 2014), asserting that mathematics education is a political activity that aims to identify and challenge social, political, and economic injustices (Ernest, 1994; Gutstein, 2006; Skovsmose, 1994a, 2011).
The critical element in CME is rooted in a profound intellectual tradition, extending from Kantian critique through Marxist political economy to the Frankfurt School, whose thinkers, including Horkheimer, Adorno, and Marcuse, distinguished critical theory from traditional theory by employing an interdisciplinary, dialectical-materialist approach to dismantle oppressive social structures (Alrø & Skovsmose, 2002; Avcı, 2019; Skovsmose, 1994a). Unlike traditional theory, which employs mathematical and scientific laws to maintain the equilibrium of existing social arrangements, critical theory seeks to expose and transform them (Cotton, 2012; McLaren, 2014, 2015; Shor, 1987).
The theoretical foundations of CME are firmly rooted in the Freirean tradition (Freire, 1970a, 1970b), particularly the problem-posing pedagogical paradigm. Building on this critical approach, scholars such as Ole Skovsmose (1990, 1994a) have examined the shaping power of mathematics. They argue that mathematics is not a neutral representation of reality, but rather an active force that shapes our sociotechnical infrastructures and normative practices. However, a crucial distinction must be made between neoliberal critical thinking and the critical essence of CME. Avcı (2019) argues that critical thinking often aligns with neoliberal demands for efficiency. In contrast, CME is rooted in a

transformative tradition that seeks to foster class consciousness and democratic citizenship (Bigelow & Peterson, 2002; Borba & Skovsmose, 1997; Dowling, 1997).

In the current climate of neoliberal encroachment on education, where STEM subjects are increasingly seen as tools for global market competition, CME emerges as a key site of ontological resistance (Skovsmose, 2022). While bodies such as the National Council of Teachers of Mathematics (2000) often conceptualise social justice as equal opportunity, CME deconstructs this as a neoliberal artifice that obscures the socioeconomic precarity and historical trauma experienced by students (Avcı, 2019; Gutstein & Peterson, 2005). Therefore, a substantive commitment to social justice in mathematics requires a radical examination of structural inequalities and a shift away from the performative rhetoric of diversity and inclusion towards a transformative struggle against systemic stratification (Skovsmose, 2008).

Through the strategic integration of dialogic pedagogy, collective enquiry and Skovsmose's landscapes of investigation, the CME project aims to reconstitute students as autonomous political subjects capable of transformative agency (Skovsmose, 2003, 2011). To chart the development of these ideas, the present study conducts a comprehensive bibliometric analysis of literature published between 2000 and 2025, elucidating the evolutionary trajectory of these critical discourses in response to the growing complexities of hyper-globalisation.

Perspectives on Critical Mathematics Education

Critical Mathematics Education (CME) is characterised by a plurality of perspectives that converge on a single premise: mathematics education is never neutral, but is a socio-political activity that either perpetuates existing power imbalances or serves as a means of emancipation (Apple, 1992, 2019; Avcı, 2019; Skovsmose, 1994a). As Ernest (2004) argues, mathematics is inextricably embedded within socio-political contexts, meaning any pedagogical intervention is inherently ideological. This perspective encourages an epistemological shift from the content of the curriculum to how it is delivered, seeking to expose the interests served by hierarchical educational policies and the populations marginalised by oppressive institutional structures (Avcı, 2019; Skovsmose, 1994b).

Based on this socio-political foundation, Ole Skovsmose's scholarship (1994a, 2011) introduces a pivotal philosophical dimension through the theoretical concept of mathematics' formatting power. This perspective posits that mathematics functions not merely as a descriptive medium, but as an active force that shapes social reality through technological architectures, algorithmic governance and bureaucratic systems. In this context, traditional mathematical skills are inadequate for meaningful participation in society (Bartell, 2013; Stinson et al., 2012). Consequently, CME advocates cultivating mathemacy: a form of reflective knowledge based on Freirean literacy (Freire, 1994, 1997a, 1997b; Moses & Cobb, 2001). This critical competence enables individuals to evaluate the normative implications of mathematical applications, empowering them to transition from passive observers to politically engaged citizens capable of exercising rigorous democratic agency within an increasingly technocratic global order (Skovsmose, 1994b, 2022).

These theoretical and ideological orientations culminate in a pedagogical praxis that opposes Paulo Freire's banking model of education (Freire, 1985, 2000). Rejecting the passive reception of commodified knowledge, CME promotes dialogic engagement and collaborative inquiry, combining functional numeracy with rigorous critical literacy (Atweh & Bland, 2005; Skovsmose, 2011). This stance compels students to interrogate material conditions, from ecological degradation to economic exploitation, employing mathematical mediation as a vehicle for social critique, and striving toward a substantively just democratic order (Avcı, 2019; Frankenstein, 1998; Klein, 1932; Özdemir & Avcı, 2024; Vithal, 2003).

A Brief Historical Background

The emergence of CME in the 1980s marked a significant shift in focus from purely cognitive development to a multidimensional exploration of mathematics as a socio-political endeavour (Frankenstein, 1987, 1989; Freitas, 2008; Mukhopadhyay & Greer, 2005; Stinson et al., 2007). While earlier paradigms treated the mathematics classroom as a sanctuary of neutrality, Marilyn Frankenstein's pioneering scholarship (1983) redefined this space by framing the maths curriculum as a site for the reinvention of Paulo Freire's critical pedagogy. This conceptual breakthrough shifted the focus towards a praxis that enables students to decode the socio-economic asymmetries embedded in their lived experiences. It positioned mathematics not as a passive subject of study, but as a reflective tool for scrutinising structural injustices (Frankenstein, 1990, 1995; Gutstein, 2003; Özdemir & Avcı, 2024).

During this formative period, the field's intellectual landscape was significantly enriched by diverse traditions that challenged Western-centric and colonialist epistemologies. Ubiratan D'Ambrosio's introduction of ethnomathematics in 1985 and 1998 disrupted the hegemony of absolute truths by foregrounding the cultural and ethnographic dimensions of mathematical knowledge. His work elucidated how power relations within society act as filters that marginalise non-dominant cultural codes, thereby necessitating an educational framework that recognises pluralistic modes of thinking. Concurrently, Stieg Mellin-Olsen (1987) expanded the critical discourse by combining Vygotskian activity theory (Vygotsky, 1978) with Bernstein's linguistic analyses (Lerman & Zevenbergen, 2004). He claimed that students' systemic failure is frequently a consequence of a pedagogical gap between their indigenous mathematical cultures and the alienated curricula of formal schooling.

While Frankenstein anchored the movement in Freirean principles, Ole Skovsmose (1994a) established a rigorous philosophical connection with the Critical Theory of the Frankfurt School (Frankenstein, 1983; McLaren, 1999; McLaren & Giarelli, 1995; Habermas, 1972, 1973, 1979). Skovsmose's contribution was transformative. He challenged the positivist notion of mathematics and put forward a new classification of knowledge (Skovsmose & Greer, 2012). This taxonomy, consisting of mathematical, technological and reflective knowledges, elevated the goal of mathematics education beyond mere algorithmic proficiency. By emphasising reflective knowing as the vital capacity to evaluate the social consequences of mathematical applications, Skovsmose effectively addressed the existential question of whether mathematics can be a force for social change in modern societies (Skovsmose, 1998).

By the late 1990s and early 2000s, these converging perspectives, spanning social justice pedagogy and ethnomathematical critique, had established CME as a robust academic field (Atweh & Brady, 2009; Chartres, 2008). The historical evolution of these discourses reflects a shift from localised interventions to a global critique of how mathematics serves the technocratic demands of the modern order. As Keitel and Vithal (2008) and Ernest (2001) have observed, CME's history is one of continuous growth, evolving from critiquing classroom interactions to resisting the neoliberal standardisation of knowledge, with the aim of reclaiming mathematics as an essential tool for democratic agency and social emancipation.

Research Rationale and Intellectual Mapping

Despite the profound theoretical foundations of CME established over several decades, a significant gap remains in quantitative understanding of its global evolution and scholarly trends. Although discourses on the formative power of mathematics, social justice, and resistance to neoliberal regimes are well documented (Alrø et al., 2010; Avcı, 2019; Ernest, 2002; Skovsmose, 2023), a longitudinal examination of CME's publication trends, collaborative networks, and intellectual structure would provide a more comprehensive view of the field's development and ongoing trajectory.

CME scholarship, by its very nature, sits at the intersection of education, sociology, critical theory, and philosophy, a positioning that has historically led to fragmented and siloed knowledge production. Science mapping is therefore not merely a methodological convenience but an intellectual necessity: it allows the field to see itself whole, revealing which research communities are in dialogue, which knowledge networks remain hierarchical or exclusionary, and how the vision of decolonial mathematics education has diffused across the global scholarly landscape. This approach enables researchers to identify key themes, highlight knowledge gaps, and trace conceptual evolution across the academic landscape (Baker et al., 2020; Ellegaard & Wallin, 2015; Özdemir, 2024). It is precisely this capacity to reveal structural patterns and address existing gaps in the literature that makes science mapping the most suitable framework for the present study.

Within the broader field of educational research, bibliometric tools are increasingly being used to examine conceptual shifts and disciplinary development across academic areas (Aria & Cuccurullo, 2017; Cisneros et al., 2018). However, comprehensive systematic mapping within the specific realm of Critical Mathematics Education remains limited, despite CME's distinctive position as both a theoretical framework and a practical response to deepening global educational crises. Against this backdrop, the primary objective of this article is to conduct a systematic science mapping review of existing CME literature to chart its scientific output and intellectual evolution, with particular interest in the extent to which CME has transitioned from theoretical critique to a globally recognised movement engaged in addressing structural inequalities in education. The following research questions guided this inquiry:

Research Question 1: What are the key publication outlets, publications, countries, institutions, authors, and research networks that define the indexed CME literature?

Research Question 2: What are the primary research topics investigated in the literature from 2000 to 2025, and how has the conceptual orientation of CME research evolved across this period?

Method

This descriptive study used the bibliometric analysis method to systematically examine existing research on CME. This is defined as a rigorous quantitative assessment of a specific body of literature based on its bibliographic characteristics (Brown et al., 2020; Hawkins, 2001; Khan et al., 2021). Such studies review scholarly literature within the framework of predefined criteria and perform quantitative analyses to map publication patterns, structural networks and conceptual shifts over time (Agarwal et al., 2016; Donthu et al., 2021). Consequently, bibliometric studies have become a highly valued research tool across diverse academic fields as they provide researchers with essential, data-driven insights into the historical trajectory and emerging trends of a given discipline (Ellegaard & Wallin, 2015). The design, execution, and reporting of this science mapping study adhere to the GLOBAL (Guidance List for the repOrting of Bibliometric AnaLyses) checklist standards, ensuring transparency, reproducibility, and methodological integrity (Ng et al., 2025).

Data Collection Procedure

The data for this study were obtained on 25 February 2026 from two of the world's most authoritative and comprehensive citation databases: the Web of Science (WoS) Core Collection and Scopus. Maintained by Clarivate Analytics, the WoS Core Collection is widely recognised for its rigorous curation and strict indexing standards, providing access to high-impact journals (Huang et al., 2022; Zhu & Liu, 2020). In contrast, Scopus, developed by Elsevier, provides extensive coverage of the social and educational sciences (Burnham, 2006; Schotten et al., 2017). Combining data from both databases provides a robust foundation for bibliometric analysis and minimises the risk of overlooking significant scholarly contributions (Birkle et al., 2020; Mongeon & Paul-Hus, 2016; van Eck & Waltman, 2010).

The literature search was conducted using the exact keyword phrase 'Critical Mathematics Education'. To guarantee comprehensive coverage of the relevant literature, the search was systematically executed across the fields of article titles, abstracts and author keywords in both databases.

A note on demarcation is required at this point. The exact-phrase strategy adopted here retrieves the literature that explicitly names itself as Critical Mathematics Education. It does not retrieve the considerably broader terrain of critical work in mathematics education, which includes ethnomathematics (D'Ambrosio, 1985, 1998; Knijnik, 1998, 2002), teaching mathematics for social justice (Gutstein, 2003, 2006), critical statistics and data education (Weiland, 2019), critical race and feminist scholarship in mathematics education (Gutiérrez, 2013; Stinson et al., 2007), and the Indigenous, decolonial and popular-education traditions that address mathematical knowledge without adopting CME as a label. This study therefore maps a demarcated and self-identifying subfield rather than the whole of critical mathematics studies in education. Wherever the term field is used in what follows, it should be understood in this restricted sense.

Following the initial search, inclusion and exclusion criteria were applied to refine the dataset. The analysis was restricted to English-language scholarly records published up to the end of 2025 and indexed in the selected Web of Science and Scopus fields. Records from 2026 were excluded to avoid introducing a partial publication year. The source-level output was retained as indexed in the two databases, so the corpus is dominated by journal articles while a small number of book-based source records remain visible in the source analysis. English-language restriction was used for consistency in text mining, not as an indicator of scholarly quality. Because indexing can occur retrospectively, the 2025 count should be interpreted as the records indexed by the retrieval date rather than as an immutable final total.

As the search was conducted across two major databases, significant overlap in the retrieved literature was anticipated. The initial datasets were extracted and the Scopus records were first converted to the Web of Science (WoS) format using CiteSpace software to ensure data uniformity. The datasets from both databases were then imported and merged. A rigorous data cleaning and deduplication process was then carried out in CiteSpace to identify and remove all duplicate records, ensuring that each unique record was represented only once in the final dataset.

Methodological rigour was supported by an independent verification procedure during data retrieval. On the scheduled search date, two experts performed the same searches and extractions using separate workstations. After merging and deduplicating the data, the resulting datasets were cross-referenced for consistency. The two procedures produced the same retained record set, supporting the procedural reproducibility of the retrieval and deduplication workflow.

Data Analysis

The data collection and refinement process yielded a final dataset comprising 160 indexed scholarly publications, published between 2000 and 2025. Once the data file had been prepared, a comprehensive scientific mapping technique was applied using three analytical tools: The Bibliometrix package in R, VOSviewer (version 1.6.20) and CiteSpace (version 7.0.R0 (64-bit) Advanced) (Arruda, 2022; Chen, 2006; Chen et al., 2012; Cobo et al., 2011; Maliha, 2024; van Eck & Waltman, 2010; Wong, 2018). Scientific mapping is a robust methodological approach for evaluating structural relationships and intellectual dynamics within a research domain through visual networks (van Raan, 2014). Figure 1 illustrates the overall research procedure, including the phases of data identification, screening and analysis.

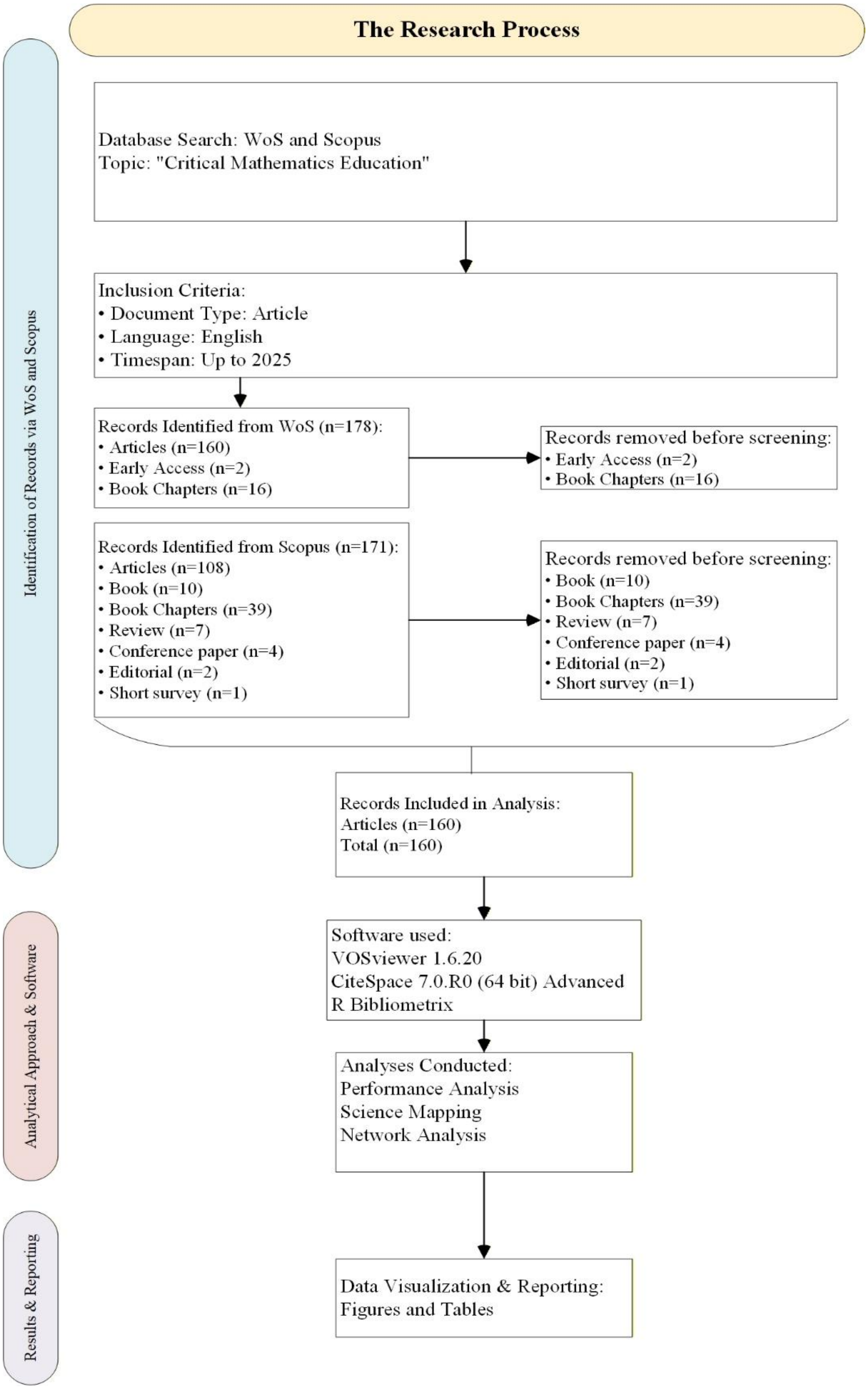

Figure 1. Research Process of the Study.

Specifically, Research Question 1 was addressed through a series of comprehensive bibliometric analyses, including citation, co-authorship, and bibliographic coupling analyses (Huang & Chang, 2011; van Eck & Waltman, 2021). Scholarly influence and author productivity were evaluated using standard bibliometric indicators and hybrid metrics such as the h, g and m-indexes. Furthermore, Price's Law (Price, 1965) was applied to identify the core group of authors who were instrumental to the field's development. Finally, temporal trends were examined to capture fluctuations in research activity across the timeframe of 2000–2025 (Biscaro & Giupponi, 2014; Ji et al., 2022).
Collaboration patterns within the CME literature were explored through co-authorship network analysis. These networks were generated using VOSviewer: node sizes reflect author productivity; links represent collaborative relationships, and total link strength (TLS) indicates the intensity of these connections within the network. The same procedures were used to examine scholarly collaboration at institutional and country levels. For country-level analyses, publications were classified as either single-country (SCP) or multi-country (MCP). This distinction enabled a precise evaluation of research produced nationally versus internationally in addressing global educational inequalities.
The intellectual structure of the field was examined in more detail using document co-citation and bibliographic coupling analyses. Co-citation analysis identified influential foundational works that were frequently cited together, highlighting shared conceptual or theoretical frameworks, particularly the integration of critical theory and mathematics. Conversely, bibliographic coupling used shared reference patterns to identify contemporary documents that address similar socio-political issues in mathematics education. Additionally, comparing local and global citation counts revealed publications that played a central role in shaping the CME discourse.
Building on this structural analysis, Research Question 2 was addressed through co-word, clustering and temporal analyses. Frequently occurring terms were

extracted from the available abstracts of the retained records and organised into thematic groupings. The tabular grouping reported in Table 4 was labelled using the log-likelihood ratio (LLR) algorithm, which identifies terms that are comparatively distinctive of a grouping (Chen, 2014; Chen et al., 2012; Yan & Zhiping, 2023). The timeline and time-zone visualisations were used as complementary representations of thematic continuity and temporal concentration rather than as numerical crosswalks to the LLR table.

The evolution of the identified topics was explored further through timeline and time-zone visualisations and burst-term analysis in CiteSpace. Such techniques help identify periods in which particular concepts receive heightened attention (Kleinberg, 2003). Cluster homogeneity was examined using the silhouette index, for which values above 0.50 are conventionally treated as indicating acceptable internal cohesion (Chen, 2014; Chuang & Chou, 2025). In the present configuration, however, the silhouette index returned zero for all fourteen LLR-based groupings, and this result was confirmed on re-analysis. The silhouette coefficient compares mean within-group dissimilarity with dissimilarity to the nearest neighbouring group (Rousseeuw, 1987). A uniform zero result means that structural separation could not be established by this distance-based criterion. Accordingly, the LLR statistics are used here to characterise the distinctiveness of labels and representative terms, not as a substitute for silhouette-based structural validation. Interpretation therefore combines LLR term distinctiveness, grouping size, mean publication year, thematic coherence and the broader network context. Betweenness centrality was used to identify concepts and publications occupying bridging positions in the network (Freeman, 1979). These values are reported as descriptive network indicators, while the temporal phases are derived from term content, mean publication years and the temporal visualisations. The fourteen groupings should therefore be read as interpretively grounded thematic structures rather than statistically separated partitions.

Reflexivity: The Politics of Bibliometric Measurement

A study that maps a critical field using bibliometric instruments must submit those instruments to the same critique it applies to mathematics itself. Citation databases are not neutral registries of knowledge. They are commercial infrastructures whose inclusion criteria, language policies and disciplinary categories are determined by a small number of publishers operating in a highly concentrated market (Larivière et al., 2015; Mongeon and Paul-Hus, 2016). What counts as an indexed contribution, and therefore as a countable contribution to CME, is settled upstream of any analysis conducted here. The formatting power that Skovsmose (1994a) attributes to mathematics operates with equal force in scientometrics. Citation counts, h-indices and cluster memberships are numerical artefacts that acquire the appearance of objective description precisely by concealing the social and economic relations that produced them (Apple, 1992).

Three consequences follow for the interpretation of the findings reported below. First, the coverage of Web of Science and Scopus is skewed towards English-language journals issued by Northern commercial houses, so scholarship circulating in Portuguese, Spanish, Turkish or Indigenous languages, in regional journals, in edited volumes and in movement literature is structurally invisible to this analysis (Mongeon and Paul-Hus, 2016). Second, every threshold applied in this study, whether the minimum of five co-citations or the requirement of one publication and one citation for inclusion in a network, performs an act of exclusion. Scholars working outside well-resourced institutions accumulate citations more slowly and are therefore the first to fall below any such threshold, which means that the maps presented here reproduce the stratification of the academic economy as though it were a distribution of intellectual significance (Gutiérrez, 2013; Knijnik, 2002). Third, prominence in these maps registers the visibility of a publication venue and the citation habits of its readership rather than the political consequence of the work. A study that transforms practice in a single classroom in a favela or a village school may leave no trace in the networks reported below.

These constraints are not incidental defects to be minimised through better technique. They are constitutive of the method. The maps that follow should therefore be read in two ways at once: as a description of one particular and institutionally privileged circuit of CME knowledge production, and as evidence of how that circuit is organised. Where the analysis identifies concentration, it identifies the shape of academic capital as much as the shape of ideas (Ng et al., 2025; Skovsmose, 2023).

Results

RQ1: What are the key publication outlets, publications, countries, institutions, authors, and research networks that define the indexed CME literature?

A total of 160 indexed scholarly publications comprise the analysed CME corpus. The temporal distribution of these publications (see Figure 2) shows sparse output during the early years followed by a marked increase after 2010.

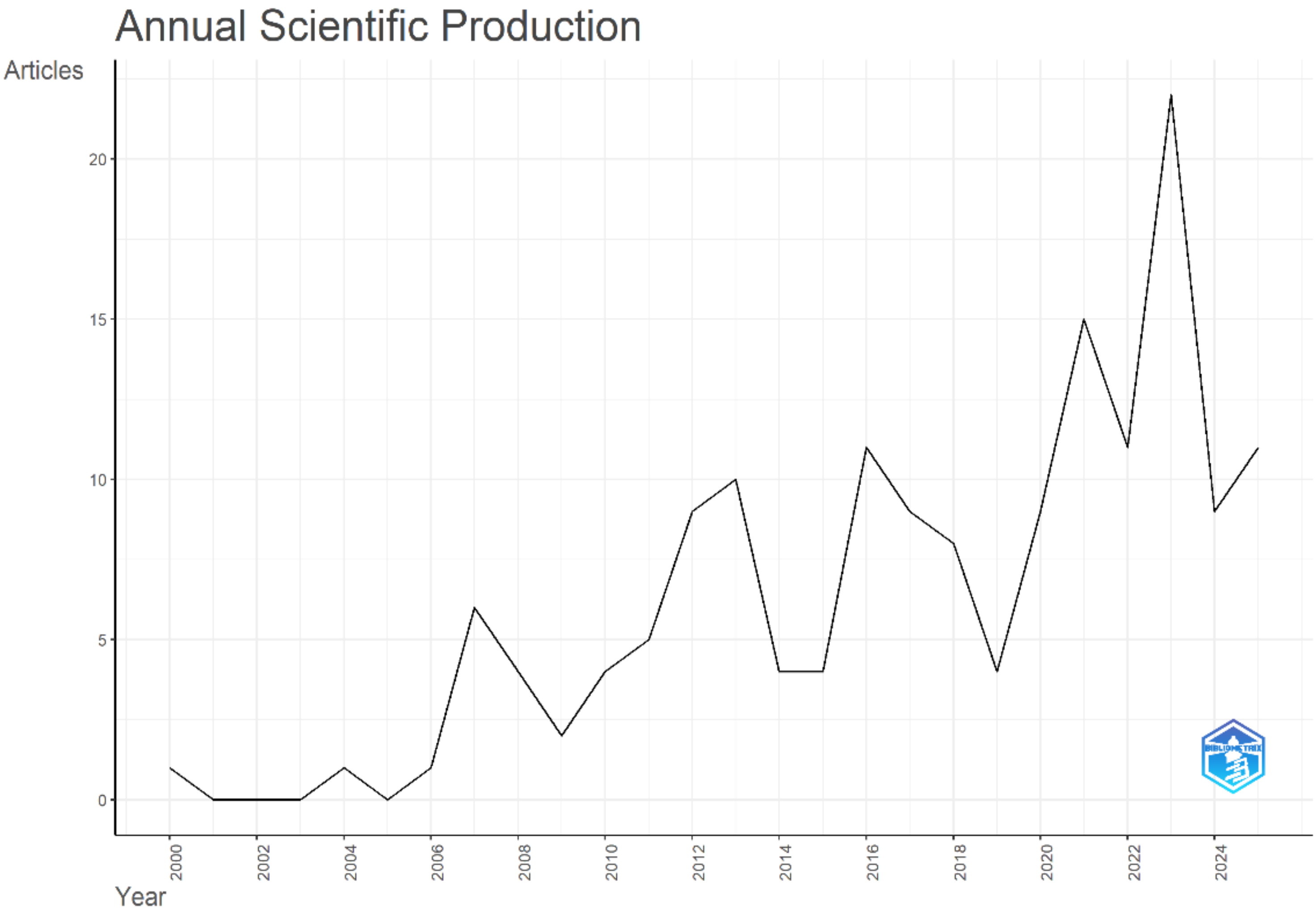

Figure 2. Annual scientific production (2000-2025).

While research output was sporadic during the early 2000s, activity increased substantially after 2010. The highest annual volume was recorded in 2023 (n = 22), with substantial contributions also recorded in 2021 (n = 15) and in both 2016 and 2022 (n = 11). The retrieval was conducted on 25 February 2026, so the 2025 count of 11 publications represents the records indexed by that date; later retrospective indexing may alter that total without changing the closed 2000-2025 publication window used in the analysis.

The structural relationships between authors, keywords and journals further illustrate the field's intellectual cohesion (see Figure 3).

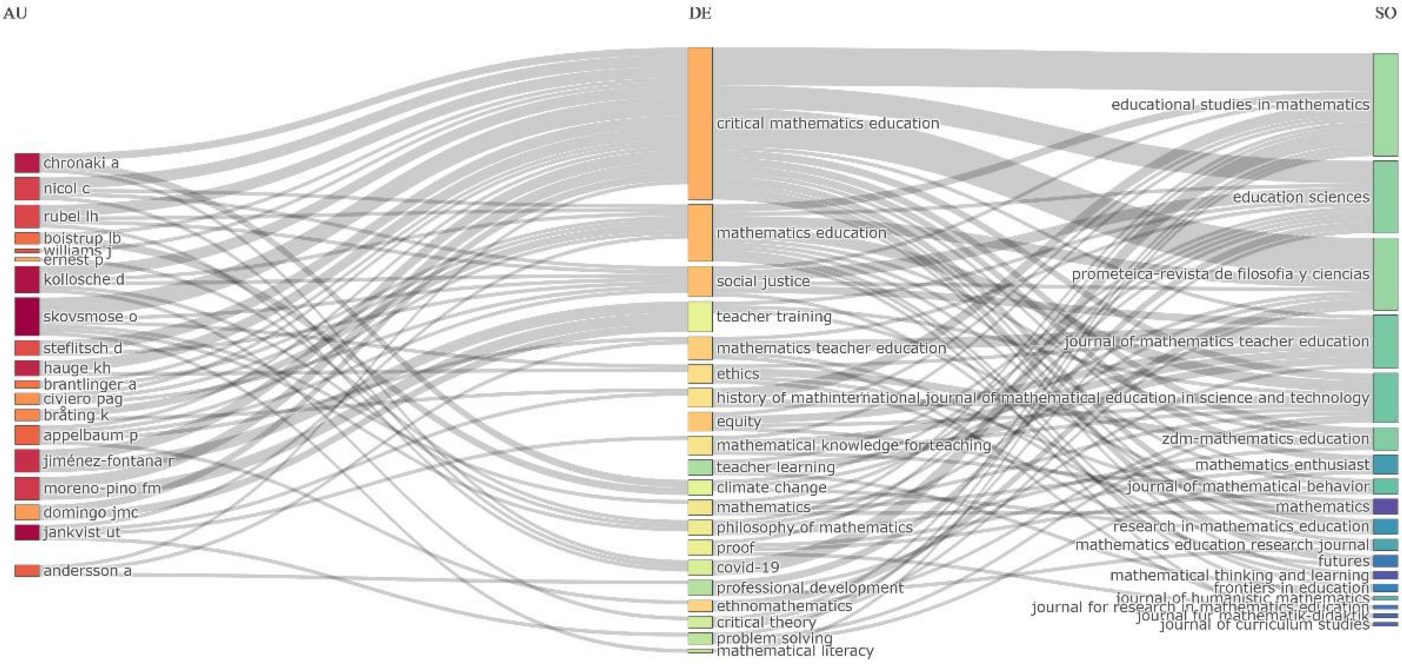

Figure 3. Three-field plot of authors (AU), keywords (DE), and sources (SO) in Critical Mathematics Education research.

Prominent scholars, including Skovsmose O., Chronaki A. and Boistrup L. B., play a key role in anchoring the CME discourse. These authors act as conceptual bridges, linking foundational themes such as social justice, equity, and ethnomathematics to major publication outlets like Educational Studies in Mathematics and Education Sciences. The scholarly impact is also reflected in citation structures: 2004 publications achieved the highest mean total citations per year (MTCY) at 8.52, followed by 2006 (5.86) and 2013 (3.11).

Leading authors, institutions, and countries: Intellectual collaboration within CME was examined through co-authorship analysis. Of the 292 authors identified in the dataset, the analysis focused on those who met a minimum threshold for scientific contribution and impact. While a significant proportion of the network consists of unconnected researchers, the collaboration map (see Figure 4) illustrates the largest group of connected individuals, comprising a core group of 20 authors. These scholars are organised into three distinct clusters characterised by 52 collaborative links and a total link strength of 79.

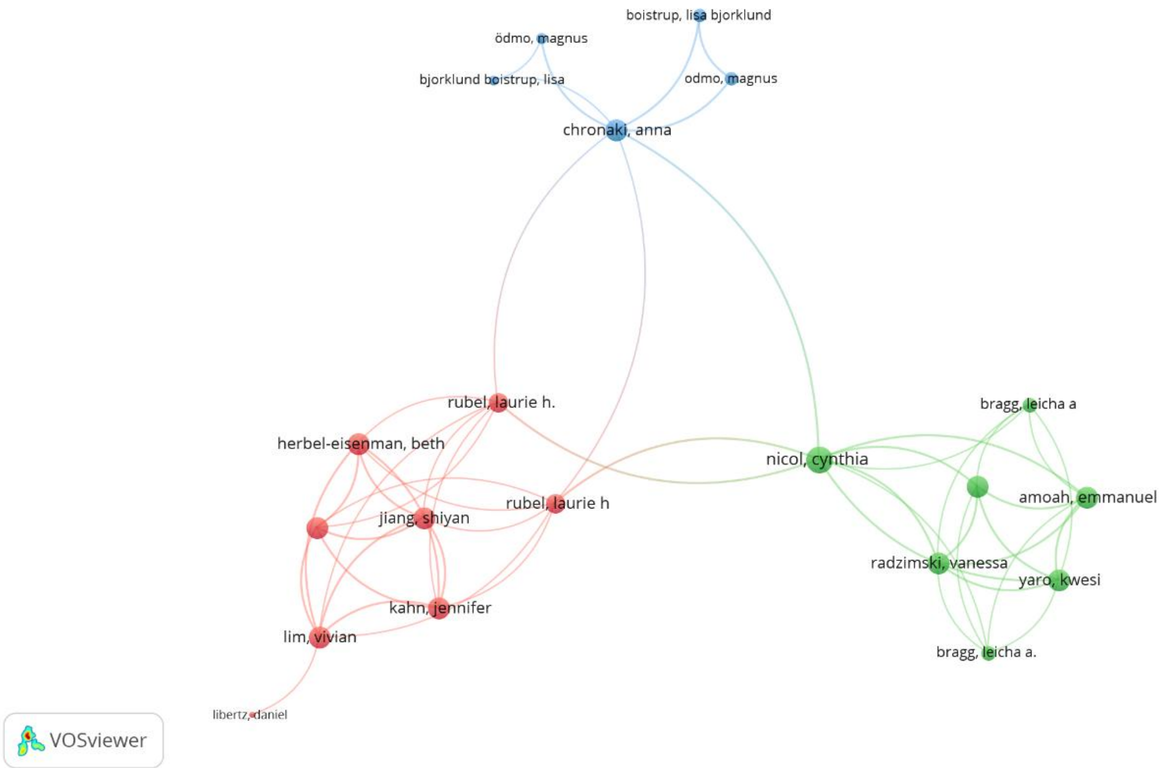

Figure 4. Network Analysis of Co-Authorship Relationships.

Analysis of the collaborative clusters reveals a network anchored by key scholars who facilitate the exchange of knowledge across research groups. The largest group, Cluster 1 (Red), includes influential figures such as Laurie H. Rubel and Beth Herbel-Eisenman, who focus on intensive internal collaborations. Cluster 2 (green) consists of seven items and is centred around Cynthia Nicol, a researcher who plays a pivotal role in connecting disparate research nodes. Finally, Cluster 3 (blue) contains five items and primarily features the joint work of Anna Chronaki and Lisa Björklund Boistrup. While the CME field possesses a dedicated core of collaborators, the structure of this network suggests that the overall landscape remains somewhat fragmented,

highlighting significant opportunities for future inter-institutional and international partnerships.
The CME scholarly landscape is defined by a group of prominent researchers with varying degrees of local and global influence. Data on individual productivity identifies Ole Skovsmose as a central figure in the field (see Table 1).

Table 1. Ranking of the Most Productive Authors Researching Critical Mathematics Education.

Rank	Author	Institutions	Country	TP	LCS	GCS	h
1	Ole Skovsmose	Aalborg University	Denmark	8	34	5656	39
2	Uffe Thomas Jankvist	University of Southern Denmark	Denmark	4	58	1495	22
3	David Kollosche	University of Potsdam	Germany	4	16	334	10
4	Julian Williams	University of Manchester	United Kingdom	3	50	3707	32
5	Cynthia Nicol	University of British Columbia	Canada	3	41	819	16
6	Laurie H. Rubel	University of Haifa	Israel	3	40	630	13
7	Rocío Jiménez-Fontana	Universidad de Cádiz	Spain	3	32	470	9
8	Francisco Manuel Moreno-Pino	Universidad de Cádiz	Spain	3	32	203	7
9	Kjellrun Hiis Hauge	Western Norway University of Applied Sciences	Norway	3	26	597	12
10	Anna Chronaki	University of Thessaly	Greece	3	23	913	14
11	Daniela Steflitsch	University of Klagenfurt	Austria	3	4	8	2

Note. TP: Total Publications in the retained corpus; LCS: Local Citation Score, citations received from records within this CME dataset; GCS: Global Citation Score as reported in the database-level bibliometric output; h: author h-index reported in the same database-level output. GCS and h are therefore descriptive, database-dependent indicators and are not calculated from the 160-record CME corpus alone. Values refer to the retrieval state of 25 February 2026.

Skovsmose shows the strongest database-level citation profile among the authors listed in Table 1, while Uffe Thomas Jankvist has the highest Local Citation Score within the retained CME corpus. This distinction separates broad database-level citation visibility from citation relevance inside the demarcated collection analysed here.

The temporal distribution of this productivity provides further context regarding the evolution of the field (see Figure 5).

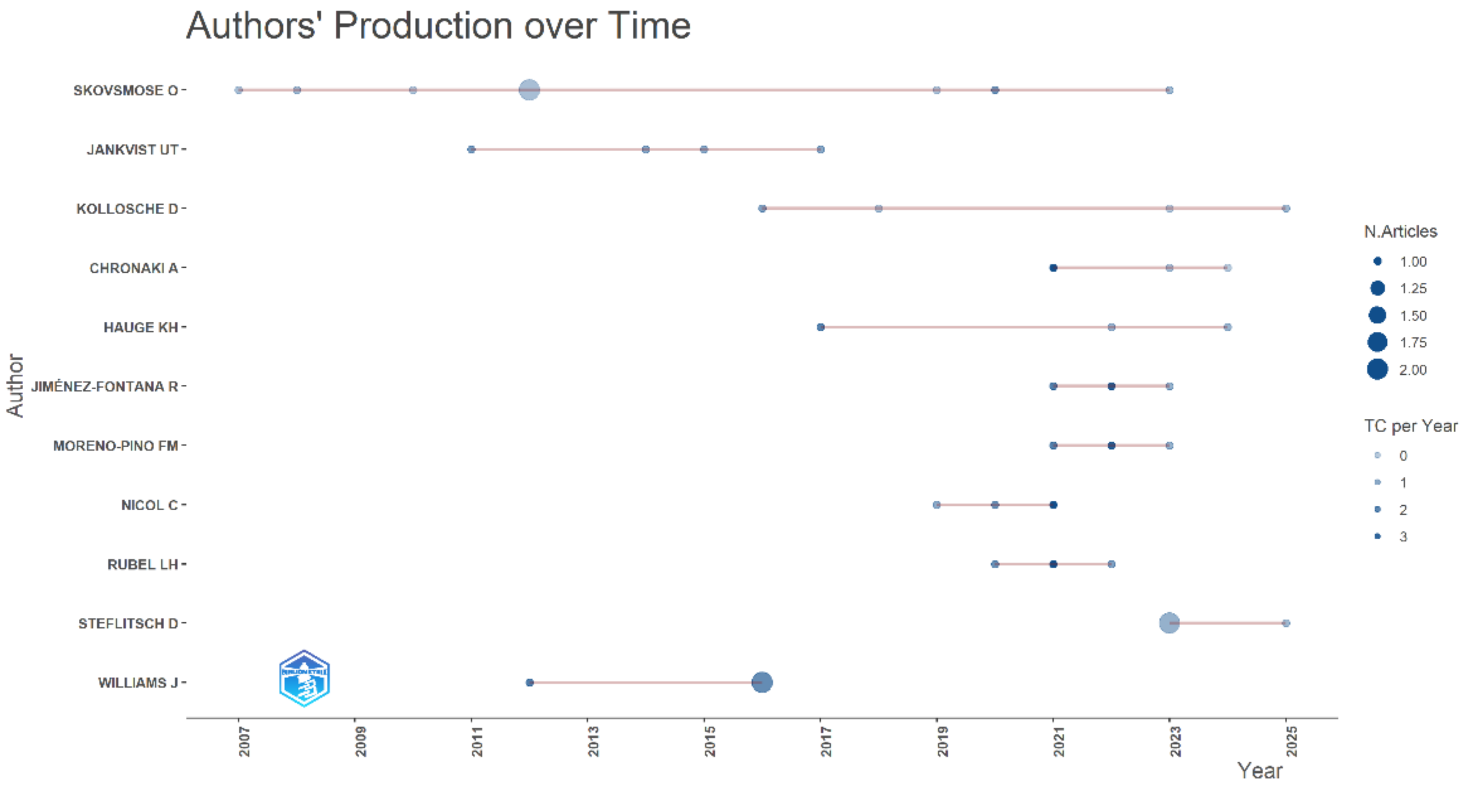

Figure 5. Productivity Analysis of the Most Productive Authors Over Time.

Ole Skovsmose and Julian Williams are two of the discipline’s foundational pillars, having maintained a consistent output and significant influence since the late 2000s. In contrast, the research activity of scholars such as Cynthia Nicol, Laurie H. Rubel and Anna Chronaki, reflects the emergence of contemporary voices that intensified the discourse between 2019 and 2025. This momentum has been further sustained by the recent work of Daniela Steflitsch and the Spanish research group led by Rocío Jiménez-Fontana and Francisco Manuel Moreno-Pino. Their contributions signify a geographical diversification that continues to revitalise the intellectual core of CME, ensuring its relevance in a variety of academic contexts.

The institutional landscape of CME research was evaluated through co-authorship analysis to identify the primary centres of knowledge production. To include organisations with a documented scholarly impact, a minimum threshold of one publication and one citation was applied. This resulted in 264 out of 335 identified institutions meeting the criteria for network analysis. While most of these organisations operate independently, the collaboration map illustrates the largest interconnected network, consisting of 19 organisations (see Figure 6). This structural core comprises 29 collaborative links and a total link strength of 31, organised into six distinct clusters.

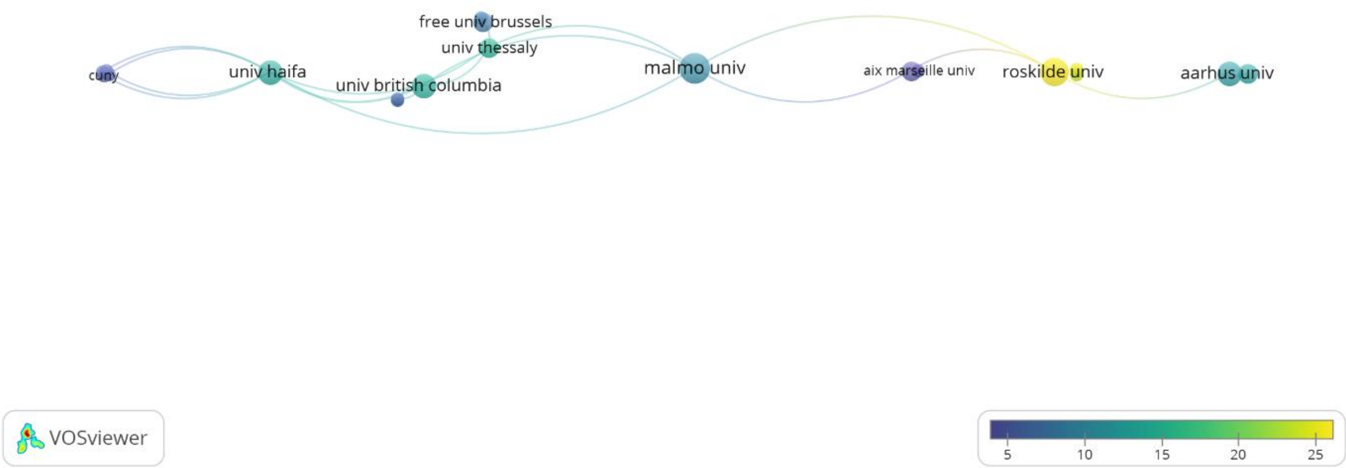

Figure 6. Overlay visualization of the institutional co-authorship network in CME research.

Analysis of the institutional network reveals a strong European influence, particularly from Scandinavian and German organisations. Figure 6 shows that the size of each node represents the volume of publications, while the colour gradient ranging from deep purple to bright yellow reflects the citation impact. Aalborg University is the most productive node in the network, with nine publications and the highest total link strength of nine. However, the overlay visualisation shows that other Scandinavian centres have an intense scientific impact; specifically, Roskilde University has a remarkable total of 208 citations, the highest in the network, despite having a more focused output of four publications. This leadership is complemented by significant international nodes, such as the University of British Columbia and the University of Haifa, which connect regional discourses to a broader global context.

The diversity of this network is further demonstrated by the affiliations of the most productive authors (see Table 1), which include research centres ranging from the University of Thessaly to Michigan State University. The presence of these institutions indicates that CME research is conducted across several world regions. It should not, however, be read as evidence that the field is global in any substantive sense. With few exceptions, the institutions appearing in this network are well-resourced universities in high-income countries, and the geographical spread observed here is a spread within the indexed Anglophone circuit rather than beyond it.
This cross-national presence is also visible in productivity and citation patterns across the countries represented in the indexed corpus. Analysis of corresponding-author affiliations (see Figure 7) shows that the USA is the leading contributor, accounting for 30% of total output with 48 publications.

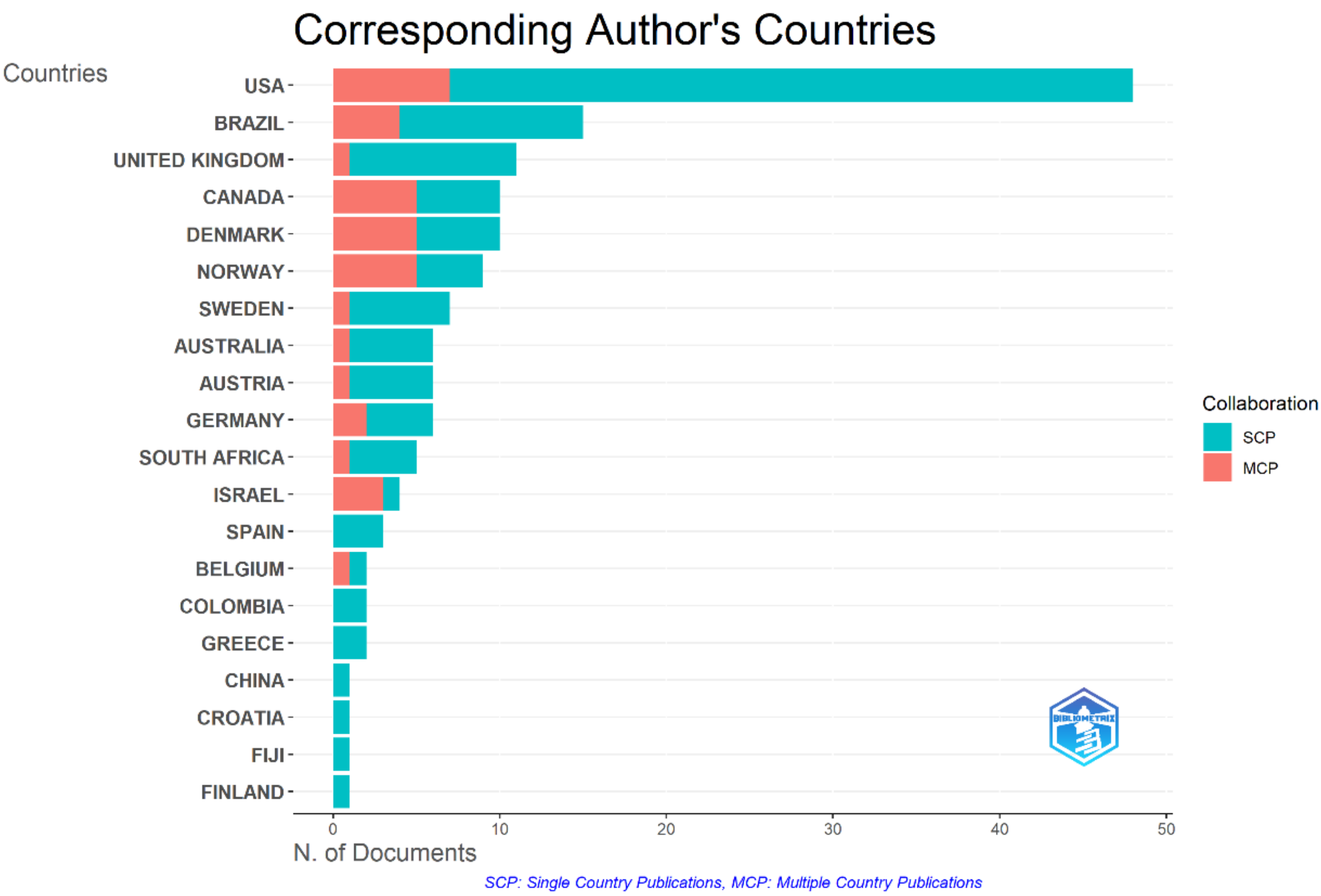

Figure 7. Corresponding author's country distribution and international collaboration (SCP vs. MCP).

Notably, 41 of these are single-country publications (SCPs), indicating a robust internal research infrastructure. Brazil is the second most prolific nation, with 15 publications showcasing a significant international collaboration rate of 26.6%. The United Kingdom, Canada and Denmark also have a substantial presence in the literature.

Although publication volume is a key indicator of activity, the scientific influence of these nations is most accurately reflected by their citation metrics (see Figure 8).

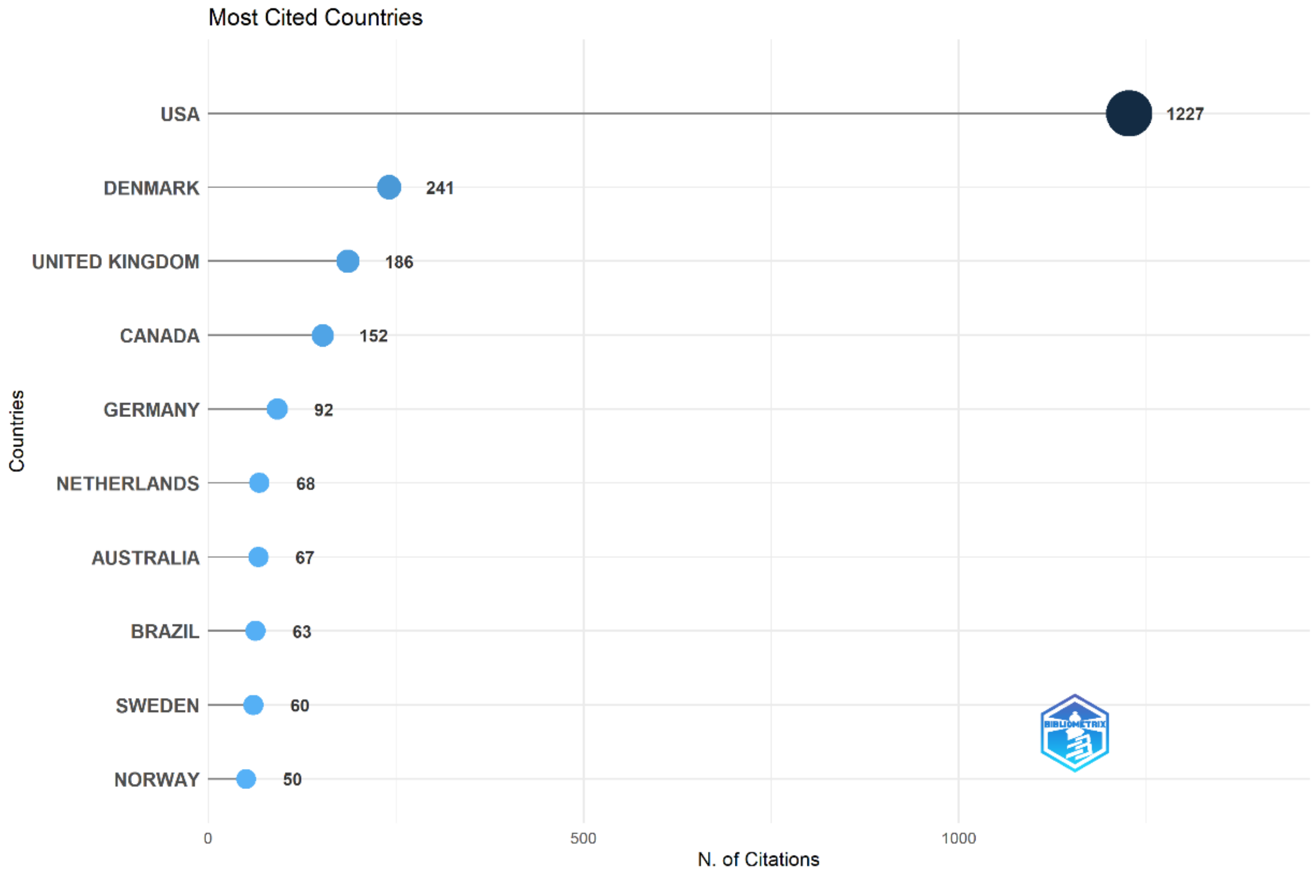

Figure 8. Top 10 most cited countries in CME research.

The USA has the largest total citation count in the country analysis, with 1,227 citations and an average of 25.6 citations per publication. Per-publication citation rates add a different perspective to absolute output: the Netherlands records an average of 68.0 citations per publication despite a smaller publication count, while Denmark records 24.1. These indicators describe citation visibility rather than research quality, and they should be interpreted in light of differences in publication age, database coverage and national research-system size.

The international collaboration network (see Figure 9) further clarifies how these nations interact within the global CME discourse.

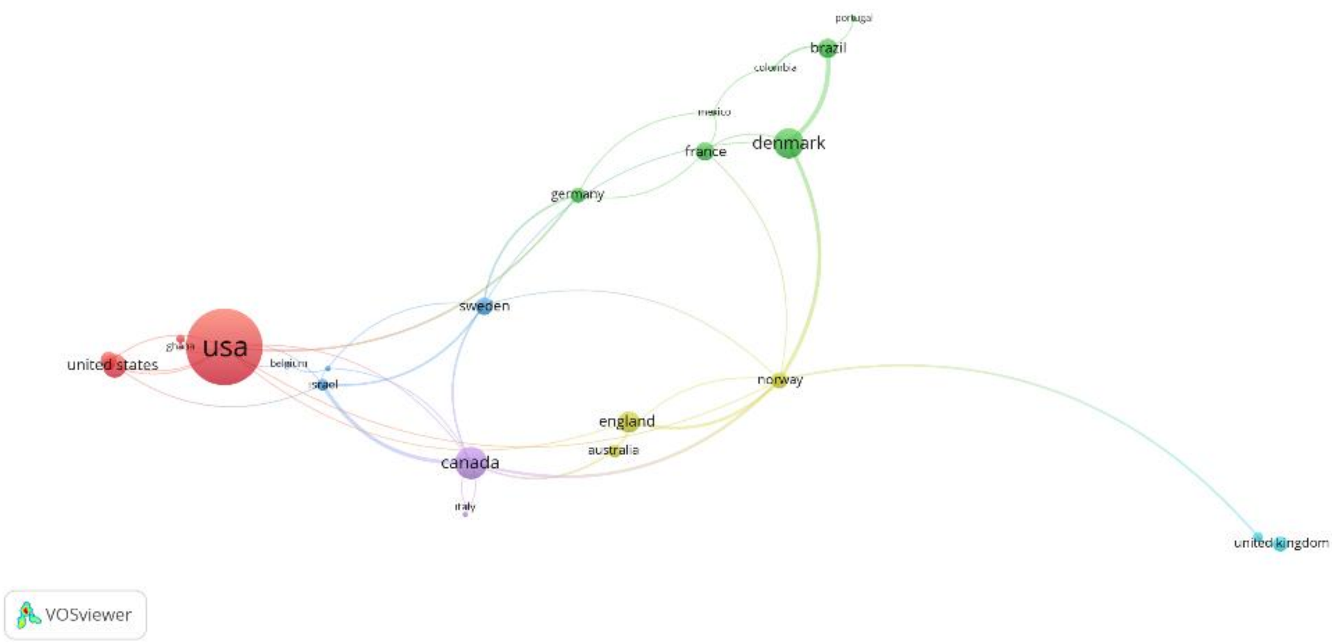

Figure 9. Co-authorship network of countries in CME research.

A minimum threshold of one publication and one citation was applied to delimit the country network. Of the 42 countries identified, 36 met this threshold, and the largest connected structure contained 27 countries organised into six network clusters. The USA was a major node, while Brazil, Denmark, France and Germany showed substantial collaborative ties and Canada, Norway and Sweden occupied bridging positions. The resulting structure reflects an academic conversation that crosses national borders while remaining concentrated within a limited number of national research systems. Internationalisation is therefore treated as a matter of degree rather than an accomplished condition.

Leading Sources and Publications

Source analysis identifies the principal publication channels through which an indexed research field becomes visible (Brookes, 1969). To examine concentration in the source field, this study applied Bradford's Law of

Scattering (Bradford, 1934, 1985). The source titles are reported as indexed in the merged database output, which is dominated by journals but also retains a small number of book-based source records. The resulting distribution reveals a concentrated publication core (see Table 2).

Table 2. Ranking of the Most Productive Publication Sources in CME

Rank	Publication Source	NP	TC	h_index	g_index	m_index
1	Educational Studies in Mathematics	24	554	13	23	0.77
2	Prometeica-Revista de Filosofía y Ciencias	13	362	7	10	0.37
3	Education Sciences	10	28	2	5	0.22
4	ZDM-Mathematics Education	10	362	7	10	0.37
5	Journal of Mathematics Teacher Education	8	223	6	8	0.32
6	International Journal of Mathematical Education in Science and Technology	6	63	4	6	0.25
7	Journal of Mathematical Behavior	5	75	4	5	0.25
8	Journal of Humanistic Mathematics	4	20	3	4	0.23
9	Critical Mathematics Education: Theory, Praxis, Reality	3	6	1	2	0.09
10	Mathematics Education Research Journal	3	64	3	3	0.19
11	Mathematics Enthusiast	3	10	2	3	0.14
12	Research in Mathematics Education	3	53	3	3	0.21
13	Science & Education	3	36	2	3	0.13

Note. NP: Number of Publications, TC: Total Citations; h-index: A metric representing both productivity and citation impact, g-index: An index weighing highly cited publications more heavily, m-index: h-index divided by years since first publication in the dataset (representing impact velocity).

Educational Studies in Mathematics emerges as the dominant source in the field, leading with 24 publications, an h-index of 13, and 554 total citations. Prometeica-Revista de Filosofía y Ciencias follows as a notable contributor, adding a significant philosophical dimension with 13 publications, while ZDM-Mathematics Education is also a major high-impact outlet, with 10 publications and a g-index of 10.

Comparative metrics further clarify the citation profile of these publication sources. Educational Studies in Mathematics combines the highest output with the highest m-index in Table 2. Journal of Mathematics Teacher Education, Education Sciences and other specialist outlets contribute additional pedagogical and institutional perspectives. The Bradford distribution therefore indicates concentration in a limited number of publication channels, while the presence of a book-based source in the indexed output reinforces the need to interpret Table 2 as a source analysis rather than a journal-only ranking.

The intellectual structure of Critical Mathematics Education is further delineated by identifying the publications that have had the greatest influence on the field's discourse. Analysing highly cited publications enables researchers to identify the foundational theories and intellectual milestones within the field (see Table 3).

Table 3. Top 10 most influential publications in CME research

Rank	Publication Name	Journal Name	GC	LC	NGC	NLC
1	The Math Wars. Educational Policy (Schoenfeld, 2004)	Educational Policy	196	3	1	1
2	Conceptualizing inquiry-based education in mathematics. (Artigue & Blomhøj, 2013)	ZDM Mathematics Education	175	1	4.02	0.59
3	Toward a framework for the development of mathematical knowledge for teaching. (Silverman & Thompson, 2008).	Journal of Mathematics Teacher Education	142	3	2.69	1.50
4	Practicing Change: Curriculum Adaptation and Teacher Narrative in the Context of Mathematics Education Reform. (Drake & Sherin, 2006)	Curriculum Inquiry	123	0	1	0
5	Seeing culture and power in mathematical learning: toward a model of equitable instruction. (Hand, 2012)	Educational Studies in Mathematics	119	0	0	0
6	Engaging pre-service middle-school teacher-education students in mathematical problem posing: development of an active learning framework. (Ellerton, 2013).	Educational Studies in Mathematics	76	0	0	0
7	Textbook research as scientific research: towards a common ground on issues and methods of research on mathematics textbooks. (Fan, 2013).	ZDM Mathematics Education	70	0	0	0
8	Hans Freudenthal: A mathematician on didactics and curriculum theory. (Gravemeijer & Terwel, 2000).	Journal of Curriculum Studies	68	0	1	0
9	Proofs as bearers of mathematical knowledge. (Hanna & Barbeau, 2008).	ZDM Mathematics Education	59	4	1.12	2
10	What Kind of Content Knowledge do Secondary Mathematics Teachers Need?(Dreher et al., 2018).	Journal für Mathematik-Didaktik	51	1	3.04	1.6

Note. GC: Global Citations (total citations across the entire database); LC: Local Citations (citations received from within this specific CME dataset); LC/GC Ratio: The percentage of local impact relative to global recognition.

Based on the identification of highly cited publications, co-citation analysis provides a deeper understanding of the intellectual structure and foundational references that underpin the CME domain. This methodological approach examines how frequently two documents are cited together, revealing the field's shared theoretical roots and conceptual clusters. Of the 9,596 references cited in this study, 90 met the minimum threshold of five citations. This resulted in a network characterised by 925 collaborative links and a total link strength of 1,613 (see Figure 10).

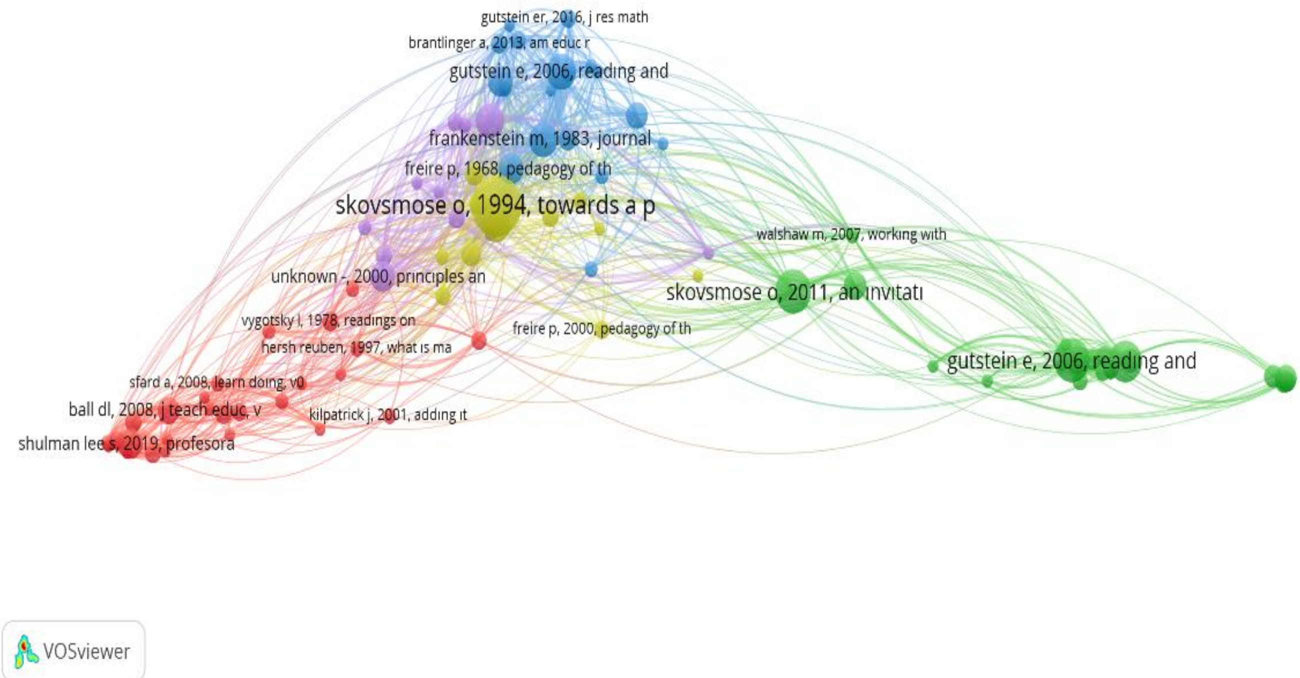

Figure 10. Co-citation network of cited references in Critical Mathematics Education research.

Analysis of the co-citation network reveals the foundational pillars of critical mathematics education, with Skovsmose emerging as the most central figure. His seminal work, Towards a Philosophy of Critical Mathematics Education (1994), has the highest number of citations in the network, at 31, and has a total link strength of 152. This establishes it as a primary reference for the entire discipline. His influence is further reinforced by later contributions such as An Invitation to Critical Mathematics Education (2011), which continues to inform contemporary discourse.

The ideological roots of the field are also represented by the works of Paulo Freire, particularly his influential text, ‘Pedagogy of the Oppressed’ (Freire, 1968/2018). With a combined citation count of 25 across different editions, Freire’s epistemology serves as a critical bridge for scholars such as Frankenstein (1983) and Gutstein (2003, 2006), who have successfully adapted these radical pedagogical theories for use in mathematics classrooms. Gutstein’s research on reading and writing the world with mathematics is especially influential and maintains a high total link strength of 93, underscoring its role in connecting social justice frameworks to empirical classroom practices.

Furthermore, the intellectual landscape is enriched by research on teacher knowledge and pedagogical content, as evidenced by the significant co-citation of Shulman (1986) and Ball et al. (2008). These works, alongside the Math Wars discourse initiated by Schoenfeld (2004), emphasise the significant tension between traditional curriculum standards and the sociopolitical shifts in mathematics education. Together, these references, ranging from Skovsmose’s foundational philosophy to Gutiérrez’s (2013) and Hand’s (2012) equity-focused frameworks, constitute a robust intellectual foundation that continues to influence the direction of CME research.

RQ2: What are the primary research topics investigated in the literature from 2000 to 2025, and how has the conceptual orientation of CME research evolved across this period?

The co-word analysis produced fourteen LLR-based thematic groupings, which are reported quantitatively in Table 4. Figure 11 provides a complementary timeline visualisation of major thematic trajectories. The numerical identifiers displayed in the timeline export and those reported in the LLR table are treated as output-specific labels rather than as a one-to-one crosswalk. Accordingly, comparisons across Figure 11, Table 4 and Figure 12 are based on thematic content and temporal position, not on matching cluster numbers.

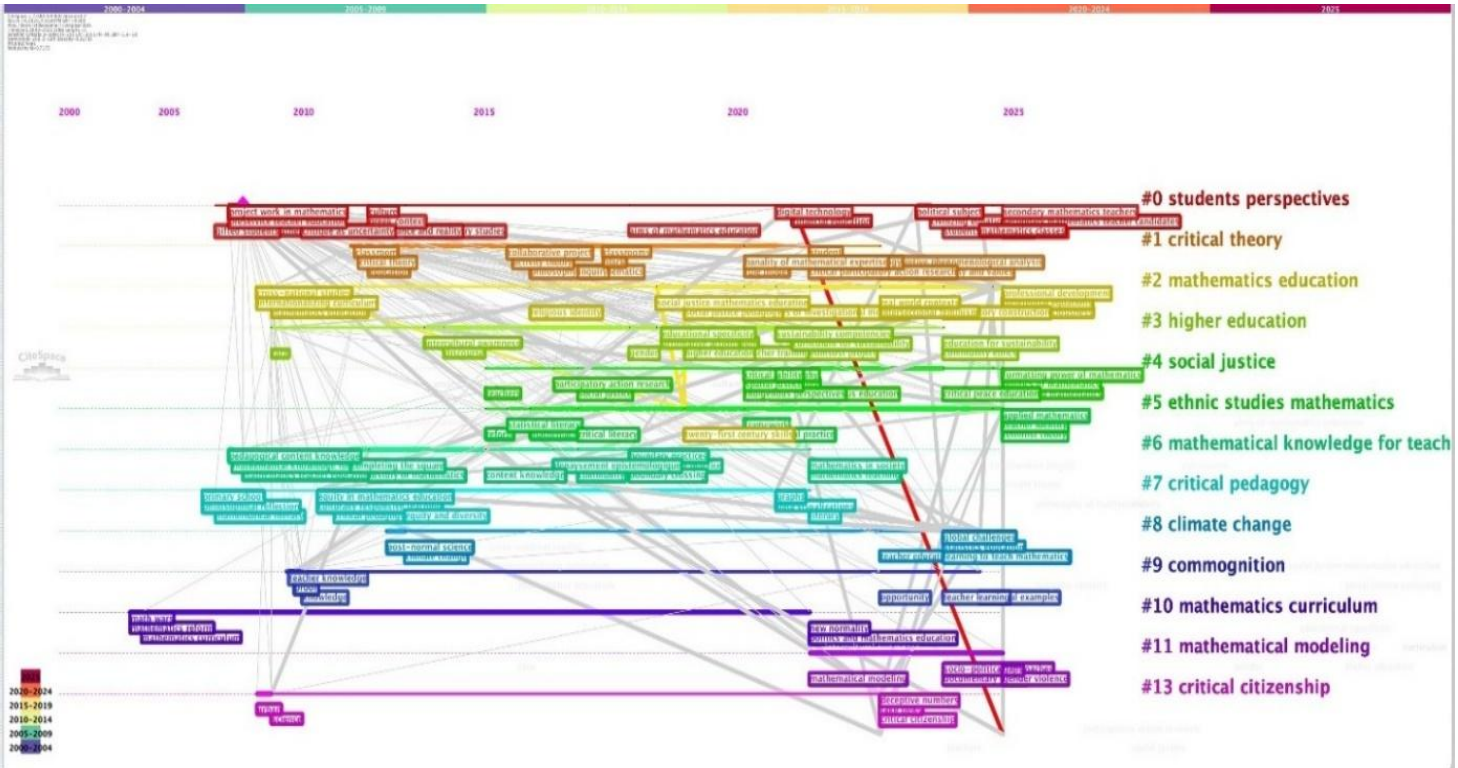

Figure 11. Timeline Visualization of Major Thematic Trajectories in Critical Mathematics Education

Table 4 shows that the largest LLR-based grouping contains 33 records and has a mean publication year of 2019. Its representative terms include mathematics education, students' perspectives, critical mathematics education, the civilising equation and critical pedagogy. Across the table, the highest-ranked terms point to several recurrent thematic families, including critical pedagogy and culturally responsive teaching, mathematical knowledge for teaching, social justice and the politics of mathematics, higher education and structural violence, climate change and global challenges, social justice pedagogy and mathematical modelling, ethnic studies mathematics, translanguaging and epistemic injustice, and critical citizenship in relation to uncertainty and deceptive numbers. Because the groupings overlap conceptually and could not be validated through silhouette separation, their substantive interpretation rests on these term constellations rather than on claims of sharply bounded thematic communities.

Table 4. LLR-Based Thematic Groupings and Representative Terms.

Cluster label	Size	Silhouette	Mean year	Top terms (log-likelihood ratio, p-level)
#0	33	0	2019	mathematics education (8.25, 0.005); students perspectives (7.41, 0.01); critical mathematics education (5.75, 0.05); civilizing equation (5.54, 0.05); critical pedagogy (5.12, 0.05)
#1	21	0	2016	critical pedagogy (19.41, 1.0E-4); mathematics education (14.98, 0.001); data visualizations (7.66, 0.01); graph reading (7.66, 0.01); culturally responsive teaching (7.66, 0.01)
#2	13	0	2013	history of mathematics (11.64, 0.001); mathematical knowledge for teaching (11.64, 0.001); mathematics teacher education (7.93, 0.005); critical mathematics education (7.29, 0.01); community of practice (5.77, 0.05)
#3	12	0	2016	philosophy of mathematics (8.56, 0.005); collaborative project (6.09, 0.05); conversation (6.09, 0.05); critical participatory action research (6.09, 0.05); banality of mathematical expertise (6.09, 0.05)
#4	12	0	2021	social justice (21.48, 1.0E-4); real-world mathematics (10.59, 0.005); formatting power of mathematics (10.59, 0.005); teaching mathematics for spatial justice (10.59, 0.005); politics of mathematics (10.59, 0.005)
#5	12	0	2020	higher education (18.61, 1.0E-4); affirmative actions (12.29, 0.001); special rights (12.29, 0.001); structural violence (12.29, 0.001); educational specificity (12.29, 0.001)
#6	11	0	2019	social justice pedagogy (19.39, 1.0E-4); differential equations (12.79, 0.001); mathematical modelling (12.79, 0.001); critical consciousness (12.79, 0.001); twenty-first century skills (6.33, 0.05)
#7	11	0	2021	climate change (24.11, 1.0E-4); role of the mathematics teacher educator (11.84, 0.001); critical mathematics education (cme) (11.84, 0.001); global challenges (11.84, 0.001); learning to teach mathematics (11.84, 0.001)
#8	8	0	2015	landscapes of investigation (14.42, 0.001); primary school (14.42, 0.001); professional development (7.11, 0.01); participatory construction (7.11, 0.01); philosophical reflection (7.11, 0.01)

#9	6	0	2008	knowledge market (8.81, 0.005); critical competencies (8.81, 0.005); prescription readiness (8.81, 0.005); functional competencies (8.81, 0.005); mathematics in action (8.81, 0.005)
#11	5	0	2025	ethnic studies mathematics (8.07, 0.005); k12 math education (8.07, 0.005); teacher identity (8.07, 0.005); portraiture (8.07, 0.005); applied mathematics (8.07, 0.005)
#12	5	0	2025	translanguaging (7.78, 0.01); dialogic pedagogy (7.78, 0.01); pluriversal curriculum (7.78, 0.01); teacher professional learning (7.78, 0.01); epistemic injustice (7.78, 0.01)
#15	4	0	2023	mathematical modeling (14.84, 0.001); documentary review (14.84, 0.001); socio-political approaches (14.84, 0.001); ethnomathematics (6.11, 0.05); mathematics education (0.44, 1.0)
#18	3	0	2022	critical citizenship (8.81, 0.005); uncertainty (8.81, 0.005); fake news (8.81, 0.005); deceptive numbers (8.81, 0.005); ethnomathematics (0.22, 1.0)

Note. CiteSpace returned a silhouette value of 0 for each of the fourteen LLR-based groupings, and the result was confirmed on re-analysis. Structural separation could therefore not be verified with the silhouette criterion (Rousseeuw, 1987). The values are reported exactly as returned by the software and are not treated as evidence of grouping quality. LLR statistics and p-levels describe the distinctiveness of representative labels or terms relative to the remainder of the corpus; they do not substitute for structural validation. Terms with p = 1.0 are retained because they appeared in the exported output but are not interpreted as statistically distinctive. Numerical identifiers in this table are specific to the LLR tabular output and are not assumed to map one-to-one onto the identifiers displayed in Figure 11. The identifiers are non-consecutive because they reproduce the labels assigned in the exported output; only the fourteen groupings retained for interpretation are listed here.

Taken together, the LLR terms indicate two broad and intersecting directions in the indexed CME literature. One direction concerns the epistemological and philosophical status of mathematics, visible in terms such as philosophy of mathematics, history of mathematics, landscapes of investigation, mathematical knowledge for teaching and mathematics in action. The other concerns equity, politics and pedagogy, visible in social justice, critical pedagogy, higher education, structural violence, climate change, ethnic studies mathematics, translanguaging, epistemic injustice and critical citizenship. These directions are analytically useful but not mutually exclusive, which is consistent with the dense thematic connections visible in the timeline representation.

A combined reading of Table 4, the timeline visualisation and the time-zone map provides a more cautious basis for interpreting thematic change over time (see Figure 12). Rather than treating the visual outputs as a stable numerical taxonomy, the temporal interpretation follows recurring terms, their approximate periods of concentration and the mean years reported in the LLR table.

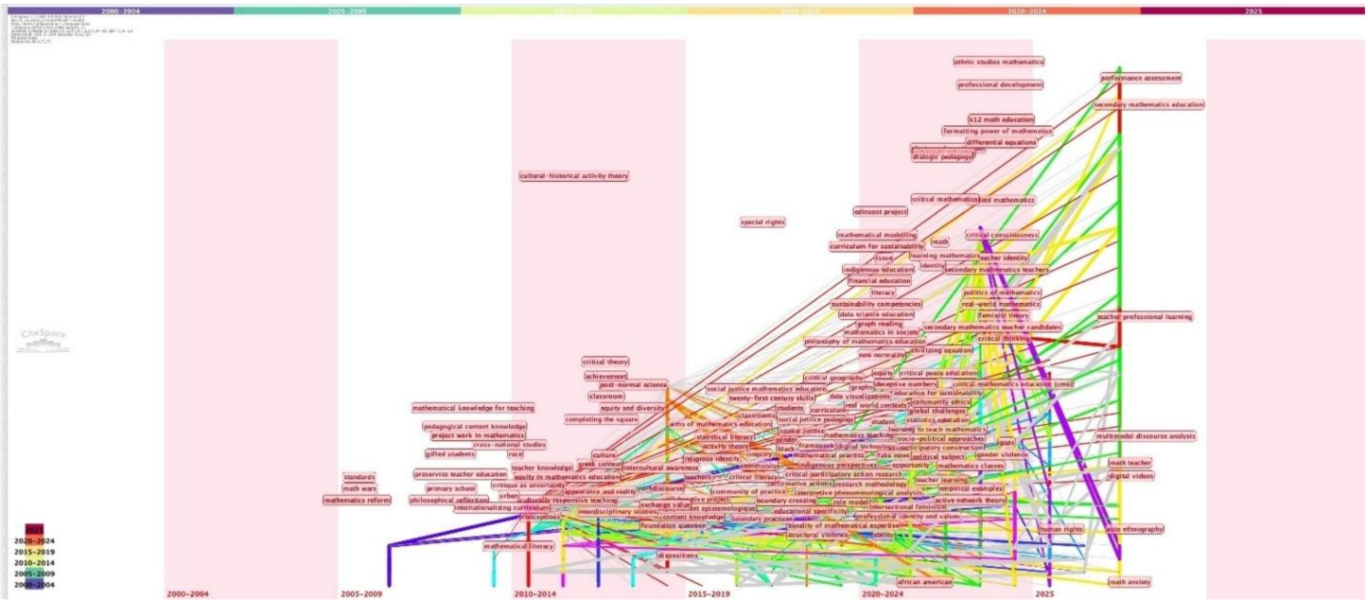

Figure 12. Time-Zone Visualization of Term Evolution in Critical Mathematics Education, 2000-2025.

The combined temporal evidence supports three broad interpretive phases. Phase I, approximately 2000-2009, can be described as foundational and epistemological formation. Early terms such as mathematics reform, mathematical literacy, knowledge market, critical competencies, functional competencies and mathematics in action point to a literature concerned with establishing the political and epistemological vocabulary through which mathematics education could be criticised and reconceptualised. This phase is treated as an interpretive temporal pattern rather than as a claim that all later themes were absent from the early literature.

Phase II, approximately 2010-2018, represents pedagogical consolidation and teacher-oriented expansion. The LLR table and temporal visualisations show increasing attention to the history and philosophy of mathematics, mathematical knowledge for teaching, mathematics teacher education, collaborative projects, critical participatory action research, critical pedagogy, culturally responsive teaching and social justice. The shift is therefore best understood as a broadening from foundational critique toward the pedagogical, curricular and professional conditions through which critical commitments might be enacted. Phase III, 2019-2025, is characterised by socio-political diversification and engagement with contemporary global problems. Social justice and the politics of mathematics remain central, while climate change, global challenges, structural violence, mathematical modelling, ethnic studies mathematics, translanguaging, pluriversal curriculum, epistemic injustice, critical citizenship, misinformation and deceptive numbers become more visible in the recent outputs. The temporal pattern suggests a widening of CME's agenda toward ecological, decolonial, linguistic and data-related questions without implying that the thematic groupings are mutually exclusive or that a single cluster identifier remains stable across CiteSpace exports.

Discussion

The primary aim of this study was to conduct a comprehensive bibliometric analysis of the CME literature published between 2000 and 2025, mapping the field's intellectual structure and tracing the conceptual trajectory of its scholarly discourse. The findings offer extensive insights into the leading journals, authors, institutions, and countries shaping CME research, as well as into the thematic clusters and temporal dynamics that characterize its intellectual evolution.

A major descriptive finding concerns the growth trajectory of the indexed CME literature. Scientific production remained relatively sparse during the early 2000s and increased markedly after 2010, with the highest annual output recorded in 2023 (n = 22). Rather than projecting future saturation from this relatively small and rapidly changing corpus, the present study limits interpretation to the observed 2000-2025 record. The pattern nevertheless indicates that CME has become increasingly visible within the indexed literature at the intersection of philosophy, critical theory and pedagogical praxis.

Regarding Research Question 1, the source analysis identified Educational Studies in Mathematics as the most prominent publication venue in the indexed CME corpus, leading with 24 publications, an h-index of 13, and 554 total citations (see Table 2). Its m-index of 0.77 is the highest among the sources listed in Table 2, indicating comparatively rapid accumulation of citation visibility within the indexed output. The second most prolific source, Prometeica-Revista de Filosofía y Ciencias, with 13 publications, is a noteworthy finding that warrants careful interpretation. Its prominence signals that CME's philosophical underpinnings, rooted in critical theory, Frankfurt School thought, and Freirean epistemology, have sustained a dedicated readership beyond anglophone educational research traditions. ZDM-Mathematics Education, with 10 publications and a g-index of 10, rounds out the core zone and reflects the journal's established role as a platform for conceptually ambitious contributions, including foundational work on inquiry-based mathematics education that intersects significantly with CME's commitments to reflective knowledge and democratic pedagogy (Artigue & Blomhøj, 2013).

The authorship analysis revealed a field anchored by a small but influential cohort of scholars. Skovsmose has the strongest database-level citation profile among the authors listed in Table 1 and also occupies the central foundational position in the co-citation network, where his 1994 work records the highest co-citation count and total link strength. These indicators should not be conflated: database-level GCS and h values describe broad citation visibility, whereas the local co-citation measures describe intellectual prominence within the demarcated CME corpus. Uffe Thomas Jankvist's leading Local Citation Score further demonstrates that broad career visibility and immediate thematic relevance are distinct dimensions of influence.

The institutional landscape of CME research reflects a strong European, and particularly Scandinavian, concentration of knowledge production. Aalborg University, with nine publications and the highest total link strength in the institutional network, functions as the field's organizational epicenter, a finding that is historically consistent with Skovsmose's long-standing institutional base there. However, Roskilde University records 208 total citations from only four publications, which indicates that citation visibility in this corpus is not a simple function of output volume. Because these are database-level counts, they describe visibility rather than conceptual quality, and differences in publication age and topic coverage may account for part of the gap. The growing presence of institutions such as the University of British Columbia, the University of Haifa, and various Brazilian universities within the collaboration network further suggests that CME is undergoing meaningful geographic diversification, even as its intellectual core remains anchored in Northern Europe. Taken together, these patterns reveal CME's hybrid intellectual identity: a field nourished simultaneously by Northern European Frankfurt School philosophy and Scandinavian welfare-state critique on one side, and by Latin American traditions of liberation pedagogy and ethnomathematics on the other. The knowledge flow between Scandinavia and Brazil is one of the more visible instances of North-South exchange within the indexed record, although the present data cannot establish how far that exchange extends beyond co-authorship counts.

At the national level, the United States dominates both in terms of publication volume (48 publications, 30% of total output) and overall citation impact (1,227 total citations). However, per-publication citation rates give a different picture: the Netherlands records an average of 68.0 citations per publication, the highest in the corpus, while Denmark records 24.1. These rates describe citation visibility rather than scholarly quality, and small denominators make them sensitive to a single highly cited item. They nevertheless indicate that absolute output and citation reach are distinct dimensions, and that smaller national research communities are not marginal to the citation structure of the indexed literature. The country collaboration network (Figure 9) further shows collaborative ties reaching beyond the anglophone core, with Brazil, France, and Germany forming strong collaborative bonds alongside the anglophone core. A substantial proportion of countries (42 identified, 27 networked) remain at the periphery of this collaboration structure, indicating that the internationalization of CME, while genuine, remains incomplete.

The co-citation analysis of foundational references provides the clearest window into the intellectual architecture of CME. The network of 90 highly co-cited works, connected by 925 collaborative links, confirms that CME draws on a coherent set of theoretical antecedents (Figure 10). Beyond Skovsmose's foundational contributions, the prominence of Paulo Freire's Pedagogy of the Oppressed (1968/2018), with a combined citation count of 25 across editions, underscores the degree to which CME's critical impulse is rooted in a broader tradition of emancipatory education. The high total link strength of Gutstein's (2003, 2006) work on reading and writing the world with mathematics (TLS = 93) suggests this tradition has found its most empirically grounded expression in the American urban school context. The significant co-citation of Shulman (1986) and Ball et al. (2008) alongside these critical frameworks reflects an important tension within CME scholarship: transformative mathematics teaching requires not only a critical political orientation but also specialized mathematical knowledge for teaching. Schoenfeld's (2004) analysis of the Math Wars, the highest globally cited publication in this dataset (196 citations), confirms that debates about mathematics curriculum are always also contests over social values and democratic access.

A particularly illuminating feature of the co-citation landscape is the appearance of Gravemeijer and Terwel (2000) among the ten most globally cited publications in this dataset. Their examination of Freudenthal's philosophy, particularly the foundational principle of mathematics as a human activity and the guided reinvention approach, reveals a deep structural resonance between Realistic Mathematics Education (RME) and CME's pedagogical commitments. Freudenthal's insistence that mathematical knowledge must emerge from the learner's own activity anticipates CME's rejection of the banking model of education and its advocacy for dialogic, student-centered mathematical engagement, suggesting that RME philosophy can serve as a productive pedagogical companion to CME's emancipatory aspirations.

Equally significant is the co-citation standing of Hanna and Barbeau (2008), whose argument that proofs are the primary bearers of mathematical knowledge introduces an important epistemological dimension into CME discourse. Their central claim that proofs convey methods, tools, strategies, and concepts of wide mathematical applicability challenges the reductionist view of learning as the acquisition of procedural competencies. This perspective aligns closely with CME's commitment to cultivating mathemacy, a reflective form of mathematical knowledge that empowers learners to evaluate the social and political implications of mathematical applications rather than merely performing algorithmic operations (Skovsmose, 1994b).

The co-citation presence of Dreher et al. (2018) further reflects CME's engagement with teacher education research. Their conceptualization of School-Related Content Knowledge (SRCK) addresses the longstanding gap between the university mathematics prospective teachers learn and the school mathematics they subsequently teach. This framework provides a theoretically rigorous complement to CME's pedagogical agenda: teachers who aspire to guide students in reading and writing the world with mathematics (Gutstein, 2003, 2006) must be able to move fluently between academic mathematical structures and the contextual reasoning that characterizes school-level mathematics.

Turning to Research Question 2, the combined LLR and temporal outputs support three broad interpretive phases rather than a single stable cluster taxonomy. Phase I (approximately 2000-2009) is best characterised as foundational and epistemological formation. Terms such as mathematics in action, functional competencies, knowledge market, mathematics reform and mathematical literacy reflect efforts to define CME's critical vocabulary and to distinguish its purposes from more technicist conceptions of mathematics education. Read through Kuhn's (1962) concept of shared paradigms, as Fan (2013) discusses it in mathematics education research, this period can be understood as a phase of conceptual consolidation.

The continuing prominence of landscapes of investigation, participatory construction and related inquiry-oriented terms also shows that foundational epistemological critique was connected to questions of classroom activity rather than being purely abstract. These frameworks position students as active inquirers exploring open-ended mathematical situations rather than passively receiving procedures, resonating with Dewey's (1997) account of experiential inquiry. CME radicalises this democratic orientation by insisting that mathematical experiences are also shaped by power, privilege and exclusion.

Phase II (approximately 2010-2018) reflects pedagogical consolidation and teacher-oriented expansion. The increasing visibility of history and philosophy of mathematics, mathematical knowledge for teaching, culturally responsive teaching, collaborative projects, critical participatory action research and critical pedagogy points to greater attention to teacher identity, curriculum reform and the enactment of critical commitments in educational practice. This pattern resonates with Drake and Sherin's (2006) account of teacher narrative and curriculum change and with Ellerton's (2013) work on problem posing in pre-service teacher education, both of which underline the importance of teachers' prior learning experiences and professional preparation in sustaining reform-oriented practice.

Phase III (2019-2025) is the most socio-politically diversified period in the indexed record. Climate change and global challenges are accompanied by terms associated with social justice, structural violence, sustainability, translanguaging, epistemic injustice, pluriversal curriculum, ethnic studies mathematics, critical citizenship and deceptive numbers. These developments indicate that recent CME scholarship is engaging not only the political neutrality of mathematics education but also the ecological, linguistic, decolonial and data-intensive conditions within which mathematical knowledge is produced and used. Hand's (2012) model of equitable mathematics instruction is useful here because it emphasises how routine classroom practices can reproduce social hierarchy even without explicit intent.

The recent prominence of translanguaging, epistemic injustice and pluriversal curriculum design points to a deepening concern with the conditions under which mathematical knowledge becomes legitimate in classrooms. A mathematics classroom that systematically excludes students' linguistic repertoires, cultural epistemologies or lived mathematical practices conflicts with both experiential continuity and the social conditions for authentic learning that Dewey (1997) considered essential. CME's emerging decolonial orientation can therefore be read as extending its democratic project from the critique of pedagogy to the critique of epistemic authority.

The appearance of ethnic studies mathematics, feminist theory and teacher identity in the most recent thematic outputs further suggests increasing engagement with intersectional frameworks attentive to race, gender, language and class. These developments should be interpreted as emerging emphases in the indexed corpus, not as evidence of discrete or statistically separated clusters. Taken together, they indicate a movement from critique of mathematics education's presumed neutrality toward the construction of alternative epistemological and pedagogical frameworks.

A bibliometric map records what a literature names, not everything it addresses, and the terms absent from Table 4 and from the timeline visualisation are as instructive as those present. Poverty, hunger, famine, migration, displacement, war, occupation and dispossession appear nowhere among the log-likelihood terms that define any of the fourteen clusters, despite these being among the material conditions that most directly shape the mathematical lives of the majority of the world's students. Structural violence surfaces once, in Cluster #5, and there in the context of affirmative action in higher education. This absence admits of two readings, and they are not mutually exclusive. It may indicate that the demarcated CME literature has pitched its critique at a level of abstraction that keeps such conditions at the margin, favouring epistemological and curricular categories over the political economy of survival. It may equally indicate that work engaging these conditions directly is being done, but is being done outside the naming conventions, journals and languages that this analysis is able to see.

The second reading carries a consequence that runs counter to the recommendation this study might otherwise have made. The appropriate response to the geographical concentration documented in Figures 6 to 8 is not, in the first instance, to encourage the development of CME in the Global South. That formulation positions Northern scholarship as the model and Southern scholarship as its future recipient, and thereby repeats the hierarchy the field claims to oppose. Brazilian, Latin American, South African and South Asian traditions of popular mathematics education, ethnomathematics and mathematics for liberation are neither absent nor nascent. They are older than the term CME itself, and in the case of ethnomathematics they are among its acknowledged sources (D'Ambrosio, 1985; Knijnik, 1998). What the present analysis makes visible is not their absence but the failure of the indexed record to register them.

The task is therefore one of recognition, translation and citation rather than of development, and it falls in the first place on the scholars, editors and journals located at the centre of the circuit mapped here.

Notwithstanding these substantive findings, several structural features of the CME research landscape warrant critical attention. The collaboration network remains fragmented: the largest connected authorship component comprises only 20 of 292 identified authors, with the overwhelming majority outside that component. This pattern mirrors findings from bibliometric analyses of adjacent fields (Özdemir et al., 2024) and suggests that CME has not yet translated its commitment to collective and dialogic inquiry into sustained collaboration at the scale visible in these databases. A related concern, consistent with Fan's (2013) observations about mathematics education research more broadly, is the predominance of descriptive questions. Future scholarship would benefit from greater methodological diversity, including longitudinal, mixed-method, design-based, quasi-experimental and, where appropriate, causal-inference approaches capable of examining how critical mathematics pedagogies are enacted and what consequences they have for learning, identity and civic agency.

Reading the Findings through Critical Education Policy

The patterns described above are not merely descriptive facts about a literature. Read through the categories the field itself supplies, they are statements about how educational knowledge is produced, legitimated and distributed. Apple's (1992) argument that curriculum and standards debates are contests over whose knowledge becomes official knowledge applies with equal force to the scholarly record examined here, since a field's canon functions as its curriculum. That thirteen leading publication sources contain the core of the indexed CME scholarship, that a single outlet accounts for fifteen per cent of the corpus, and that the ten most globally cited publications in the dataset are predominantly mainstream mathematics education papers rather than works of critical theory, together indicate that the terms on which CME becomes legible are set substantially by the mainstream venues through which it must pass. Legitimacy is conferred by the institutions being critiqued. This is close to what Apple (2014) describes as the incorporation of oppositional knowledge into a settlement that leaves the underlying distribution of authority intact.

The Frankfurt School critique that grounds CME's philosophical apparatus supplies a second and less comfortable reading. Horkheimer and Adorno's account of instrumental reason, mediated for education through Habermas's (1972) distinction between technical and emancipatory knowledge interests, holds that domination advances by converting substantive questions into problems of measurement and optimisation. Contemporary research governance does precisely this to scholarship. The h-index, the impact factor, the quartile ranking and the citation velocity function as the audit apparatus of academic labour, and researchers internalise them as the horizon of professional judgement. The present study is implicated in that apparatus rather than exempt from it. Its findings can be read simultaneously as a map of a field and as a demonstration that a field committed to emancipatory knowledge interests is nonetheless governed by technical ones.

Freire's (1970a, 2000) account of critical consciousness and dialogue frames the collaboration findings more sharply than the language of network fragmentation allows. For Freire, conscientisation is not achieved by individuals in isolation. It is constituted in dialogue, and dialogue requires sustained relations among co-investigators rather than intermittent contact. A field in which 272 of 292 authors sit outside the largest connected component is not simply under-networked. In its own terms, it is conducting anti-dialogic research about dialogic pedagogy. The banking model that CME identifies in classrooms has an analogue in a mode of scholarly production in which knowledge is deposited into journals by isolated producers and withdrawn by isolated consumers

(Freire, 1985; McLaren, 2000). Taking the field's own commitments seriously would mean treating collaborative structure not as a bibliometric indicator but as a substantive criterion of critical practice.

Giroux's (1996, 2007, 2020) conception of educators as public and transformative intellectuals bears directly on the predominance of descriptive research documented above. If the vocation of the critical educator extends beyond the university to the formation of a democratic public culture, then a literature that maps, categorises and theorises without demonstrating consequence in schools, teacher education programmes and policy arenas has not yet met its own standard. The point is not that CME should submit to the evidentiary regimes of what works policy, which would surrender the critique that constitutes it. It is that a field claiming transformative purpose owes an account of transformation, and that account must be legible to teachers, teacher educators, unions and communities as well as to journal editors. Giroux and McLaren's (1996) case for teacher education as a site of democratic engagement indicates where such an account would be most consequential, namely in the preparation of the teachers who will or will not carry the field's commitments into classrooms.

A further absence in the mapped record deserves explicit statement. While Freire occupies a central position in the co-citation network and the Frankfurt School supplies the field's declared philosophical apparatus, the revolutionary current of critical pedagogy, the explicitly Marxist line developed by McLaren (2000, 2015), Allman (2001) and the contributors to Hill, McLaren, Cole and Rikowski (2002), remains only weakly connected to the indexed CME corpus. These works do not figure among the leading co-cited references in the network mapped here, and the categories through which this tradition reads education, namely class, labour and the capital relation, do not appear among the log-likelihood terms that define the fourteen thematic clusters. This pattern is consistent with the absence of poverty, hunger and dispossession noted above, and it suggests that the indexed CME literature has absorbed the Freirean vocabulary of dialogue and conscientisation while leaving the political economy from which that vocabulary emerged largely untranslated into its research programme. McLaren's (2015) revolutionary critical pedagogy holds that a critique of schooling that brackets the capital relation ultimately reproduces it; whether or not one accepts that judgement, the mapped record shows that the question has scarcely been put to mathematics education. Bringing CME into sustained dialogue with revolutionary critical pedagogy is therefore not an act of theoretical completism but a direct response to the silences this analysis has documented.

Read together, these findings describe a field whose structural conditions of production stand in tension with its declared political project. CME critiques a mathematics education subordinated to market competitiveness, yet it is itself produced within a research economy organised by publication counts, prestige hierarchies and metricised individual performance, and mediated by an oligopoly of commercial publishers whose pricing places much of the resulting scholarship beyond the reach of the school systems it addresses (Larivière et al., 2015; Skovsmose, 2022). This is not an accusation of bad faith against individual researchers, who work under conditions they did not choose. It is an observation about the material infrastructure of critical scholarship, and one that this field is better placed than most to pursue, since the instruments of that examination are already in its possession.

Several limitations should be considered when interpreting these findings. The dataset was drawn exclusively from two major citation databases, Web of Science and Scopus, and may not capture the full range of CME scholarship, particularly work published in non-English languages or in regional journals not indexed by these databases. This limitation is especially consequential for a field with such strong Southern hemisphere and non-anglophone dimensions, as important contributions from Brazilian, Spanish, and other language contexts may be systematically underrepresented. Additionally, the use of the exact keyword phrase “Critical Mathematics Education” as the sole search term, while ensuring conceptual precision, may have excluded relevant work published under adjacent terminology. Future bibliometric investigations of CME might productively employ broader keyword strategies to capture the field’s full terminological diversity. This structural reliance on English-language databases introduces what might be termed a bibliometric epistemological contradiction: a field explicitly committed to epistemic justice, pluriversal knowledge, and the dismantling of Anglophone hegemony in education remains, in its own mapped scholarly record, largely invisible to the voices it most seeks to amplify. Future bibliometric investigations of CME should actively incorporate non-English databases and grey literature to begin redressing this structural gap. A final limitation is intrinsic to the method rather than to its execution. Co-word and co-citation techniques can establish what a literature says and how often it says it, but they cannot adjudicate what it ought to be saying. Judgements about significant absences, such as those discussed above, required reading the corpus qualitatively against the field’s own stated commitments, and readers proceeding from different political starting points would identify different absences. The maps presented here are therefore best treated as an object for critical interpretation rather than as a settled account of the field. A related constraint concerns thematic grouping and cross-output interpretation. The silhouette index returned zero for every LLR-based grouping in this configuration, so internal separation could not be verified by that criterion. LLR statistics support the distinctiveness of representative labels, not structural separation. In addition, the numerical identifiers shown in the exported timeline visualisation are not treated as a one-to-one crosswalk with the LLR identifiers in Table 4. The three temporal phases are therefore interpretive syntheses based on term content, mean publication years and temporal visualisation rather than on stable cluster numbers across outputs.

Policy Implications

The structural findings of this study carry significant implications for education policy. The persistent concentration of CME scholarship in Northern European and North American institutions represents a form of epistemic injustice. This directly contradicts the field's commitment to pluriversal knowledge production. The remedy, however, does not lie primarily in encouraging the Global South to produce more scholarship of the kind indexed here. It lies in changing what the centre reads, cites and translates. Journals should commission and translate work from non-Anglophone traditions. Editorial boards should be constituted so that such work can be reviewed on its own terms. Funders in high-income countries should support translation, open access and equitable co-authorship rather than treating internationalisation as the outward extension of existing networks. International research networks should work deliberately to decentralise the field's institutional core.

The structural fragmentation of collaboration networks reveals a further tension. The largest connected authorship cluster comprises only 20 of the 292 identified authors. A field whose theoretical apparatus is built upon Freirean solidarity and collective emancipation thus reproduces, in its own academic practice, the very individualism it critiques in mainstream educational institutions. Building CME as a genuinely dialogic research community requires deliberate investment in cross-institutional partnerships, particularly those connecting Northern and Southern scholarly traditions.

The predominance of descriptive research designs points to a need for greater methodological diversity. If CME is to examine its transformative aspirations empirically without reducing them to narrow what-works criteria, future scholarship should combine longitudinal, mixed-method, design-based and quasi-experimental approaches, using causal-inference designs where they are substantively and ethically appropriate. Such work could document not only the conceptual contours of critical mathematics pedagogy but also how it shapes learning, identity formation and civic agency over time.

A final implication concerns research assessment policy itself. The indicators employed in this study, including h-indices, citation counts and network inclusion thresholds, are the same instruments through which national research assessment systems allocate funding, promotion and institutional standing. A field committed to interrogating the formatting power of numbers carries a particular obligation to contest their use in the governance of academic labour, and to press for assessment regimes that recognise translation, community partnership, teacher education and movement scholarship as research outputs rather than as service.

Conclusion

This bibliometric analysis provides a data-driven and reflexive account of the indexed Critical Mathematics Education literature from 2000 to 2025. Across 160 scholarly publications drawn from Web of Science and Scopus, the findings illuminate the leading publication sources, authors, institutions and countries visible within the selected databases, together with the thematic groupings and temporal patterns that characterise the corpus.

Since its emergence as a coherent scholarly paradigm in the late 1990s and early 2000s, CME has moved from a philosophically grounded but institutionally marginal position toward greater international visibility within the indexed mathematics education literature. Its concerns with equity, social justice, democratic agency and the critique of mathematics as neutral are increasingly visible across the 2000-2025 record. The present analysis does not project a future saturation point, because the small, rapidly changing and database-dependent corpus does not support a sufficiently transparent forecast without additional modelling information.

At the same time, persistent structural challenges remain. Collaboration networks are fragmented, geographic representation is uneven, and the exact-phrase, English-language search captures only a demarcated part of critical work in mathematics education. Greater methodological diversity is also needed. Longitudinal, mixed-method, design-based and carefully justified causal-inference approaches could help examine not only what critical mathematics pedagogy claims conceptually but how it is enacted and experienced across diverse educational contexts.

The co-citation landscape also invites productive dialogue between CME and adjacent research traditions. The prominence of Gravemeijer and Terwel (2000) underscores the generative potential of Freudenthal's guided reinvention principle as a pedagogical companion to CME's critical apparatus. The co-citation standing of Hanna and Barbeau (2008) suggests that proof-based inquiry can cultivate the critical mathematical agency CME aspires to develop, while Dreher et al. (2018) further highlights that transformative CME pedagogy requires the specialized professional content knowledge needed to enact it effectively.

Looking ahead, emerging scholars and doctoral students in mathematics education are encouraged to attend to the most rapidly growing frontiers of CME research. These include the integration of decolonial and pluriversal epistemologies into mathematics curriculum design, the application of intersectional frameworks attending simultaneously to race, gender, language, and class in mathematical learning environments, and the cultivation of what Hand (2012) describes as a pedagogy of noticing, in which teachers become attuned to the ways that power and culture operate in moment-to-moment classroom life. The potential of mathematical modelling and data literacy as tools for critical citizenship in an era of misinformation and climate crisis also deserves sustained scholarly attention, as does the question of how teacher education programs can prepare teachers not only to solve mathematical problems but to question inherited ones and reconstruct the epistemic frames through which school mathematics has historically been organized. The implications of artificial intelligence and algorithmic governance for mathematics education's democratic aspirations constitute a final and pressing frontier. Most urgently, the field needs longitudinal empirical studies capable of answering whether students who experience critical mathematics curricula actually develop greater democratic agency and civic engagement than those who do not.

Together, the field's rich philosophical heritage and its enduring commitment to social transformation ensure that CME will remain a vital and urgently relevant area of scholarly inquiry in the decades ahead. From Dewey's foundational vision of education as democratic experience, through Freire's emancipatory pedagogy and the revolutionary critical pedagogy elaborated by McLaren and his collaborators, to CME's contemporary engagement with decolonial and intersectional frameworks, each generation of CME scholars has deepened the conviction that mathematics education is not merely a technical enterprise but a profoundly political one.

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