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Semiotic Reasoning in Mathematics: A Systematic Literature Review of Future Trends and Opportunities
Dyah Woro-wirastri Ekowati¹, Toto Nusantara², Makbul Muksar³, Dwi Agus Sudjimat⁴, Erna Yayuk⁵, Agung Deddiliawan Ismail⁶

Abstract
A way of reaching conclusions using symbols or signs is known as semiotic reasoning. Researchers need precise information on this subject. A systematic literature review (SLR) summarizes the trends and contributions of semiotic reasoning research in mathematics published in Scopus-indexed journals, as well as its future potential. In the Scopus database's search menu, the terms "reasoning" and "semiotic" were entered, and 503 articles were found. In addition, 18 papers met the criteria for analysis. PRISM is the method of inclusion and exclusion model used. Semiotic reasoning rose considerably from 2019 to 2023, with 14 articles (77.78%). The most prevalent research technique (12 articles) is the qualitative approach. The author's country of origin and international participation are mentioned. The places of origin of the writers reveal that semiotic reasoning articles have been disseminated fairly throughout all continents. Furthermore, 12 papers (66.7%) were completed entirely by themselves. There was just one study with international collaboration (5.56%). Keyword-wise, 18 works demonstrate the characterization of sign activity (semiotic) in mathematical semiotic reasoning. Aside from that, mathematical semiotic reasoning research supports classroom mathematics learning, the advancement of mathematical semiotic reasoning theory, and the application of mathematical semiotic reasoning in other scientific domains. Semiotic reasoning research has made the most important contribution to classroom mathematics instruction. Among the mathematical principles studied are numbers, geometry, derivatives, diagrams, comparison and measurement, and distribution. These discoveries might be useful. These findings may be considered or used as a beginning point for academics to research the issue of semiotic reasoning in mathematics in line with their own goals.

Keywords: semiotic reasoning, systematic literature review.

INTRODUCTION
Reasoning is the process of getting at conclusions based on previously established or accepted information (Reid & Rout, 2018; Slijepcevic, 2020). Students have the option to

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INTRODUCTION

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examine their talents or experiences in grasping mathematical topics while reasoning in mathematics study (Price et al., 2020; Selleri & Carugati, 2018). As stated by Sáenz-Ludlow and Presmeg, mathematics exploration by instructors and students includes activities with objects, symbols, or signs (Doina et al., 2012; Presmeg, 2016). Semiotics is the study of the development of signs and symbols for communicating information (Knight et al., 2020; Solovova, 2019). Semiotic reasoning is the thinking that uses objects, symbols, or signs (Espeland et al., 2018; Prain et al., 2022; C. W. Suryaningrum & Ningtyas, 2019; Christine Wulandari Suryaningrum et al., 2020). Mathematics students and teachers can identify the meaning behind these signs and symbols by semiotic analysis (Mills & Doyle, 2019; Wati et al., 2023).

Also, semiotic reasoning is often used in mathematics education, which involves a variety of components such as symbolic, visual, and speaking markers (Giacomone et al., 2018; Gürefe, 2022). These aspects are used to explain and teach mathematical topics in a more physical and understanding form to learners (Bobrova, 2021a). Mathematics instructors may adapt to students' unique learning methods and preferences by integrating different semiotic systems (Park et al., 2020). The cognitive process of generating meaning from signs and symbols is referred to as semiotic reasoning (Burgos & Godino, 2020; Slijepcevic, 2020). In other words, it includes interpreting and analyzing different signs and their relationships for the purpose to comprehend and express meaning. This semiotic reasoning process is not confined to language or textual symbols, but also includes visual, auditory, gestural, and spatial semiotic systems (C.-L. Chen & Herbst, 2013a). Semiotic reasoning is therefore more than simply a cerebral process; it is accomplished by active participation in semiosis, which involves every sign action or sign process (Ferguson, 2022). Students can better comprehend and learn abstract mathematical topics by transforming them into concrete and accessible forms via semiotic reasoning (Wati et al., 2023).

The capacity of students to participate in semiotic reasoning is essential in mathematics education because it helps them learn and interpret mathematical topics using signs (Nielsen et al., 2022). Several studies have found that semiotic thinking can aid in problem solving and comprehension of mathematical ideas (Barcelos et al., 2018; Pikkarainen, 2021). Other study indicates that semiotic thinking might be beneficial in elementary school. Overall, semiotic reasoning is crucial in mathematics education because it allows students to understand and interpret mathematical topics by using signs and representations. According to several research, semiotic reasoning integrating all semiotic components can significantly contribute to the understanding of mathematical topics (Christine W. Suryaningrum et al., 2018).

There are various possibilities for future research and inquiry as semiotic thinking gets recognition and becomes an essential aspect of mathematics instruction. In this regard, according to the results of a search in the world's most significant known journal database, Scopus, performed in September 2023, there were 550 articles on the topic "semiotic and reasoning" until September 2023. These articles must be thoroughly reviewed in order to glean useful information on the future of semiotic thinking in mathematics. A Systematic Literature Review (SLR) is one of the most recommended strategies for research and analysis. Previously, several studies suggested that the required categories being examined include distribution year, research categories, author's nationality, keywords, international collaboration, and the funding (Cole, 2019; Husamah et al., 2022; Mystakidis et al., 2021).

We identified five review-based papers on semiotic reasoning in the Scopus database. One English book review document, two English journal publications, one African language article (Schalkwyk, 2017), and one English conference review article "36th International Conference on Conceptual Modeling (2017)". One SLR is devoted to the study of African literary novels (Schalkwyk, 2017). One SLR is dedicated to the realm of marketing. A overview of the literature on argumentation, rhetoric, philosophy, cultural

studies, and language studies in India. The SLR described in the article published in the "36th International Conference on Conceptual Modeling" (2017) is concerned with modeling concept objects. One SLR offered a thorough review of the literature on reported evidence of mathematics learning. This SLR is limited to planar geometry and algebra and aims to improve computational thinking abilities (Barcelos et al., 2018).

However, no SLR studies education or mathematical education in general. As a result, it can be stated that SLR has not been found to focus on the existence part of semiotic reasoning in general in mathematics learning. Hence, the purpose of this systematic literature review (SLR) is to summarize the trends and contributions of semiotic reasoning research published in journals included in the Scopus database, as well as their future potential. It aims that this SLR will help to the advancement of semiotic reasoning studies and serve as a resource for academics and readers who are researching this issue. This study concentrates on the publication of original articles on the theme of semiotic reasoning and its relationship to future existence, which has never been done before by other researchers, in order to provide a research baseline and even serve as a basis for determining the future direction of semiotic reasoning. The review of the extent of material that we utilize only includes research/original publications, offering an overview of the researchers' focus and alignment on this issue (Chatterjee & Sen, 2014; Dekkers et al., 2022). This study present an overview of semiotic reasoning publication trends as according to by the database of Scopus, as well as the contribution made by semiotic reasoning and its future opportunities, that are very likely to become a reference for policymakers, practitioners, actors in education and learning mathematics, and its applications in the general public (Lawson-Adams & Dickinson, 2020; Wu & Fitzgerald, 2021).

METHOD

Research framework

The purpose of the Systematic Literature Review (SLR) conducted in this study is to make precise and serious efforts to identify, assess, and analyze the articles discovered (Dekkers et al., 2022; Parisoto & Pinheiro, 2016). Following that, in-depth analysis is used to gain answers to research questions. The findings of this SLR present a brief summary of semiotic reasoning research trends and contributions, as well as future potential, which are explored using a systematic and transparent way of addressing research questions.

Research Questions (RQ)

Research questions are designed to characterize a specific area of study. The study questions are as follows:

a. What is the current trend in "semiotic reasoning" articles in Scopus-indexed journals?

The distribution of year, research kind, author's nationality and international collaboration, and keywords in each semiotic reasoning research paper are used to describe publication patterns in this study.

b. What is the contribution of "semiotic reasoning" research, and what are the future prospects?

Inclusion criteria

The keywords " semiotic AND reasoning " are used in this study's search menu in the Scopus database. Article searches will be conducted until September 2023. Data from search results was stored in *CSV and *RIS formats and synced with Reference Manager (Mendeley). Researchers employ VOS-viewer software to make data more transparent,

interesting, and communicative. As for history search for articles in Scopus, namely (TITLE-ABS-KEY(semiotic reasoning) AND (LIMIT-TO (SUBJAREA, "SOC") OR LIMIT-TO (SUBJAREA, "MATH")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (EXACTKEYWORD, "Semiotics") OR LIMIT-TO (EXACTKEYWORD, "Reasoning")) AND (LIMIT-TO (OA, "all"))). These keywords found 505 articles in search results. To collect acceptable publications, researchers apply the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) methodology for exclusion and inclusion. This PRISMA model is based on Gallagher et al. (2016)'s viewpoint and has been widely used by various authors in previously published SLRs. There are several important notes used as the basis for inclusion criteria in this SLR, categorized as follows: (1) the subject area is "Social Sciences", "Mathematics"; (2) publications including research articles/original articles; (3) articles use English; (4) only open access articles; and (5) articles are filtered based on the keywords "semiotic", "reasoning". Figure 1 indicates the inclusion and exclusion criteria used in this study.

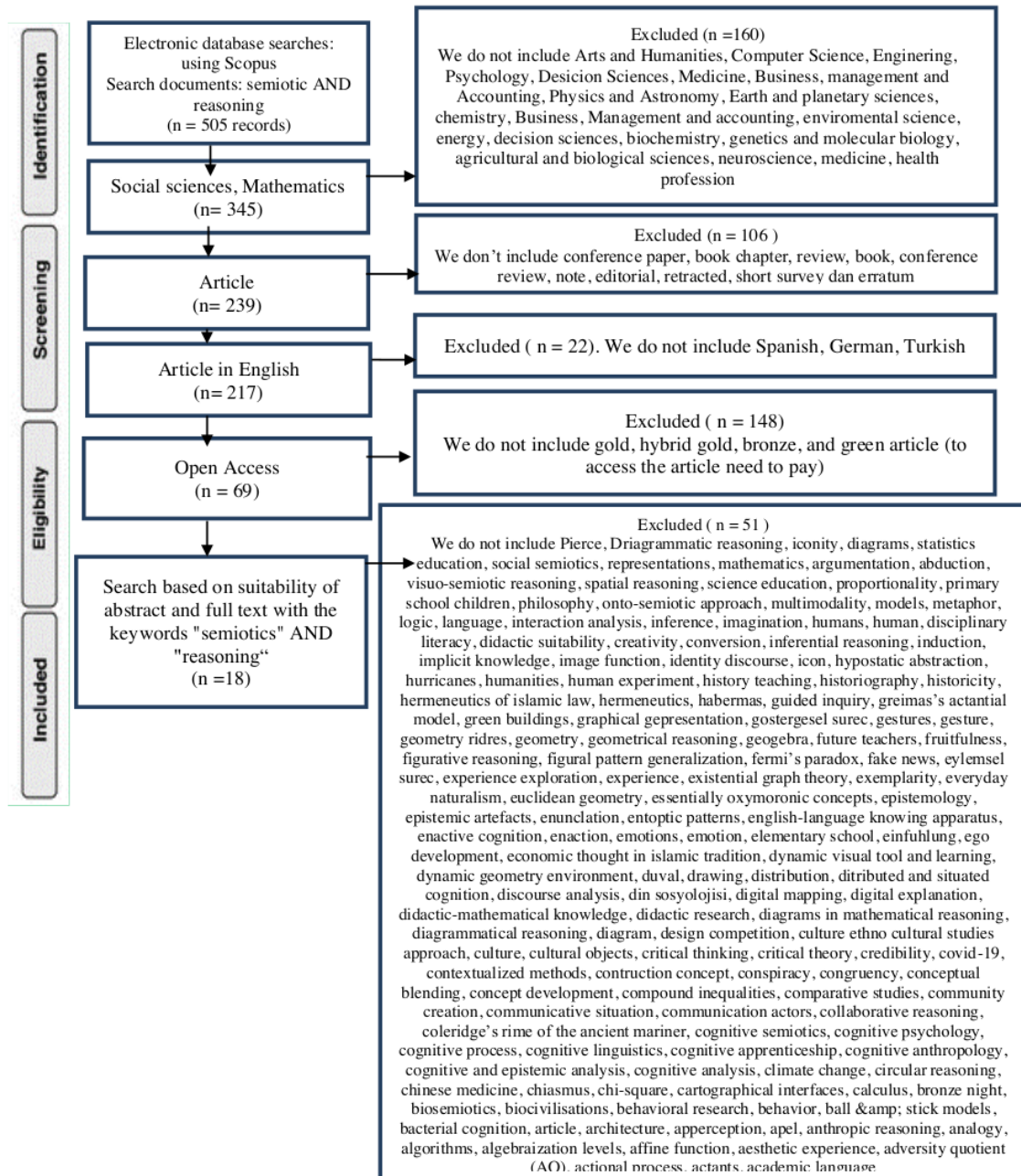


Figure 1. Systematic review flow diagram using the PRISMA model

In Figure 1 it can be explained that the initial search found 505 articles. Then the articles were filtered into the subject areas "social sciences" and "mathematics", the results obtained were 345 articles. This shows that as many as 160 do not meet the criteria. Next, we used the article criteria, obtaining 239 articles. A total of 106 publications were removed, including conference papers, book chapters, reviews, books, conference reviews, notes, editorials, retracted papers, brief surveys, and errata. After that, we will

employ 217 English articles. This implies that 22 articles in Spanish, German, and Turkish are no longer available. Following that, we utilized the open-access article filter, which yielded 69 publications that fit the criterion. This reveals that there are 148 items that are not allowed.

The next step is to take articles with the keywords "semiotic" and "reasoning" and remove the keywords "Pierce, Diagrammatic reasoning, iconity, diagrams, statistics education, social semiotics, representations, mathematics, argumentation, abduction, visuo-semiotic reasoning, spatial reasoning, science education, proportionality, primary school children, philosophy, onto-semiotic approach, multimodality, models, metaphor, logic, language, interaction analysis, inference, imagination, humans, human, disciplinary literacy, didactic suitability, creativity, conversion, inferential reasoning, induction, implicit knowledge, image function, identity discourse, icon, hypostatic abstraction, hurricanes, humanities, human experiment, history teaching, historiography, historicity, hermeneutics of Islamic law, hermeneutics, Habermas, guided inquiry, Greimas's actantial model, green buildings, graphical presentation, gostergeşel surec, gestures, gestures, geometry ridres, geometry, geometrical reasoning, geogebra, future teachers, fruitfulness, figurative reasoning, figural pattern generalization, fermi's paradox, fake news, eylemsel surec, experience exploration, experience, existential graph theory, exemplarity, everyday naturalism, euclidean geometry, essentially oxymoronic concepts, epistemology, epistemic artefacts, enunciation, entoptic patterns, english-language knowing apparatus, enactive cognition, enaction, emotions, emotions, elementary school, einfuhlung, ego development, economic thought in Islamic tradition, dynamic visual tools and learning, dynamic geometry environment, duval, drawing, distribution, distributed and situated cognition, discourse analysis, din sosyolojisi, digital mapping, digital explanation, didactic-mathematical knowledge, didactic research, diagrams in mathematical reasoning, diagrammatic reasoning, diagrams, design competition, culture ethno cultural studies approach, culture, cultural objects, critical thinking, critical theory, credibility, covid-19, contextualized methods, construction concept, conspiracy, congruency, conceptual blending, concept development, compound inequalities, comparative studies, community creation, communicative situation, communication actors, collaborative reasoning, Coleridge's rime of the ancient mariner, cognitive semiotics, cognitive psychology, cognitive process, cognitive linguistics, cognitive apprenticeship, cognitive anthropology, cognitive and epistemic analysis, cognitive analysis, climate change, circular reasoning, Chinese medicine, chiasmus, chi-square, cartographical interfaces, calculus, bronze night, biosemiotics, biocivilisations, behavioral research, behavior, ball & stick models, bacterial cognition, articles, architecture, apperception, apples, anthropic reasoning, analogy, algorithms, algebraization levels, affine function, aesthetic experience, adversity quotient (AQ), actional process, actants, academic language". There were a total of 51 items eliminated. In the last stage, existing articles are examined to ensure they reflect the subject being addressed, that the complete text is accessible, and that the piece is published in English. Based on this, we discovered just 18 articles that were suitable or matched the requirements, while 487 items did not and were eventually eliminated.

RESULTS

Publication trend's theme semiotic reasoning

Distribution year

Searching for papers on the topic of semiotic reasoning finds information that this issue may be described in Figure 2 discussing publications by year from 2005 to 2023.

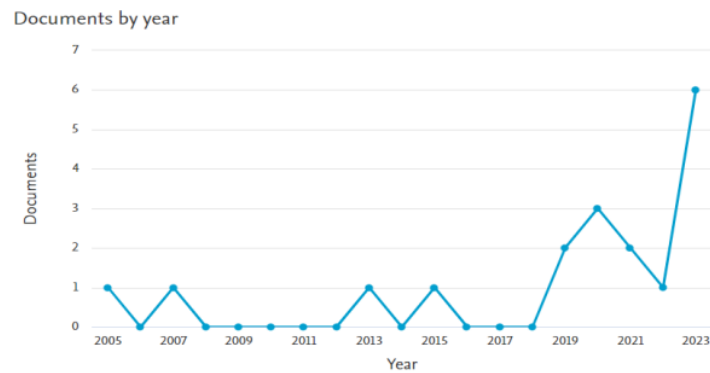


Figure 2. Distribution of years of articles

According to Figure 2, there were two publications on semiotic reasoning from 2005 and 2009, respectively. Between the years 2010 and 2014, there was a drop in publications, with only one publication each. The number of publications on the issue of semiotic reasoning has increased dramatically during the previous five years, from 2019 to 2023, by 14 articles (77.78%). The peak will be six published papers (33.33%) in 2023, and it is still feasible that this topic might increase. Keep in mind that this data search was conducted till September 2023. If the article search is run until December 2023, adding articles is still feasible.

Research Types

Table 1 shows the trend of study categories relating to "semiotic reasoning" themes.

Table 1. Types of Research on Science Learning Themes

No	Type of Research	Amount	References
1	Qualitative	12	(Bobrova, 2021a; Carter, 2019; C.-L. Chen & Herbst, 2013a; Goubran, 2021; M Kirk et al., 2023; O'Mahony, 2023; Røgild-Müller, 2022; Smith et al., 2020; F Stjernfelt, 2021; Christine Wulandari Suryaningrum et al., 2020; Terracciano, 2023; Wąsik, 2015)
2	Quantitative	3	(A Bakker & Hoffmann, 2005; Hoffmann, 2007; Frederik Stjernfelt, 2019)
3	Case studies	2	(Berners-Lee, 2023; Wille, 2020)
4	Mix-method	1	(Giberti et al., 2023)

Semiotic thinking was studied using a qualitative technique (12 papers). Three researchers conducted quantitative research; one paper employed mixed techniques, while the other two used case studies. This demonstrates that semiotic reasoning may be approached quantitatively and qualitatively. As a result, other researchers used the strategy to merge the two (1 article). R&D did not have any semiotic reasoning concerns as of September 2023.

Author's Nationality and International Collaboration

The authors who had a part in semiotic reasoning writings are shown in Figure 3 below based on the search results of 18 articles.

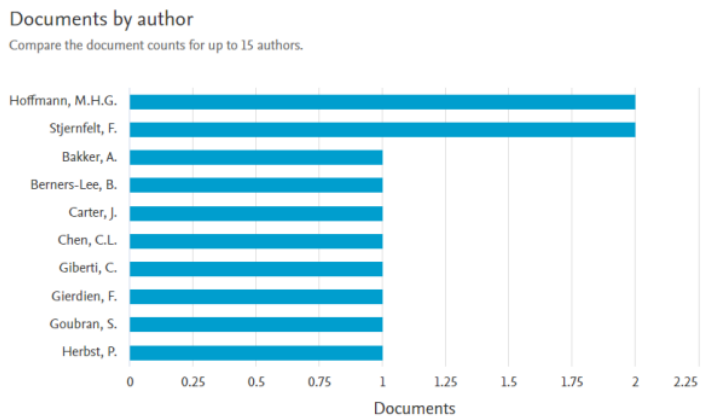


Figure 3. Author of Semiotic Reasoning Publications

As of September 2023, the writers Hoffmaan, MHG, and Stjernfelt, F. have the most publications, with two. According to the findings of the study of 18 papers, the semiotic reasoning publications most often refer to Pierce CS, as indicated in Figure 4 below.

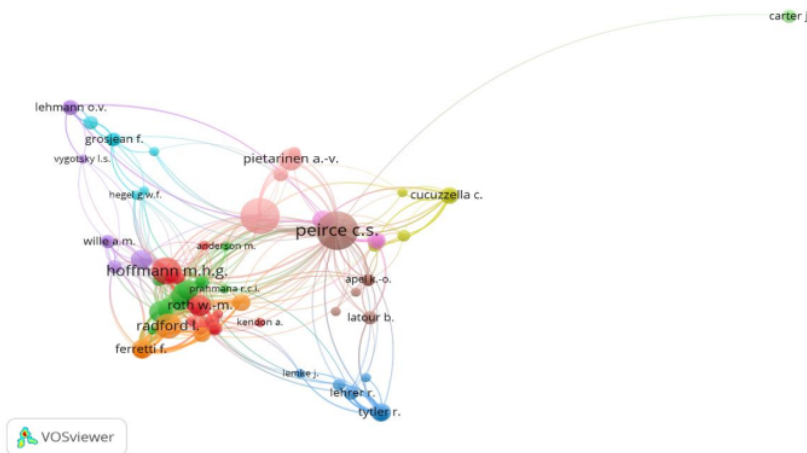


Figure 4. Authors Referred to in Semiotic Reasoning Publications

Table 3 shows the trend of the author's nationality of research connected to "semiotic reasoning" subjects.

Table 3. Author's Nationality and Continental on Semiotic Reasoning Themes

No.	Country	Continent	Amount	Number of Publications	References
1.	Indonesia	Asia	6	1	(C W Suryaningrum et al., 2020)
2.	United States	America	4	3	(Berners-Lee, 2023; C. L. Chen & Herbst, 2013; Hoffmann, 2007)
3.	Denmark	Europe	4	4	(Carter, 2019; Røgild-Müller, 2022; F Stjernfelt, 2021; Frederik Stjernfelt, 2019)
4.	Italy	Europe	4	2	(Giberti et al., 2023;

No.	Country	Continent	Amount	Number of Publications	References
					Terracciano, 2023)
5.	Australia	Australian	3	1	(M Kirk et al., 2023)
6.	South Africa	Africa	3	1	(Smith et al., 2020)
7.	Austria	Europe	1	1	(Wille, 2020)
8.	Canada	America	2	2	(A Bakker & Hoffmann, 2005; Goubran, 2021)
9.	Ireland	Europe	1	1	(O'Mahony, 2023)
10.	Netherlands	Europe	1	1	(A Bakker & Hoffmann, 2005)
11.	Poland	Europe	1	1	(Wąsik, 2015)
12.	China	Asia	1	1	(Shimek, 2021)

Table 3 shows that the authors of this article are from a total of 12 different nations. If expressed as a percentage, the figure is 6.21% of the world's total 193 countries. With 6 writers (19.35%), Indonesia has the highest number of semiotic reasoning authors. The United States comes second in semiotic reasoning publications, with 5 authors (16.12%). writers from Denmark and Italy are in third position, with four writers each (12.90%). Australia (3 writers, 9.6%) and South Africa (2 authors, 6.45%) take the fourth and fifth places, respectively. Authors from other nations contributed 1 author to semiotic reasoning publications. Austria, Canada, Ireland, the Netherlands, Poland, China, and the United Kingdom are the countries in concern.

The writers of semiotic reasoning papers are overwhelmingly from the European continent, with 12 authors (38.70%) being from the continent. The Asian continent is represented by seven writers (22.58%). With 6 article writers (19.35%), authors from the American continent take third position. Meanwhile, three articles (9.67%) were written by authors from the Australian continent. Finally, three writers (9.67%) are from the African continent. Figure 5 displays the writers' majority from the European continent. Even from that, examining the regions of origin of the writers indicates that semiotic reasoning articles are evenly distributed throughout all continents. As a result, the importance of semiotic thinking has become a global problem.

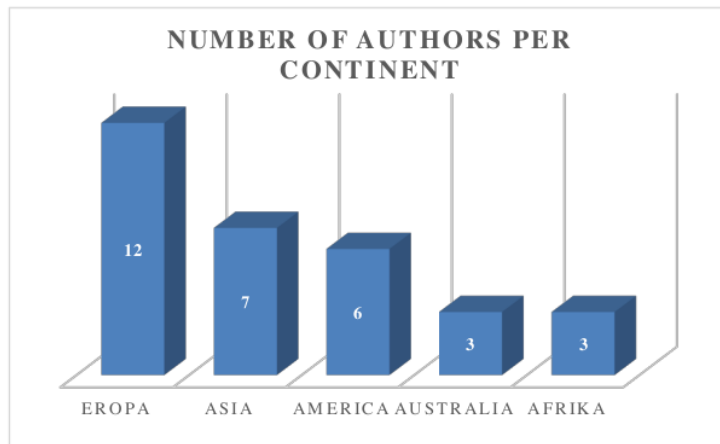


Figure 5. Number of Authors from Each Continent

Furthermore, Figure 6 displays author cooperation in article publications, including both worldwide and national level collaborations, as well as authors who conduct research/publications without cooperating.

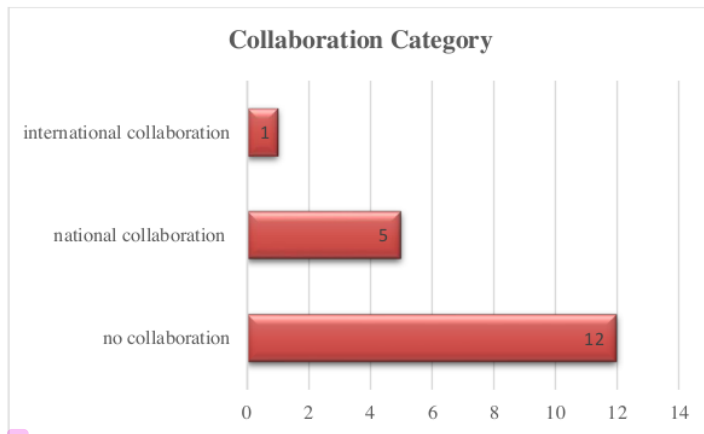


Figure 6. Author collaboration in writing articles

Figure 6 shows that there were more publications with a non-collaboration status (12 papers or 6.67%). Collaborative publications were 6 articles (33.33%), or half the number of non-collaborative publications. There are 18 articles in all. Figure 7 shows the number of scientists who wrote a single paper.



Figure 7. Number of Authors in The Publication

According to the findings in Figure 7, single authors continue to write the majority of semiotic reasoning articles. One publication is the outcome of international collaboration. When studying national collaborations starting from one institution, interesting data was collected, and there were even collaborations between university scholars and school instructors. These writers appear to be cooperating across scientific areas and agencies to collect thorough and detailed data.

Keywords

Figure 8 depicts trends in terms often used by writers in writing on the topic of "semiotic reasoning." The data is gathered using a type analysis based on co-occurrence with the unit analysis "all keywords" and counting approach, with the minimum number of occurrences of a term being one.

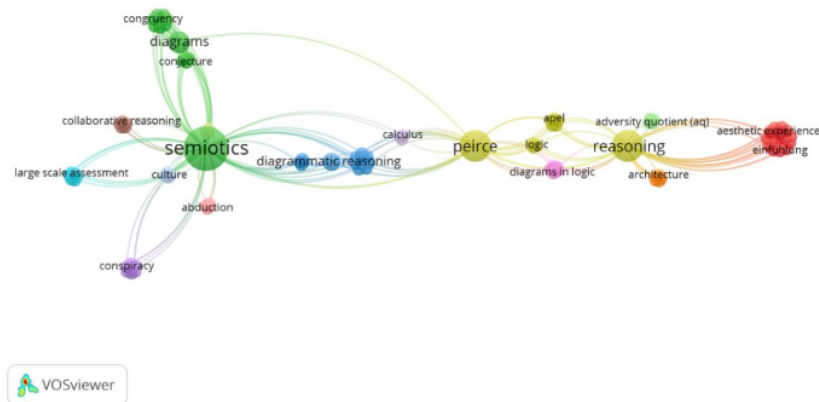


Figure 8. VOS-viewer Display for Type of Analysis “Co-Occurrence □ Keywords”

The terms that were used the most in a row were semiotic, reasoning, piercing, aesthetic experience, and diagrammatic reasoning, as can be seen in figure 8.

Semiotic reasoning research contributions and future opportunities

Contribution

Based on the results of the analysis of 18 articles, contribution information was obtained in Table 5 as follows.

Table 5. Contribution

No	Article	Contribution
1.	(Wille, 2020)	<ul style="list-style-type: none"> a. Focus on students' explanations and reasoning regarding the derivative. b. Analysis method and study in a grade 11 class.
2.	(C. L. Chen & Herbst, 2013)	<ul style="list-style-type: none"> a. Investigated semiotic bundles in students' geometrical reasoning. b. Examined how students utilized semiotic resources in developing their reasoning.
3.	(Christine Wulandari Suryaningrum et al., 2020)	<ul style="list-style-type: none"> a. Describes phases of semiotic reasoning in constructing properties of a rectangle. b. Highlights the importance of understanding mathematical concepts.
4.	(F Stjernfelt, 2021)	<ul style="list-style-type: none"> a. The paper discusses the connection between Peirce's doctrine of reasoning and his philosophy of consciousness. b. The paper investigates the implications of the cognitive criterion that reasoning be self-controlled.
5.	(Goubran, 2021)	<ul style="list-style-type: none"> a. Semiotics as a theoretical basis for examining sustainable architectural design b. Differentiating between deductive and abductive sustainable design reasoning
6.	(Wąsik, 2015)	<ul style="list-style-type: none"> a. The paper discusses the distinction between the observable self and the inferable self in communication. b. It argues for a multispectral typology of selves based on linguistic and cultural texts.
7.	(Giberti et al., 2023)	<ul style="list-style-type: none"> a. Consider the long history of the percent concept b. Rasch model's interpretation of student difficulties
8.	(O'Mahony, 2023)	<ul style="list-style-type: none"> a. New orientation in scholarship in social sciences b. Incorporation of historical and recent developments in critical theory
9.	(A Bakker &	<ul style="list-style-type: none"> a. Use of semiotics in mathematics education

No	Article	Contribution
	Hoffmann, 2005)	b. Explanation of learning through diagrammatic reasoning
10.	(Smith et al., 2020)	a. Difficulties in teaching and learning geometry at the school level b. Understanding the difficulties in teaching and learning geometry
11.	(Røgild-Müller, 2022)	a. Significance of moments of stillness and stillness b. The connection between silence and <i>Einführung</i> (feeling in and through others, objects, and oneself)
12.	(Terracciano, 2023)	a. Researching conspiracists' social media representations of the Covid-19 pandemic. b. Charting the phenomenon of "selective negationism " in conspiracy theories.
13.	(F Stjernfelt, 2019)	a. Dimensions of Peircean diagrammatically b. Comparison, measurement, and subdivision of diagrams
14.	(Hoffmann, 2007)	a. Learning is explained as the development of cognitive systems. b. Cognitive systems are semiotic systems dependent on signs and representations.
15.	(Bobrova, 2021b)	a. Contributes to debates on logical diagrams and reasoning studies. b. Provides possibilities for applying diagrams in investigations on the nature of reasoning.
16.	(M Kirk et al., 2023)	a. Semiotic perspective on critical thinking in guided inquiry b. Analysis of teacher and student interactions
17.	(Berners-Lee, 2023)	a. GSV imagery is used in GIS projects. b. Analysis of Geoguessr gameplay demonstrates practical integration.
18.	(Carter, 2019)	a. Explores the role of diagrams in mathematics b. Introduces the concept of 'faithful representation' for explaining fruitfulness

Based on the information explained in Table 5, it is known that the contribution of semiotic reasoning research is divided into three things, namely the contribution of semiotic reasoning to classroom learning, the development of semiotic reasoning theory, and the application of semiotic reasoning in other scientific fields. The greatest contribution of semiotic reasoning research leads to learning in the classroom. A total of 11 articles (61.11%) discussed semiotic reasoning during classroom learning (Arthur Bakker & Hoffmann, 2005; Bobrova, 2021b; Carter, 2019; C.-L. Chen & Herbst, 2013b; Giberti et al., 2023; Hoffmann, 2007; Melinda Kirk et al., 2023; Smith et al., 2020; Frederik Stjernfelt, 2019; C W Suryaningrum et al., 2020; Wille, 2020). Apart from that, semiotic reasoning research also contributed to the development of semiotic reasoning theory which was published by 4 articles (22.22%). Finally, contributions were made by 3 articles (16.67%) on the application of semiotic reasoning in other scientific fields.

DISCUSSION

Publication trends on the theme of semiotic reasoning

Distribution year

Publication of semiotic reasoning began in 2005. In the first decade, research on the topic of semiotic reasoning was not yet very developed. It was recorded that in 2005-2018, there were four publications. In 2019-2023 the number of publications with the theme of semiotic reasoning experienced a sharp increase of 14 articles (77.78%). It is still possible that publications will continue to increase because searches will be carried out until September 2023.

The increase in semiotic reasoning research in mathematics learning in the last five years cannot be separated from the role of signs in mathematical activities. In mathematics activities, a student needs to be fluent in mathematical sign activities (Chong et al., 2019;

Tyasing Swastika et al., 2019). Activities with this sign experienced expansion. The marks produced by students are not only limited to written answers (Danielsson & Selander, 2021). Written texts have expanded in oral form, finger-arm movements (gestures), artifacts, learning videos, interactions, communication, and even the learning media used (Silvestri et al., 2021; Xu & Ke, 2014). From the theoretical point of view of the philosophers Wittgenstein and Peirce, on the one hand, mathematics is seen as a game of signs, while on the other hand experiments with signs enable reasoning that can be observed, communicated, and explained (Godino et al., 2021).

Research types

Based on search results on 18 semiotic reasoning articles, it was concluded that the qualitative approach is the most dominant research type. A total of 12 articles used a qualitative approach, and 3 other articles used quantitatively. Meanwhile, 2 other articles used case studies, and a mixed-method approach was carried out by 1 other article. This shows that the issue of semiotic reasoning can be approached through quantitative and qualitative or a combination of both (mixed methods) depending on the goals, mission, and needs of the researchers.

The use of qualitative and quantitative methodologies, as well as their combination, as part of study types demonstrates the complexity of mathematics, both in learning and in its application in everyday life (Creswell, 2009). The events that occur, particularly in classrooms, are extremely complex, necessitating the application of complementing quantitative and qualitative paradigms in study. Data collection and analysis from visible and unseen sources, such as silent data (Røgild-Müller, 2022), necessitate the consideration of several points of view. This enables a more detailed comprehension of the observed situations. Semiotic analysis (A Bakker & Hoffmann, 2005; Goubran, 2021; Terracciano, 2023) by various studies that are also validated in the findings of this systematic study strengthens the constraints of the research types discovered (Petran et al., 2020). This demonstrates the significance of semiotic reasoning research in the realm of mathematics (Perit Çakır et al., 2009).

Author's Nationality and International Collaboration

Charles Sanders Peirce (1839-1914) is the most generally cited author in semiotic reasoning research, and his concepts regarding diagrams and diagrammatic reasoning may be utilized to more clearly define actions with signs in mathematics (Chu, 2022; Hoffmann, 2007). According to Peirce's idea, students think using signs that permit students to communicate with one another and have significance for the surrounding world (Abbas & Kadim, 2019; Lukianova & Fell, 2015). Peirce's semiotic theory's essential principles is that everything can be a sign if it can represent anything according to individual perception and thinking. Sign theory, which focuses on the triad dimension or trichotomy system, was highlighted by Peirce (Brazgovskaya, 2019). Peirce grouped his theory into three elements in the semiotic triad dimension: signs, objects, and interpretants (Barbieri, 2009; Christine Wulandari Suryaningrum et al., 2020). A sign is a visual depiction of an object. The term interpretant refers to a comprehension or notation. To depict something using an item. If there is no a interpreter nothing can represent a sign. This interaction is a necessary component of Peirce's semiotic triad. Each sign can function as both an object and an interpreter of other signs. Signs, according to Peirce, are grouped into three types: icons, indices, and symbols (Gormley et al., 2021; van Hateren, 2015). Icons are designs that seem like references.

Indonesian authors has the greatest rank among semiotic reasoning authors, with 6 authors (19.35%). However, there has only been one publication on semiotic reasoning. The United States ranks second in semiotic reasoning publications, with 5 authors (16.12%). authors from Denmark and Italy are in third position, with four authors each (12.90%). Australia (3 authors, 9.6%) and South Africa (2 authors, 6.45%) take the fourth and fifth spots, respectively. Authors from other nations contributed 1 author to semiotic

reasoning publications. Austria, Canada, Ireland, the Netherlands, Poland, China, and the United Kingdom are the countries in concern.

The authors of semiotic reasoning papers are mainly from the European continent, with 12 authors (38.70%) being from the continent. The Asian continent is represented by seven authors (22.58%). With 6 contributors to articles (19.35%), authors from the American continent take third position. Meanwhile, three articles (9.67%) were written by authors from the Australian continent. Finally, three of the authors (9.67%) are from the African continent. The writers' geographic origins demonstrate that semiotic reasoning articles have been distributed equitably throughout all continents. As a result, the importance of semiotic thinking has become a global problem.

Non-collaboration papers were published in 12 cases (66.7%). Six papers (33.33%) were published cooperatively, both domestically and internationally. There was one publication that included international collaboration. Based on these findings, international collaboration in semiotic reasoning research should be strengthened. International collaboration has several challenges in the Asian environment. Language challenges, funding, limited time for face-to-face encounters, and certain political issues are all possibilities. Obstacles encountered by researchers provide new chances for future researchers because they allow for the formation of new solidarity in semiotic reasoning research that cannot be obtained using limited collaboration in a single nation.

Keywords

Keywords identified from 18 semiotic reasoning articles are semiotics, pierce, reasoning, aesthetic experience, diagrammatic reasoning, einfuhlung, congruency, diagrams, conjecture, collaborative reasoning, large-scale assessment, conspiracy, culture, abduction, calculus, diagrams logic, apple, adversity quotient, architecture. The findings of these identified keywords show information about the characterization of sign activity (semiotic) in semiotic reasoning. Pierce's theory's the terms diagram, diagrammatic reasoning, and logical diagram depart from the conventional understanding of diagrams in mathematics and mathematics education. Diagrams are complicated signs: indexes can draw attention to something, create a subset of icons, and indicate convention-based connections. Diagrams in mathematics comprise words or algebraic equations, graphs of functions, and geometric figures. Diagrams, according to Peirce's idea, have various qualities that make them acceptable (Giacomone et al., 2019; Saens-Ludlow & Gert Kadunz, 2015). Other keywords represent relationships with activities, materials, and research subjects.

Semiotic reasoning research contributions and future opportunities

Contribution

Semiotic reasoning research has made three contributions in the scientific field of mathematics: the contribution of semiotic reasoning to classroom learning, the development of semiotic reasoning theory, and the application of semiotic reasoning in other scientific fields (Prayitno et al., 2022). Semiotic reasoning research has impacted classroom learning from preschool to high school students. There was just one article about research on children under the age of five. Research involving grade 3 students in elementary schools was published in one publication (Christine Wulandari Suryaningrum et al., 2020), while research involving grade 3 students and teachers (M Kirk et al., 2023) was published in one journal. Meanwhile, three publications on research involving junior high school students have been published. Other contributions to semiotic reasoning study were made in high school classes. However, there are classroom-based articles that do not give information on the subjects covered. Numbers, geometry, derivatives, diagrams, comparison and measurement, and distribution are the materials employed in semiotic reasoning study. Based on the findings of this analysis, it is possible to infer that semiotic reasoning research has been conducted at all grade levels but is not yet complete.

The kindergarten and primary school levels, which employ the most physical things, have received the least attention. Aside from that, no study involving students with specific needs or courses at higher education levels has been conducted. Researchers in the future can follow up on semiotic reasoning research needs that have yet to be answered.

The development of semiotic reasoning theories is the next contribution of semiotic reasoning research. Such as the theory of self-control syntactic development, the theory of polyglotism as multilingualism and multiculturalism, critical theory, theories of stillness, and *Einfühlung* (the process of feeling in and through people, others, objects, and self). This scientific idea still needs significant improvement. Particularly today, as we join the era of the Sustainable Development Goals (SDGs). The fourth of the Sustainable Development Goals (SDGs) is quality education (Shaw et al., 2021; Türkmen, 2022). The evolution of scientific theories occurred over time.

Semiotic reasoning research has also contributed to the study of architecture, communication science in mass media (Terracciano, 2023), and the digital age of Google Maps Gameplay and Google Street View (GSV) (Berners-Lee, 2023). In this situation, applications in other scientific domains continue to present great prospects for additional research. This is due to Peirce's semiotic theory, which stresses the logic and philosophy of signals that exist in society and are often used (Brenner, 2015). Logic, according to Peirce, should investigate how people think. According to Peirce's principal theoretical concept, that reasoning is carried out through indicators that allow us to think, relate to others, and give meaning to what the universe presents. In terms of sign variation, humans have multiple options (Chesnokova, 2021). As a result, semiotic reasoning research has a good chance of being studied in depth in the future.

CONCLUSION

The findings of this systematic literature review give interesting and significant information on the trend of "semiotic reasoning" publishing in Scopus-indexed journals, as well as the contribution of semiotic reasoning research and future potential. The distribution of year, research kind, author's nationality and international collaboration, and keywords in each paper are used to describe publication trends in this study. According to the year distribution data, 2005-2018 generated four publications, with a significant increase in the following year. In the year 2019-2023, 14 articles (77.78%) were published. This publication has the potential to grow further because searches will be conducted until September 2023. In terms of research method, 12 papers (66.67%) employ a qualitative approach. Meanwhile, the other three publications make use of quantitative data. In the meanwhile, two more papers used case studies, and one used a mixed-method approach. This shows that, depending on the researchers' aims, purpose, and requirements, the subject of semiotic reasoning may be conducted using quantitative, qualitative, or a combination of both (mixed methodologies).

Based on author nationality and international collaboration, Indonesia has the most authors, with six (19.35%). The United States is the second most common author, with 5 authors (16.12%). authors from Denmark and Italy are in third position, with four authors each (12.90%). Australia (3 authors, 9.6%) and South Africa (2 authors, 6.45%) take the fourth and fifth spots, respectively. Authors from other countries contributed 1 author to publications related to semiotic reasoning. The countries in question are Austria, Canada, Ireland, the Netherlands, Poland, China and the United Kingdom. Based on the continent of origin, the authors of semiotic reasoning publications are dominated by authors from countries from the European continent, totaling 12 authors (38.70%). In second place, there are 7 authors from the Asian continent (22.58%). The third place is occupied by authors from the American continent with 6 article authors (19.35%). Meanwhile, authors from the Australian continent accounted for 3 articles (9.67%). Lastly, there are 3 authors from the African continent (9.67%). The continental origin of the authors shows that

semiotic reasoning publications have been spread evenly across all continents. Thus, it can be concluded that the urgency of semiotic reasoning has become a global concern. Articles published with non-collaboration status (12 articles or 66.7%). Publications carried out collaboratively, both nationally and internationally, were 6 articles (33.33%). Found 1 publication involving international collaboration. Based on these findings, international collaboration in semiotic reasoning research needs to be improved. Furthermore, related to the keywords identified from the 18 semiotic reasoning articles are semiotics, pierce, reasoning, aesthetic experience, diagrammatic reasoning, einfuhlung, congruency, diagrams, conjecture, collaborative reasoning, large-scale assessment, conspiracy, culture, abduction, calculus, diagrams logic, apple, adversity quotient, architecture. The findings of the keywords that have been identified show information about the characterization of sign activity (semiotic) in semiotic reasoning.

What is the current contribution of "semiotic reasoning" research, and what are the future prospects? Semiotic reasoning research makes three contributions: semiotic reasoning in classroom learning, the development of semiotic reasoning theory, and the application of semiotic reasoning in other scientific domains. The most significant contribution of semiotic reasoning research is to classroom instruction. Semiotic reasoning research has benefited classroom learning by including preschool through high school students. Thus, semiotic reasoning research has been conducted at all grade levels, although it is not yet complete. The kindergarten and primary school levels, which employ the most physical things, have received the least attention. Aside from that, no study involving students with specific needs or courses at the tertiary level has been conducted. Future scholars can follow up on semiotic reasoning research demands that have yet to be addressed. The development of semiotic reasoning theories is the next contribution of semiotic reasoning research. This scientific idea still need significant improvement. Particularly today, as we enter the era of the Sustainable Development Goals (SDGs). The fourth of the Sustainable Development Goals (SDGs) is quality education. Semiotic reasoning research has recently made contributions to the domains of architecture, communication science, and the digital world. Application to other scientific domains still presents great opportunity for researchers to advance. Because Peirce's semiotic theory stresses the logic and philosophy of signals in society, this is the case. As a result, semiotic reasoning research has a good chance of being studied in depth in the future.

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