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Semiotic Representations in Mathematics Education: A Bibliometric Analysis

Fatqurhohman
University of Muhammadiyah Jember, Indonesia

Abstract: This study analyzes the development of semiotic representation in mathematics education using a bibliometric approach. Semiotic representation is essential for understanding abstract mathematical concepts, yet limited innovation in this area calls for deeper exploration. Bibliometric data were retrieved from the Scopus database (2005–2024) using the keyword “Semiotics Representation.” A total of 62 documents were selected based on type, language, and thematic relevance. VOSviewer was employed to map publication trends, citations, and collaboration networks among researchers, institutions, and countries. The results reveal a significant growth in publications, peaking in 2020–2024 (31 publications), while the highest citation rate occurred in 2010–2014 (433 citations). The most cited article, published in 2012, received 233 citations. Key authors include Ifunanya Ubah, with the United States leading in publications (10) and citations (490). Strong international collaborations are observed among the United States, Australia, and New Zealand. Georgia State University is the most productive institution, and Educational Studies in Mathematics emerges as the leading journal. Dominant themes include mathematical concepts, connections, semiotic approaches, and graphical representations. Future research should leverage visual-based tools to encourage innovative studies. This study provides strategic insights for enhancing mathematics education, particularly in adapting to the digital era.

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1. Introduction

Semiotic representation is a concept that integrates two main elements: representation and semiotics. Representation refers to the means of depicting or conveying meaning through various forms of symbols or signs (Fatqurhohman & Susetyo, 2022; Sánchez & Alemán, 2022), while semiotics focuses on signs and symbols (Gottlieb et al., 2022), including the interpretation of their meanings (Ferretti et al., 2024; Zhao, 2023). In this context, semiotics examines the relationship between the signifier and the signified, both of which represent specific objects or ideas (Lomas, 2019). For instance, the "+" symbol in mathematics has a signifier in the form of its visual symbol and a signified meaning representing the operation of addition. Based on their relationship with their objects, signs can be classified into three types: icons, which physically resemble their objects; indices, which have a cause-and-effect relationship; and symbols, which rely on conventions or habits (Ledezma et al., 2023; Zhao, 2023).

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In mathematics, representation serves as the ability to understand and describe mathematical concepts through various means such as graphs, tables, diagrams, symbols, and more (Fatqurhohman et al., 2020; Tupamahu et al., 2023). This process involves translating (Fatqurhohman & Susetyo, 2022) and visualizing mathematical concepts into more concrete forms according to established rules and conventions (Chico & Montes, 2023; Gottlieb et al., 2022; Septian et al., 2020). Signs and symbols play a crucial role in creating meaning and understanding within the context of mathematics education (Purwasih et al., 2024; Sánchez & Alemán, 2022). Mathematical representation enables students to solve more complex and abstract mathematical problems through a deeper comprehension of the represented objects (Ferretti et al., 2024), and to relate the meanings of those symbols to real-life contexts (Font et al., 2019; Sevinc, 2023).

Effective mathematics education relies not only on mastering mathematical formulas or procedures but also on students' ability to understand and utilize various forms of representation in solving mathematical problems (Fatqurhohman, 2016). Representations may include symbols, images, graphs, or other visual forms that convey the meaning of mathematical concepts (Fatqurhohman et al., 2020; Fatqurhohman & Susetyo, 2022). In this context, semiotics plays a vital role in interpreting mathematical problems through signs and symbols (Ledezma et al., 2023; Zhao, 2023), by providing a theoretical framework for understanding how students process and interpret mathematical symbols during learning (Beltrán-Pellicer & Godino, 2020; Godino et al., 2022).

The concept of representation in mathematics is often linked to the theory of semiotic representation, which involves selecting, processing, and converting between various semiotic registers such as symbols, images, or notations (Montenegro et al., 2021; Sánchez & Alemán, 2022). The relationship between understanding and semiotic registers is crucial in mathematics education, emphasizing that without adequate comprehension, students may struggle to grasp complex mathematical concepts, particularly when interpreting symbols and their interrelations (Moreno-Arotzena et al., 2021). Therefore, visual and dynamic representations in mathematics education play an important role in clarifying abstract concepts, helping students connect mathematics to real-life contexts, and facilitating their understanding (Gulkilik et al., 2020; Moyer-Packenham et al., 2022). Additionally, semiotic representation fosters student engagement in solving mathematical problems and supports inclusive learning (Asenova et al., 2023; Ledezma et al., 2023; Mainali, 2021). Applying this approach opens opportunities for broadening research on semiotic representation, particularly in global mathematics education (Capone et al., 2021). Consequently, innovations in curriculum design, teaching methods, inclusive assessments, and technology-based learning media that support semiotic representation are strategic steps toward improving the effectiveness of mathematics education at an international level (Berciano et al., 2021; Gulkilik et al., 2020).

The study of semiotic representation has now expanded into various fields, such as technology (Lepore & Mennuni, 2023; Moyer-Packenham et al., 2022) and communication (Aiello & Van Leeuwen, 2023; Ibrahim & Sulaiman, 2020), focusing on bridging abstract mathematical concepts with everyday experiences. Moreover, this research encompasses problem-solving across various mathematics subjects, such as geometry, algebra, and mathematical modeling, demonstrating that semiotic representation enhances students' conceptual understanding and problem-solving skills (Dahiana et al., 2023; Purwasih et al., 2024; Rodriguez-Nieto et al., 2023). However, in-depth studies on the application of semiotic representation in mathematics education remain limited, highlighting the need for further research to explore the full potential of this approach in enhancing the quality of mathematics learning.

One promising approach for gaining deeper insights is bibliometric research. This method enables researchers to map the development of studies, analyze trends, citations, and collaborations among researchers and institutions in the field of semiotic representation (Lim & Kumar, 2024). Bibliometric analysis also reduces subjectivity and bias in literature reviews while providing a comprehensive quantitative mapping of research trends and collaboration developments (Setianingrum & Da Costa, 2023). Thus, bibliometric analysis can offer an overarching view of the evolution of semiotic representation research, identify research gaps, and provide strategic directions for future studies (Donthu et al., 2021).

This study aims to fill the gap in research on semiotic representation in mathematics education through a bibliometric analysis. The primary focus is to analyze research trends, citation patterns, and collaborations over the past two decades (2005–2024), using the Scopus database as the main data source. This approach is expected to provide a comprehensive mapping of the development of semiotic representation research, particularly in the context of mathematics education.

The findings of this study are anticipated to identify key trends, potential cross-institutional collaborations, and unexplored research gaps. Furthermore, this research aims to contribute significantly to the academic community by offering strategic insights to support future innovations in the study of semiotic representation. Based on this research focus, the problem statement posed is “What are the patterns of development in semiotic representation research in mathematics education over the past two decades?”.

2. Method

This study employs a meta-analysis method complemented by bibliometric analysis to conduct a systematic review of research on semiotic representation in mathematics education, focusing on publications from 2005 to 2024 sourced from the Scopus database (https://www.scopus.com). According to (Mukherjee et al., 2022), bibliometric and meta-analytic approaches use quantitative and statistical techniques to evaluate the bibliographic elements of scientific publications. These analyses also help identify knowledge gaps, generate new research ideas, and provide a general overview of research developments in a specific field (Donthu et al., 2021). The document selection process in this study follows the PRISMA guidelines, including identification, screening, and inclusion phases (Page et al., 2021). Specifically, each step for conducting bibliometric analysis in this research is detailed as follows.

2.1. Identification

The researcher conducted a comprehensive identification of research data using the keyword “Semiotics Representation” through the Scopus database (https://www.scopus.com) on November 16, 2024, at 10:00 AM WIB. This process aimed to find prospective documents relevant to the study of semiotic representation in mathematics education. It yielded an initial dataset of 1,957 documents published between 2005 and 2024, sourced from journal articles, books, book chapters, proceedings, and reviews.

2.2. Screening

In the screening phase, the researcher classified documents based on document type, publication status, and language. Only officially published articles written in English were selected, while other types, such as books, book chapters, proceedings, and reviews, were excluded. Furthermore, the articles were filtered by focusing on the field of mathematics, resulting in 454 documents that met the criteria.

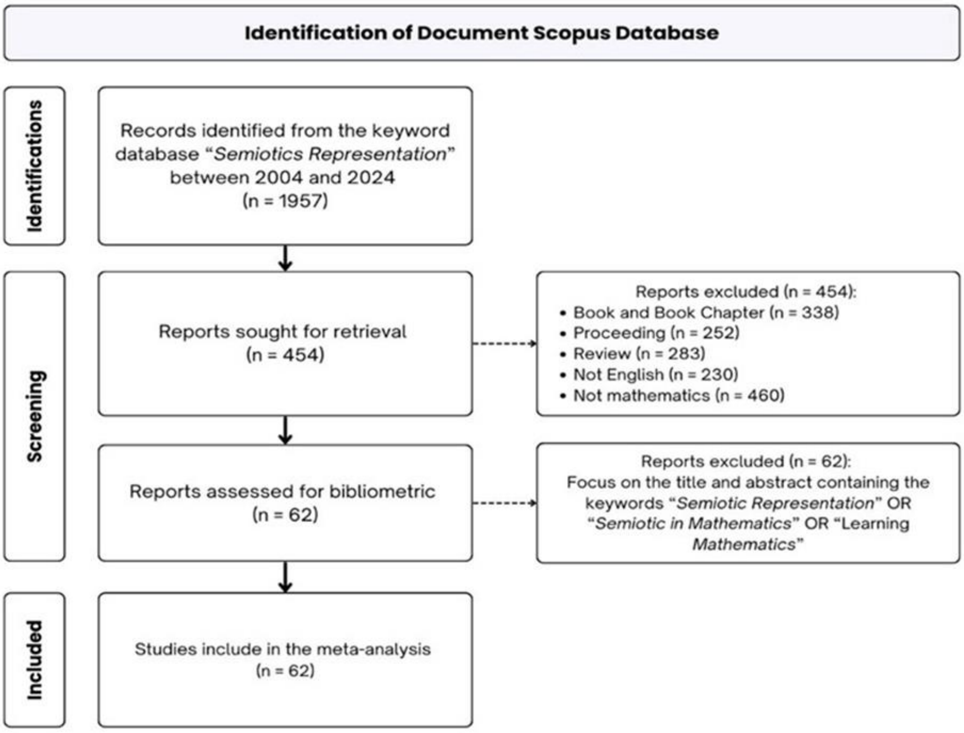
2.3. Included

In this stage, the researcher conducted the final selection by applying inclusion criteria to identify documents related to research on semiotic representation in mathematics education. Specifically, the title or abstract of the document had to contain the keywords "Semiotic Representation", OR "Semiotic in Mathematics", OR "Learning Mathematics". This final selection process resulted in 62 documents.

2.4. Analyzing Data

The database documents that met the established criteria were downloaded from Scopus (https://www.scopus.com) in Comma Separated Values (CSV) format. This format includes several details, such as bibliometric information, abstracts, keywords, and bibliographic data. The data analysis in this study covers two main aspects: (1) Analysis of publication and citation trends, and (2) Mapping and bibliometric network analysis.

Figure 1 illustrates the overall data collection process using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework.



3. Results And Discussion

3.1. Results

This study presents the development pattern of research articles related to semiotic representation during the publication period from 2005 to 2024, covering two main aspects, (1) Analysis of publication and citation trends, and (2) Mapping and bibliometric network analysis.

3.1.1. Publication and Citation Trend Analysis

This study analyzes the development of publications and citations related to semiotic representation in mathematics education. Figure 2 shows the results of the analysis of publication and citation trends related to semiotic representation in mathematics education during the period 2005–2024.

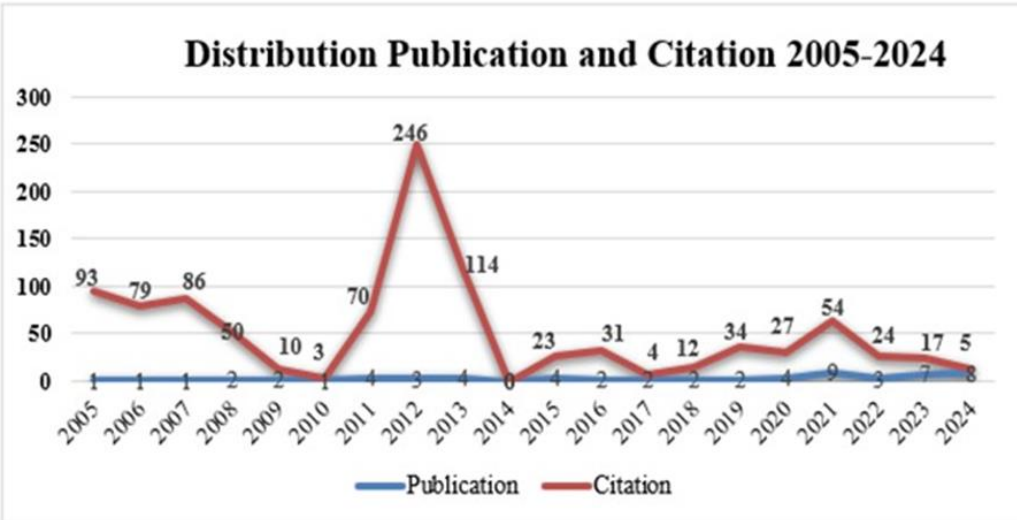


Figure 2 shows the trend of growth in the number of publications and citations related to semiotic representation in mathematics education during the period 2005–2024. This graph provides an overview of the fluctuations in the number of publications and citations each year, reflecting the interest and focus of researchers and academics on this topic. The number of publications shows significant growth when measured in five-year intervals, while the number of citations tends to decrease over time.

Based on the selection of 62 article documents that met the criteria for the publication period from 2005 to 2024 related to semiotic representation in mathematics education, the highest development in the number of publications occurred in the period 2020–2024, with 31 documents (51%), followed by the periods 2015–2019 and 2010–2014, each with 12 documents (19%), and the period 2005–2009 with only 7 documents (11%). In terms of citations, the highest occurred in the period 2010–2014 with 433 citations, followed by 318 citations in the 2005–2009 period, 127 citations in the 2020–2024 period, and 104 citations in the 2015–2019 period. Furthermore, the highest number of publications per year occurred in 2021, with 9 documents, while the highest number of citations occurred in 2012 with 246 citations.

3.1.2. Co-citation Mapping Analysis

The previous analysis examined the research trends, including publication and citation patterns. Next, bibliometric mapping aims to visualize the relationships between documents, sources, authors, organizations, and countries related to semiotic representation research in mathematics education during the period from 2005 to 2024. This bibliometric analysis is based on the 62 selected documents using the VOSviewer application. Table 1 shows the fifteen most-cited documents related to semiotic representation in mathematics education.

Table 1. Fifteen documents with the highest citation

No.	Title	Source Journal	Publisher	Authors (Year)	Citation
1	Visual semiotics & uncertainty visualization: An empirical study	IEEE Transactions on Visualization and Computer Graphics	IEEE Computer Society	(Maceachren et al., 2012)	233
2	Diagrammatic reasoning as the basis for developing concepts: A semiotic analysis of students' learning about statistical distribution	Educational Studies in Mathematics	Springer	(Bakker & Hoffmann, 2005)	93
3	Semiotic representations: Building complex literacy practices through the arts	Reading Teacher	International Literacy Association	(Cowan & Albers, 2006)	79
4	A Study of Semiotic Registers in The Development of The Definite Integral of Functions of Two and Three Variables	International Journal of Science and Mathematics Education	Springer	(McGee & Martinez-Planell, 2014)	51
5	Understanding the role of emotion in sense-making. A semiotic psycho analytic oriented perspective	Integrative Psychological and Behavioral Science	Springer	(Salvatore & Venuleo, 2008)	51
6	Information, semiotics, and symbolic systems	Semiotica	De Gruyter	(Auletta, 2007)	35
7	Objectification and semiotic function	Educational Studies in Mathematics	Springer	(Santi, 2011)	28
8	Signifying the accumulation graph in a dynamic and multi-representation environment	Educational Studies in Mathematics	Springer	(Yerushalmy & Swidan, 2012)	27
9	Exploring Student Reasoning and Representation Construction in School Science Through the Lenses of Social Semiotics and Interaction Analysis	Research in Science Education	Springer	(Knain et al., 2021)	21
10	Sense-making regarding matrix representation of geometric transformations in R2: a semiotic mediation perspective in a dynamic geometry environment	ZDM - Mathematics Education	Springer	(Turgut, 2019)	19
11	Objects, signs, and representations in the semio-cognitive analysis of the processes involved in teaching and learning mathematics: A Duvalian perspective	Educational Studies in Mathematics	Springer	(Iori, 2017)	17
12	A fuzzy semantic representation and reasoning model for multiple associative predicates in knowledge graph	Information Sciences	Elsevier	(Li et al., 2022)	16
13	The use of semiotic	Pythagoras	AOSIS	(Ubah &	15

	representations in reasoning about similar triangles in Euclidean geometry			Bansilal, 2019)	
14	The semiotic and conceptual genesis of angle	ZDM - Mathematics Education	Springer	(Tanguay & Venant, 2016)	14
15	Sign language in light of mathematics education: An exploration within semiotic and embodiment theories of learning mathematics	American Annals of the Deaf	JSTOR	(Krause & Wille, 2021)	11

Table 1 shows the 15 documents that have had a significant impact on research regarding semiotic representation in mathematics education, with publication periods between 2005 and 2024. These documents were written by authors from various countries, including the United States, Australia, New Zealand, the Netherlands, the United Kingdom, Canada, Puerto Rico, Italy, Israel, Norway, Sweden, Turkey, China, South Africa, Germany, and Austria. The most cited document (Maceachren et al., 2012), authored by three researchers from the United States, Australia, and New Zealand, holds the highest citation count. On the other hand, the document with the lowest citation count in the list (Krause & Wille, 2021) was written by two researchers from Germany and Austria. These findings suggest that the most cited documents are typically produced by authors affiliated with prestigious universities and supported by international collaboration, involving diverse academic backgrounds, countries, and research topics.

Table 2 shows the top five authors with the highest number of publications and citations in the field of semiotic representation in mathematics education. The number of publications indicates the authors' level of activity and contribution to the research area, while the number of citations reflects the influence and relevance of their work within the academic community. This data highlights the most influential researchers in the field, providing insights into the key contributors who have shaped the current understanding and development of semiotic representation in mathematics education.

Table 2. Five authors with the highest number of publications and citations

No	Author(s)	Affiliation	Publication	Citations
1	Ubah, I	University of Johannesburg	2	19
2	Ferguson, J. P	Deakin University	2	15
3	Rodriguez-Nieto, C. A	University of the Coast	2	7
4	Wilhelmi, M. R	University of Navarra	2	7
5	Font, V	University of Barcelona	2	7

Table 2 shows that 146 authors have participated in research related to semiotic representation in mathematics education, with 5 authors meeting the threshold of having at least 2 connections between documents. These five authors have an equal number of 2 publications, but their citation counts vary. The highest citation count is 19 (Ubah, 2022; Ubah & Bansilal, 2019). The collaborative contributions of authors from various countries play a significant role in enhancing the quality of mathematics education, tailored to curriculum characteristics and an inclusive, effective approach. This collaboration is significantly enriching the development of theory and practice related to semiotic representation.

Next, the contribution of countries is measured based on the number of publications and citations they have received. Table 3 presents the top 10 countries with the highest contributions in terms of the number of publications and citations related to the topic of semiotic representation in mathematics education.

Table 3. Ten Countries with the highest number of publications and citations

No	Country	Publication	Citations
1	United States	10	490
2	Australia	7	307
3	Italy	7	109
4	South Africa	6	21
5	Spain	5	20
6	Turkey	4	40
7	Canada	3	117
8	United Kingdom	3	100
9	Brazil	3	12
10	Colombia	3	9

Table 3 shows that 43 countries participated in research related to semiotic representation in mathematics education, with 10 countries having at least 3 document connections. The data, sourced from Scopus, covers the period from 2005 to 2024. The United States is the largest contributor, with 10 publications generating 490 citations. Australia ranks second, with 7 publications and 307 citations, followed by Italy in third place, which has the same number of publications as Australia but with fewer citations (109). South Africa contributed 6 publications with 21 citations, followed by Spain with 5 publications and 20 citations. Turkey ranks next with 4 publications and 40 citations, followed by Canada (3 publications, 117 citations), the United Kingdom (3 publications, 100 citations), Brazil (3 publications, 12 citations), and Colombia (3 publications, 9 citations). This data illustrates the diverse contributions from various countries related to research on semiotic representation in the development of mathematics education.

Further, these countries span various regions, including Europe, North America, Oceania, South America, Africa, and Asia. European countries, including Italy (7), the United Kingdom (3), and Spain (5), made the largest contribution, totaling 15 publications (about 31.25%). North American countries, comprising the United States (10) and Canada (3), contributed a total of 13 publications (around 27.1%). Oceania, represented by Australia, contributed 7 publications (approximately 14.6%). South American countries, including Brazil (3) and Colombia (3), accounted for 6 publications (about 12.5%). Africa, represented by South Africa, contributed 6 publications (about 12.5%). Lastly, Turkey from Asia ranked last with 4 publications (about 8.3%). This distribution highlights the global nature of research in semiotic representation in mathematics education, with significant contributions from both developed and developing countries.

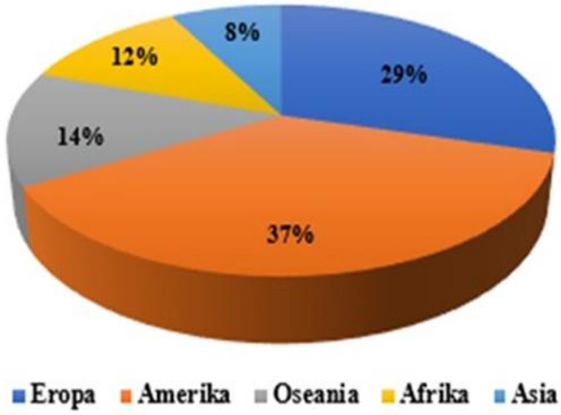


Figure 3 illustrates that the Americas region has the largest percentage of publications (37%), consisting of both North and South America, followed by Europe with the second-largest percentage (29%). Developing countries such as Oceania (14%), Africa (12%), and Asia (8%) also contribute to the research. The significant contribution of the Americas to publications is largely due to its strong research infrastructure (with many leading universities and research institutions), substantial research funding, diverse cultures, and extensive global collaboration networks.

Next, Table 4 presents the top five organizations/affiliations with the largest number of publications and citations related to the topic of semiotic representation in mathematics education.

Table 4. Five Affiliation with the highest number of publications and citations

No	Organization / Affiliation	Publication	Citations
1	Georgia State University	2	84
2	Curtin University	2	50
3	University Of Bologna	2	45
4	University Of Johannesburg	2	19
5	University Of Kwazulu-Natal	2	16

Table 4 shows that 89 organizations/affiliations have participated in research related to semiotic representation in mathematics education, with 5 organizations/affiliations meeting the threshold of having at least 2 connections between documents. These five organizations/affiliations have the same number of publications (2), but with varying citation counts. Georgia State University has the highest contribution with 84 citations, followed by Curtin University with 50 citations, University of Bologna with 45 citations, University of Johannesburg with 19 citations, and University of Kwazulu-Natal with 16 citations. This indicates that the countries contributing the most based on these organizations/affiliations are the United States (Georgia State University), followed by Australia (Curtin University), Italy (University of Bologna), and South Africa (University of Johannesburg and University of Kwazulu-Natal).

Table 5 will likely highlight the top ten sources or journals that have made the most significant contributions in terms of publications and citations related to semiotic representation in mathematics education. This data would provide a clear picture of the journals that have played the most prominent role in disseminating and advancing research in this field, as well as the level of attention the published research has garnered from the academic community. It would show how influential certain journals are in promoting the topic, based on the number of publications and citations they have received. This information would be useful for understanding the key platforms that shape and reflect trends in this area of study.

Table 5. Five sources/journal with the highest number of publications and citations

No	Sources / Journal	Publisher	Publication	Citations
1	Educational Studies in Mathematics	Springer	6	174
2	International Journal of Mathematical Education in Science and Technology	Taylor and Francis	4	22
3	International Journal of Science and Mathematics Education	Springer	3	62
4	ZDM-Mathematics Education	Springer	3	37
5	Semiotica	De Gruyter Mouton	2	36

Table 5 provides a detailed overview of the top sources or journals contributing to research on semiotic representation in mathematics education. From the data, it's evident that Educational Studies in Mathematics is the leading journal, with the highest number of publications (6) and citations (174), followed by International Journal of Mathematical Education in Science and Technology (4 publications and 22 citations). Other notable journals include International Journal of Science and Mathematics Education (3 publications, 62 citations), ZDM – Mathematics Education (3 publications, 37 citations), and Semiotica (2 publications, 36 citations).

The analysis further reveals that Springer is the most prominent publisher, contributing the largest share of publications (12) and citations (273), primarily through journals like Educational Studies in Mathematics, International Journal of Science and Mathematics Education, and ZDM–Mathematics Education. Taylor and Francis follow with contributions through the International Journal of Mathematical Education in Science and Technology (4 publications, 22 citations), while De Gruyter Mouton contributes through Semiotica (2 publications, 36 citations). This information highlights the significant role that Springer plays in advancing research on this topic, both in terms of volume and impact.

3.1.3. Co-keywords Analysis

Co-keyword analysis is a bibliometric method used to uncover and explore hidden structures within document texts by evaluating the co-occurrence of keywords within documents. This approach helps to map conceptual structures, identify dominant themes, and reveal research trends (Donthu et al., 2021). It involves collecting keywords, normalizing to avoid duplication, analyzing the relationships between keywords, and visualizing a network that clearly depicts conceptual connections.

In this study, the co-keyword analysis began by examining the keywords used by the authors in the documents. The analysis results show 1,171 co-occurring keywords, with 37 keywords meeting the threshold of a minimum occurrence of 5 keywords. Figure 4 illustrates four main clusters in different colors, which are connected to the topic of semiotic representation in mathematics education: red, green, blue, and yellow.

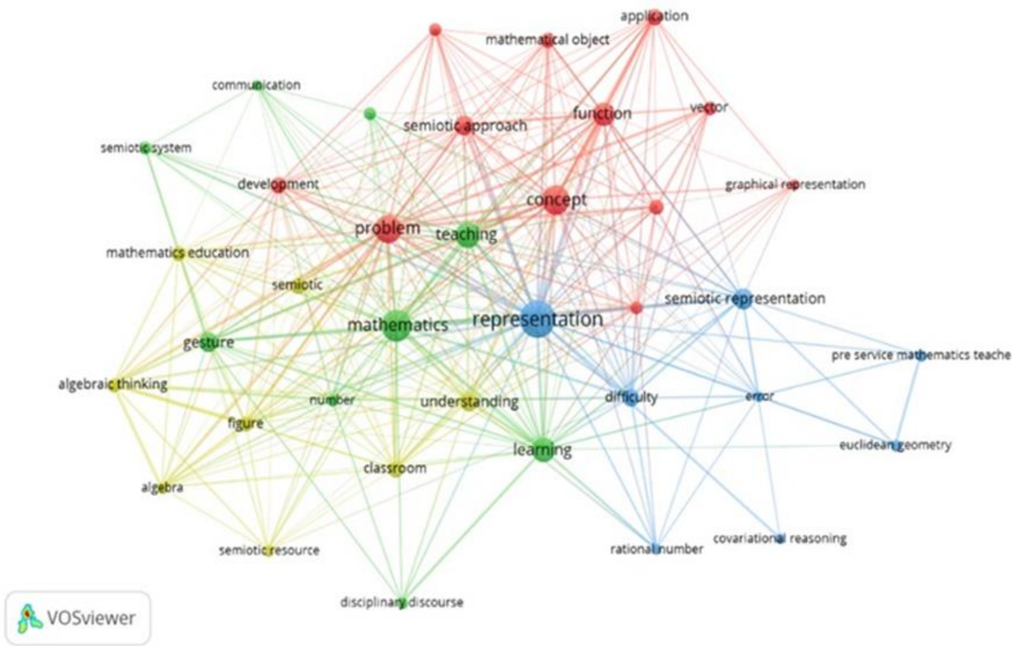


Figure 4. Network visualization of co-keyword analysis

Figure 4 shows 37 keywords grouped into four clusters. The red cluster contains twelve keywords “Concept, Problem, Function, Semiotic Approach, Development, Application, Mathematical Connection, Mathematical Object, Vector, Mathematical Activity, Mathematical Concept, Graphical Representation”. The green cluster includes nine keywords “Mathematics, Teaching, Learning, Gesture, Semiotic Register, Semiotic System, Number, Disciplinary Discourse, Communication”. The blue cluster consists of eight key-word ”Representation, Semiotic Representation, Difficulty, Pre-Service Mathematics Teacher, Euclidean Geometry, Error, Covariational Reasoning, Rational Number”. Lastly, the yellow cluster has eight keyword ”Understanding, Semiotic, Classroom, Mathematics Education, Figure, Algebraic Thinking, Semiotic Resource, Algebra”.

Table 6. Clustering of keywords

Cluster	Keyword	Number of Occurrences	Total Link Strength
Cluster 1 (Node Red)	Concept	39	0.3373
	Problem	34	0.3613
	Function	25	0.3945
	Semiotic Approach	19	0.2721
	Development	13	0.3453
	Application	12	0.6042
	Mathematical Connection	10	0.5983
	Mathematical Object	10	0.3548
	Vector	9	0.901
	Mathematical Activity	8	0.1842
	Mathematical Concept	8	0.2921
	Graphical Representation	5	0.8642
Cluster 2 (Node Green)	Mathematics	46	0.2689
	Teaching	29	0.215
	Learning	27	0.4838
	Gesture	17	0.6588
	Semiotic Register	8	0.4703
	Semiotic System	8	11.391

	Number	7	0.8728
	Disciplinary Discourse	6	10.095
	Communication	5	0.7543
Cluster 3 (Node Blue)	Representation	62	0.2152
	Semiotic Representation	21	10.659
	Difficulty	15	0.3833
	Pre-Service Mathematics Teacher	7	66.269
	Euclidean Geometry	6	62.247
	Error	5	17.243
	Covariational Reasoning	5	16.695
	Rational Number	5	0.9764
Cluster 4 (Node Yellow)	Understanding	16	0.2038
	Semiotic	13	0.3395
	Classroom	13	0.2677
	Mathematics Education	11	0.6211
	Figure	10	1.022
	Algebraic Thinking	9	15.556
	Algebra	7	17.132
	Semiotic Resource	6	10.088

Table 6. The most dominant keywords in each cluster are “Concept (39)” in the red cluster, “Mathematics (46)” in the green cluster, “Representation (62)” in the blue cluster, and “Understanding (16)” in the yellow cluster. These four keywords are closely interconnected in the context of mathematics education. “Concept” serves as the core of mathematics learning, representing the abstract ideas underlying each topic. To understand a concept, “Representation” is necessary, functioning as a tool or medium to transform abstract ideas into something more concrete, such as symbols, diagrams, or visual models. Meanwhile, Representation aids students in developing “Understanding,” which refers to a deep comprehension of mathematical concepts, enabling students to apply these concepts flexibly in various situations. These keywords are embedded within the framework of “Mathematics,” which provides the disciplinary context as part of a holistic learning process.

3.2. Discussion

Research on semiotic representation in mathematics education explores the role of signs, symbols, and diagrams in supporting mathematics learning. The analysis of publication and citation trends from 2005 to 2024 reveals a fluctuating pattern, with the number of publications continuing to increase while the number of citations tends to decrease, or vice versa. The peak of publications occurred in the period 2020–2024 with 31 documents, while the highest number of citations was recorded in the period 2010–2014, with 433 citations. The year 2021 saw the highest number of publications, with 9 documents, while 2012 marked the peak of citations with 246. According to (Hebler & Ziegler, 2022), the decline in citations in semiotic research is believed to be caused by saturation of the theme, a lack of innovative contributions, and a shift in academic focus toward new topics, such as digital technology and data-driven approaches. This situation has led to the perception of a lack of contributions to novelty, relevance, and the appeal of developing effective teaching strategies, which in turn impacts the interest and attention of the academic community towards the potential of semiotic representation in enhancing the quality of mathematics education.

The analysis results show various contributions related to the number of publications and citations from collaborations between authors, affiliations, and journals from countries such as the United States, Australia, New Zealand, the Netherlands, the United Kingdom, and others. This was revealed by (Yao, 2021) in his research that international author collaboration can expand the advancement of knowledge and practice, as well as disseminate findings to diverse populations, regions, and cultures. Meanwhile, findings from (Pinho & Reeves, 2021) reveal that cross-country collaboration promotes broader knowledge and technology exchange, accelerating scientific progress and innovation. For instance, an analysis of documents shows the highest citation (233 citations) from 10 documents (Maceachren et al., 2012), involving three researchers from the United States, Australia, and New Zealand, who collectively contributed to the field of visual semiotics.

An analysis of the authors shows that (Ubah, 2022; Ubah & Bansilal, 2019) from the University of Johannesburg, South Africa, have the most citations (19 citations). However, these results contradict the analysis of countries and affiliations, as the United States emerges as the primary contributor with 10 publications and 490 citations, while South Africa contributed only 6 publications and 21 citations. Moreover, Georgia State University ranks first with 84 citations, while the University of Johannesburg is ranked fourth among the top five institutions, with 19 citations. Further analysis of journal sources reveals that Educational Studies in Mathematics (published by Springer) ranks first with 6 publications and 174 citations out of the 41 participating journal sources. This journal focuses on both theoretical and practical research in mathematics education, is based in the Netherlands, and has a significant influence in the field of mathematics education, surpassing other journals such as International Journal of Mathematical Education in Science and Technology and ZDM-Mathematics Education.

Thus, international collaboration between authors, affiliations, and leading countries has a significant impact on the development of publication and citation in research, which in turn enhances the relevance and application of research findings across various global educational systems. The strong connections between leading journals and international publishers also reinforce the dissemination of the underlying theories of research, particularly in the field of mathematics education. With these relationships, research gains broader coverage, allowing researchers to share findings and new perspectives, as well as creating opportunities for innovation in the development of mathematical teaching methods and strategies. Such collaboration also facilitates the exchange of knowledge between countries and improves the quality and impact of research at a global level.

Furthermore, Figure 5 presents an overlay visualization analysis of co-keywords from 2005–2024 using VOSviewer. This analysis provides a structured overview of the relationships between keyword concepts, highlighting their relevance and centrality within the academic context. The interconnectedness is grouped into four clusters that contribute significantly to the research in this field.

“Cluster 1” focuses on the application and semiotic approach to teaching mathematical concepts, encompassing the interconnection of three keywords “mathematical concept”, “semiotic approach”, and “application”. The semiotic approach is crucial for linking mathematical concepts with more concrete representations through visual aids, which supports teachers in understanding student behavior. This is confirmed in (Burgos et al., 2021; Godino et al., 2022) research that the onto-semiotic approach helps in understanding mathematical objects holistically, and who highlight the importance of the onto-semiotic complexity in decision-making during the student learning process.

“Cluster 2” focuses on the learning environment in teaching mathematical concepts, encompassing the interconnection of three keywords “mathematics”, “teaching”, and “learning”. An effective learning environment is created through good communication between teachers and students, along with the application of appropriate methods. The use of gestures as non-verbal expressions can strengthen this communication, helping to explain abstract concepts in a clearer and more understandable way. This is reinforced by

(Robutti et al., 2022), who emphasize that gestures are an essential tool in communication, thinking, and learning mathematics, playing a crucial role in conveying non-verbal information in interpersonal communication within the classroom. Therefore, teaching that utilizes various semiotic systems can create a learning environment that supports more meaningful mathematical communication in various contexts.

“Cluster 3” focuses on the development of representational skills in the practice and application of teaching mathematical concepts, encompassing the interconnection of three keywords “representation”, “semiotic representation”, and “pre-service mathematics teacher”. This highlights that teachers' skills in using semiotic representations, such as symbols, signs, and images in mathematics teaching, strengthen the understanding of abstract mathematical concepts. This is in line with what (Fatqurhohman & Susetyo, 2022) expressed in his research that, representation plays an essential role in mathematics learning through symbols, signs, diagrams, and images. Furthermore, it helps engage students in learning by linking abstract ideas to the real world and enhances students' understanding of complex mathematical concepts (Mainali, 2021).

"Cluster 4" focuses on mathematical understanding and semiotic concepts in mathematics education, encompassing the interconnection of three keywords: "understanding," "semiotic," and "mathematics education." This highlights that the integration of visual and semiotic representations in mathematics learning can create meaningful learning experiences and address ambiguities in complex mathematical concepts. It supports the development of mathematical concepts and enhances students' motivation. Semiotic representation through visual learning aids in managing the complexity of relationships between objects, signs, and representations (Beltrán-Pellicer & Godino, 2020; Godino et al., 2022).

“Cluster 4” focuses on mathematical understanding and semiotic concepts in mathematics education, encompassing the interconnection of three keywords “understanding”, “semiotic”, and “mathematics education”. This indicates that integrating visual and semiotic representations in mathematics learning can create meaningful learning experiences, address ambiguities in complex mathematical concepts, support the development of mathematical concepts, enhance student motivation, and manage the complexity between objects, signs, and representations through visual learning.

This suggests that incorporating visual and semiotic representations in mathematics education fosters meaningful learning experiences, resolves ambiguities in complex mathematical concepts, facilitates the development of mathematical understanding, boosts student motivation, and effectively navigates the interplay between objects, signs, and representations through visual learning methods.

4. Conclusion

This bibliometric study confirms that semiotic representation in mathematics education experienced significant development between 2005 and 2024, with fluctuating publication and citation trends each year. The study identified 62 relevant articles during this period, with the peak of publications occurring from 2020 to 2024, totaling 31 articles, and 2021 standing out with nine publications. Meanwhile, the highest number of citations was recorded between 2010 and 2014, with a peak of 433 citations, particularly in 2012 with 246 citations. These findings indicate a growing academic interest in this topic.

The majority of contributors to this field, including authors and articles, originate from leading countries such as the United States, Australia, and New Zealand. This level of contribution is likely supported by robust research infrastructure (universities and renowned research institutions), substantial research funding, cultural diversity, and extensive global collaborative networks. Additionally, the most productive affiliation was Georgia State University, while the journal with the largest number of publications was Educational Studies in Mathematics.

Furthermore, the findings demonstrate that semiotic representation in mathematics education during this period is closely related to its application, particularly in areas connected to mathematics and representation. Key topics include mathematical concept, mathematical connection, mathematical object, mathematical activity, problem, function, vector, graphical representation, semiotic approach, and development. Future researchers are encouraged to focus on these identified topics, leveraging visual-based applications to explore and steer the field towards more innovative and relevant investigations.

REFERENCES

1. *Aiello, G., & Van Leeuwen, T. (2023). Michel Pastoureau and the history of visual communication. Visual Communication, 22(1). https://doi.org/10.1177/14703572221126517*

2. *Asenova, M., Del Zozzo, A., & Santi, G. (2023). Unfolding Teachers' Interpretative Knowledge into Semiotic Interpretative Knowledge to Understand and Improve Mathematical Learning in an Inclusive Perspective. Education Sciences, 13(1). https://doi.org/10.3390/educsci13010065*

3. *Auletta, G. (2007). Information, semiotics, and symbolic systems. Semiotica, 166. https://doi.org/10.1515/SEM.2007.061*

4. *Bakker, A., & Hoffmann, M. H. G. (2005). Diagrammatic reasoning as the basis for developing concepts: A semiotic analysis of students' learning about statistical distribution. Educational Studies in Mathematics, 60(3). https://doi.org/10.1007/s10649-005-5536-8*

5. *Beltrán-Pellicer, P., & Godino, J. D. (2020). An onto-semiotic approach to the analysis of the affective domain in mathematics education. Cambridge Journal of Education, 50(1). https://doi.org/10.1080/0305764X.2019.1623175*

6. *Berciano, A., Jiménez-Gestal, C., & Salgado, M. (2021). Kindergartners' Use of Symbols in the Semiotic Representation of 3-Dimensional Changes. International Electronic Journal of Mathematics Education, 12(3). https://doi.org/10.29333/iejme/615*

7. *Burgos, M., Bueno, S., Pérez, O., & Godino, J. D. (2021). Onto-semiotic complexity of the Definite Integral. Journal of Research in Mathematics Education, 10(1). https://doi.org/10.17583/redimat.2021.6778*

8. *Capone, R., Adesso, M. G., Del Regno, F., Lombardi, L., & Tortoriello, F. S. (2021). Mathematical competencies: a case study on semiotic systems and argumentation in an Italian High School. International Journal of Mathematical Education in Science and Technology, 52(6). https://doi.org/10.1080/0020739X.2020.1726517*

9. *Chico, J., & Montes, M. Á. (2023). Semiotic Representations of Multiplication and Division in Elementary School Textbooks. Bolema - Mathematics Education Bulletin, 37(75). https://doi.org/10.1590/1980-4415v37n75a14*

10. *Cowan, K., & Albers, P. (2006). Semiotic Representations: Building Complex Literacy Practices Through the Arts. The Reading Teacher, 60(2). https://doi.org/10.1598/rt.60.2.3*

11. *Dahiana, W. O., Herman, T., Nurlaelah, E., & Pereira, J. (2023). Student Semiotic Representation Skills in Solving Mathematics Problems. Jurnal Didaktik Matematika, 10(1). https://doi.org/10.24815/jdm.v10i1.30770*

12. *Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., & Lim, W. M. (2021). How to conduct a bibliometric analysis: An overview and guidelines. Journal of Business Research, 133. https://doi.org/10.1016/j.jbusres.2021.04.070*

13. *Fatqurhohman, F. (2016). Transition Process of Procedural to Conceptual Understanding in Solving Mathematical Problems. International Education Studies, 9(9), 182. https://doi.org/10.5539/ies.v9n9p182*

14. *Fatqurhohman, F., Sa'dijah, C., Sudirman, & Sulandra, I. M. (2020). Pictorial of representation in solving word problems. International Journal of Scientific and Technology Research, 9(3), 1057–1060.*

15. *Fatqurhohman, F., & Susetyo, A. M. (2022). Symbolic-Pictorial Representation Transition in Solving Mathematical Problems. Edumatica: Jurnal Pendidikan Matematika, 12(01). https://doi.org/10.22437/edumatica.v12i01.15291*

16. *Ferretti, F., Gambini, A., & Spagnolo, C. (2024). Management of semiotic representations in mathematics: Quantifications and new characterizations. European Journal of Science and Mathematics Education, 12(1). https://doi.org/10.30935/scimath/13827*

17. *Font, V., Godino, J. D., & Contreras, A. (2019). From Representations to Onto-Semiotic Configurations in Analysing Mathematics Teaching and Learning Processes. In Semiotics in Mathematics Education. https://doi.org/10.1163/9789087905972_010*

18. *Godino, J. D., Burgos, M., & Gea, M. M. (2022). Analysing theories of meaning in mathematics education from the onto-semiotic approach. International Journal of Mathematical Education in Science and Technology, 53(10). https://doi.org/10.1080/0020739X.2021.1896042*

19. *Gottlieb, H., González, L. G., & Kuznik, A. (2022). Semiotics and translation. Hermeneus, 24. https://doi.org/10.24197/her.24.2022.643-675*

20. *Gulkilik, H., Moyer-Packenham, P. S., Ugurlu, H. H., & Yuruk, N. (2020). Characterizing the growth of one student's mathematical understanding in a multi-representational learning environment. Journal of Mathematical Behavior, 58. https://doi.org/10.1016/j.jmathb.2020.100756*

21. *Hebler, N., & Ziegler, A. (2022). Evidence-based recommendations for increasing the citation frequency of original articles. Scientometrics, 127(6). https://doi.org/10.1007/s11192-022-04378-7*

22. *Ibrahim, I., & Sulaiman, S. (2020). Semiotic Communication: An Approach Of Understanding A Meaning In Communication. International Journal of Media and Communication Research, 1(1). https://doi.org/10.25299/ijmcr.v1i1.4584*

23. *Iori, M. (2017). Objects, signs, and representations in the semio-cognitive analysis of the processes involved in teaching and learning mathematics: A Duvalian perspective. Educational Studies in Mathematics, 94(3). https://doi.org/10.1007/s10649-016-9726-3*

24. *Knain, E., Fredlund, T., & Furberg, A. (2021). Exploring Student Reasoning and Representation Construction in School Science Through the Lenses of Social Semiotics and Interaction Analysis. Research in Science Education, 51(1). https://doi.org/10.1007/s11165-020-09975-1*

25. *Krause, C. M., & Wille, A. M. (2021). Sign language in light of mathematics education: An exploration within semiotic and embodiment theories of learning mathematics. American Annals of the Deaf, 166(3). https://doi.org/10.1353/aad.2021.0025*

26. *Ledezma, C., Font, V., & Sala, G. (2023). Analysing the mathematical activity in a modelling process from the cognitive and onto-semiotic perspectives. Mathematics Education Research Journal, 35(4). https://doi.org/10.1007/s13394-022-00411-3*

27. *Lepore, M., & Mennuni, F. (2023). GeoGebra Augmented Reality to Facilitate the Manipulation of Different Semiotic Representations of Paraboloids. International Journal for Technology in Mathematics Education, 30(3). https://doi.org/10.1564/tme_v30.3.3*

28. *Li, P., Wang, X., Liang, H., Zhang, S., Zhang, Y., Jiang, Y., & Tang, Y. (2022). A fuzzy semantic representation and reasoning model for multiple associative predicates in knowledge graph. Information Sciences, 599. https://doi.org/10.1016/j.ins.2022.03.079*

29. *Lim, W. M., & Kumar, S. (2024). Guidelines for interpreting the results of bibliometric analysis: A sensemaking approach. Global Business and Organizational Excellence, 43(2). https://doi.org/10.1002/joe.22229*

30. *Lomas, T. (2019). Positive Semiotics. Review of General Psychology, 23(3). https://doi.org/10.1177/1089268019832849*

31. *Maceachren, A. M., Roth, R. E., O'Brien, J., Li, B., Swingley, D., & Gahegan, M. (2012). Visual semiotics & uncertainty visualization: An empirical study. IEEE Transactions on Visualization and Computer Graphics, 18(12). https://doi.org/10.1109/TVCG.2012.279*

32. *Mainali, B. (2021). Representation in teaching and learning mathematics. International Journal of Education in Mathematics, Science and Technology, 9(1). https://doi.org/10.46328/ijemst.1111*

33. *McGee, D. L., & Martinez-Planell, R. (2014). A Study of Semiotic Registers in The Development of The Definite Integral of Functions of Two and Three Variables. International Journal of Science and Mathematics Education, 12(4). https://doi.org/10.1007/s10763-013-9437-5*

34. *Montenegro, J. A., Rosa Borba, R. E. D. S., & Bittar, M. (2021). Registers of Semiotic Representations Aiding the Learning of Combinatorial Situations. Mathematics Enthusiast, 18(3). https://doi.org/10.54870/1551-3440.1537*

35. *Moreno-Arotzena, O., Pombar-Hospitaler, I., & Barragués, J. I. (2021). University student understanding of the gradient of a function of two variables: an approach from the perspective of the theory of semiotic representation registers. Educational Studies in Mathematics, 106(1). https://doi.org/10.1007/s10649-020-09994-9*

36. *Moyer-Packenham, P. S., Roxburgh, A. L., Litster, K., & Kozlowski, J. S. (2022). Relationships Between Semiotic Representational Transformations and Performance Outcomes in Digital Math Games. Technology, Knowledge and Learning, 27(1). https://doi.org/10.1007/s10758-021-09506-5*

37. *Mukherjee, D., Lim, W. M., Kumar, S., & Donthu, N. (2022). Guidelines for advancing theory and practice through bibliometric research. Journal of Business Research, 148. https://doi.org/10.1016/j.jbusres.2022.04.042*

38. *Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. In The BMJ (Vol. 372). https://doi.org/10.1136/bmj.n71*

39. *Pinho, D. L. M., & Reeves, S. (2021). An interprofessional international research collaboration: exploration of key opportunities and challenges. Journal of Interprofessional Care, 35(1). https://doi.org/10.1080/13561820.2020.1711716*

40. *Purwasih, R., Turmudi, & Dahlan, J. A. (2024). How do you solve number pattern problems through mathematical semiotics analysis and computational thinking? Journal on Mathematics Education, 15(2). https://doi.org/10.22342/jme.v15i2.pp403-430*

41. *Robutti, O., Sabena, C., Krause, C., Soldano, C., & Arzarello, F. (2022). Gestures in mathematics thinking and learning. In Handbook of Cognitive Mathematics (Vols. 2–2). https://doi.org/10.1007/978-3-031-03945-4_8*

42. *Rodriguez-Nieto, C. A., Font, V., Rodriguez-Vásquez, F. M., & Pino-Fan, L. R. (2023). Onto-semiotic analysis of one teacher's and university students' mathematical connections when problem-solving about launching a projectile. Journal on Mathematics Education, 14(3). https://doi.org/10.22342/jme.v14i3.pp563-584*

43. *Salvatore, S., & Venuleo, C. (2008). Understanding the role of emotion in sense-making. A semiotic psychoanalytic oriented perspective. Integrative Psychological and Behavioral Science, 42(1). https://doi.org/10.1007/s12124-007-9039-2*

44. *Sánchez, D. J. Q., & Alemán, L. V. M. (2022). Srengthening Mathematical Representation and Communication Capacity Through The Use of Semiotics Representation Registers. Journal of Engineering Research, 2(14). https://doi.org/10.22533/at.ed.3172142206077*

45. *Santi, G. (2011). Objectification and semiotic function. Educational Studies in Mathematics, 77(2–3). https://doi.org/10.1007/s10649-010-9296-8*

46. *Septian, A., Suwarman, R. F., Monariska, E., & Sugiarni, R. (2020). Somatic, auditory, visualization, intellectually learning assisted by GeoGebra to improve student's mathematical representation skills. Journal of Physics: Conference Series, 1657(1). https://doi.org/10.1088/1742-6596/1657/1/012023*

47. *Setianingrum, I., & Da Costa, A. (2023). Mapping research on Indonesian professional teacher: The bibliometric analysis. Journal of Professional Teacher Education, 1(2). https://doi.org/10.12928/jprotect.v1i2.638*

48. *Sevinc, S. (2023). Knowledge-in-action for crafting mathematics problems in realistic contexts. Journal of Mathematics Teacher Education, 26(4). https://doi.org/10.1007/s10857-022-09541-8*

49. *Tanguay, D., & Venant, F. (2016). The semiotic and conceptual genesis of angle. ZDM - Mathematics Education, 48(6). https://doi.org/10.1007/s11858-016-0789-5*

50. *Tupamahu, P. Z., Ratumanan, T. G., & Laamena, C. (2023). Students' Mathematical Representation and Communication Ability in Mathematics Problem Solving. Jurnal Didaktik Matematika, 10(1). https://doi.org/10.24815/jdm.v10i1.29376*

51. *Turgut, M. (2019). Sense-making regarding matrix representation of geometric transformations in R2 : a semiotic mediation perspective in a dynamic geometry environment. ZDM - Mathematics Education, 51(7). https://doi.org/10.1007/s11858-019-01032-0*

52. *Ubah, I. (2022). Pre-service mathematics teachers' semiotic transformation of similar triangles: Euclidean geometry. International Journal of Mathematical Education in Science and Technology, 53(8). https://doi.org/10.1080/0020739X.2020.1857858*

53. *Ubah, I., & Bansilal, S. (2019). The use of semiotic representations in reasoning about similar triangles in Euclidean geometry. Pythagoras, 40(1). https://doi.org/10.4102/PYTHAGORAS.V40I1.480*

54. *Yao, B. (2021). International Research Collaboration: Challenges and Opportunities. In Journal of Diagnostic Medical Sonography (Vol. 37, Issue 2). https://doi.org/10.1177/8756479320976130*

55. *Yerushalmy, M., & Swidan, O. (2012). Signifying the accumulation graph in a dynamic and multi-representation environment. Educational Studies in Mathematics, 80(3). https://doi.org/10.1007/s10649-011-9356-8*

56. *Zhao, Y. (2023). Redefining 'Sign'/'Symbol' and Semiotics. Signs and Media, 2(1–2). https://doi.org/10.1163/25900323-12340022*

Fatqurhohman
University of Muhammadiyah Jember, Indonesia
frohman86@unmuhjember.ac.id