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Trends in Research on Mathematical Representation in Mathematics Learning: A Systematic Literature Review

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Trends in Research on Mathematical Representation in Mathematics Learning: A Systematic Literature Review

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Abstract

Mathematical representation is one of the skills that students need to master because it can help them in various problem-solving tasks. This research is a literature review of articles related to mathematical representation in mathematics education. The articles are those published in journals indexed by Scopus from 2020 to 2024. The results of this study indicate that there has been an increase in the number of studies on mathematical representation in mathematics education from 2023 to 2024, with qualitative research being the most commonly used design. Test sheets are also frequently used to measure mathematical representation, while this area of research is largely focused on the social sciences. The United States has become the country with the highest number of studies related to mathematical representation in mathematics education over the past four years, with frequently appearing keywords being teachers and students, in addition to students being the most involved participants. Based on these findings, several recommendations for future research are proposed, namely the increased frequency of classroom action research to investigate the ability of mathematical representation in learning is highly necessary, as well as the development and collaboration of research instruments, such as combining test sheets with observation instruments to observe students' processes in using mathematical representation when solving problems or understanding mathematical concepts.

Introduction

Mathematical representation plays a very important role in mathematics learning (Anwar et al., 2019; Dung & Dang, 2024; Khairunnisak et al., 2021; Rahmawati & Anwar, 2020), as it greatly impacts students' ability to understand abstract concepts and facilitates them in solving mathematical problems (Bouck et al., 2023). Each student is expected to be able to develop mathematical representation skills and apply them flexibly in problem-solving situations using various representations such as symbols, diagrams, graphs, images, and other visual aids (Alghamdi et al., 2020; Gvozdic & Sander, 2020; Manoharan & Kaur, 2023). Therefore, a quality mathematics learning process (Cerezci, 2021; Cowie, 2024) needs to provide opportunities for students to explore and enhance their mathematical representation skills.

Mathematics learning needs to create an interactive learning environment and support students in developing mathematical representations, so students need to be encouraged to use various representation tools and techniques, such as diagrams, graphs, physical models, spatial representations, and mathematical software (Bonafini & Lee, 2021; Harris et al., 2023; Paoletti et al., 2022). In this regard, teachers must also be able to design collaborative learning activities that enable students to share ideas and discuss ways to represent mathematical problems to avoid misunderstandings (Campbell & Baldinger, 2021; Miller et al., 2020). By assigning challenging and relevant tasks, students can connect mathematical concepts with real-world situations, allowing them to understand and interpret problems well through mathematical representations (Ayan-Civak et al., 2024). This approach not only enhances students' representation skills but also develops the critical and creative thinking necessary to solve complex problems (Moleko & Mosimege, 2021; Savard, 2022). Therefore, the exploration of mathematical representations must be an integral part of an effective mathematics learning process.

Unfortunately, the potential and benefits of mathematical representation in problem-solving as well as in mathematics education have not been fully developed (Miller & Armour, 2021). This situation occurs because some teachers still struggle to design effective learning (Mason, 2023). As a result, the level of students' mathematical representation skills is still relatively low (Bouck et al., 2024; Rexigel et al., 2024; Rojo & Wakim, 2023). However, mathematical representation skills are very important for students to be able to face various types of existing problems (Bouck et al., 2023; Khairunnisak et al., 2021).

Although there have been many previous studies discussing mathematical representation, there are still few studies that systematically map the development of mathematical representation studies based on literature reviews or scientific references taken from the Scopus database. Several previous studies have examined the use of mathematical representations in the context of problem-solving (Cuevas-Vallejo et al., 2023; Cui et al., 2024; Freiman & Fellus, 2021; Lei & Xin, 2023; Verschaffel et al., 2020). However, until now, research on mathematical representation in mathematics education has not had a well-structured mapping of study developments. As a result, subsequent research lacks a clear scientific framework for developing mathematical representations. Therefore, further efforts are needed to develop a more focused and systematic study in this field.

Using content analysis on several articles published in Scopus-indexed scientific journals from 2020 to 2024, this research aims to gather information on various studies discussing mathematical representation in mathematics education. In detail, this research aims to answer the following questions: 1) How has the trend in the number of studies on mathematical representation changed from year to year? 2) What types of research are often used in conducting studies on mathematical representation? 3) What instruments are used in data collection? 4) What field area investigates mathematical representation the most? 5) Which country conducts the most research to observe the development of mathematical representation? 6) What keywords do researchers use to investigate mathematical representation? and 7) What educational levels are most commonly involved in research related to mathematical representation?.

This research applies the Systematic Literature Review (SLR) method with the aim of answering a specific question, namely how the development of research related to mathematical representation in mathematics learning

published in international journals indexed by Scopus over the past four years, from 2020 to 2024. These specific questions are explained through more specific sub-questions, namely: 1) how is the trend in the number of studies on mathematical representation from year to year? 2) What types of research are often used in conducting studies on mathematical representation? 3) What instruments are used in data collection? 4) What field area investigates mathematical representation the most? 5) Which country conducts the most research to observe the development of mathematical representation? 6) What keywords do researchers use to investigate mathematical representation? and 7) What educational levels are most commonly involved in research related to mathematical representation?.

Methodology

The research question above will be explained procedurally according to the general standards of a Systematic Literature Review (SLR). This process includes several steps, namely: first, determining the main keywords for article retrieval from the Scopus database, which are "mathematical representation" and "learning"; second, specifying the type of documents to be retrieved, which are journals indexed in Scopus; third, limiting the publication period of articles between 2020 and 2024; fourth, determining the type of file to be reviewed, which is the RIS file; fifth, selecting a reference management application, which is Mendeley; sixth, using the VOSviewer application; and finally, analyzing the articles with the VOSviewer features to visualize the network between keywords and identify the most researched keywords.

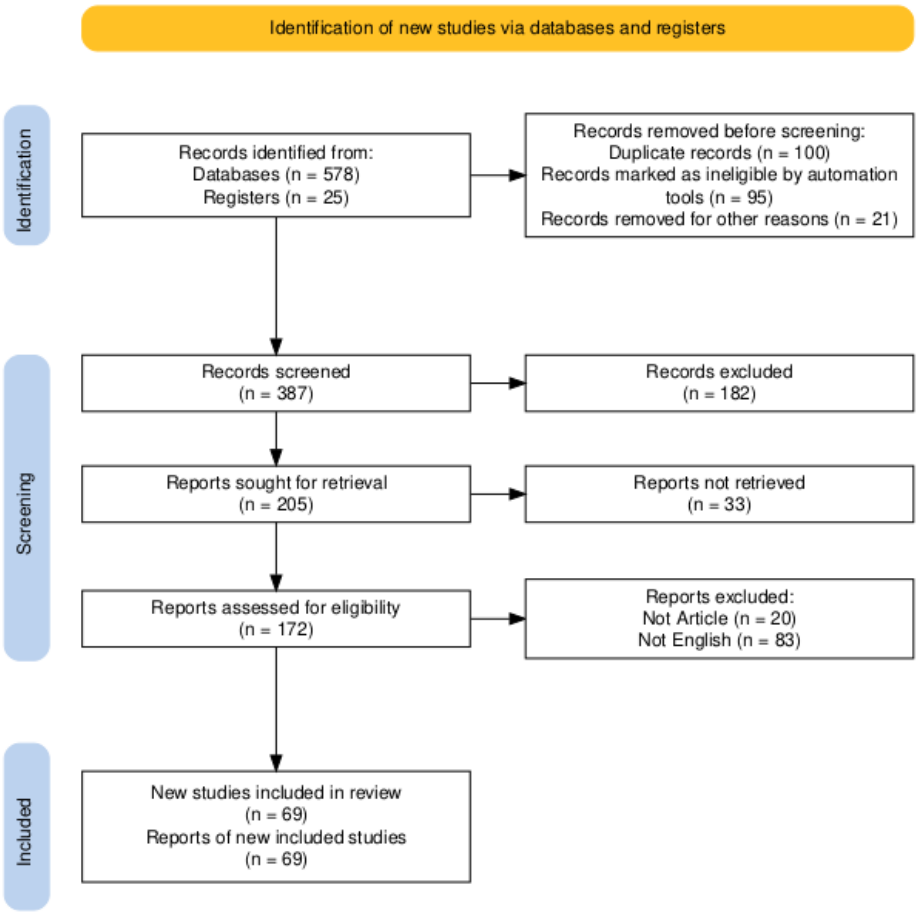

Diagram 1. Stages of Article Retrieval

The stages of this research were conducted according to the PRISMA (Preferred Reporting Items of Systematic reviews and Meta-Analyses) protocol, namely identification, screening, and inclusion of articles from the Scopus database (Rethlefsen et al., 2021). The identification stage is related to the initial phase of article retrieval, which is carried out by registering an account on the premium Scopus database; logging in with an official account, and entering the terms "mathematical representation" and "learning" in the article search column on Scopus. At this stage, 578 articles appeared, in addition to 25 articles from other sources. Then, they were strictly verified, resulting in the discovery of 387 duplicate articles. The screening stage, which is the stage to determine the number of articles recorded from the Scopus database and aligned with the chosen study topic, while there are articles that are not well recorded related to the ease of full paper access; inappropriate subject areas; references not from scientific journals; the language used is not English; and establishing 69 articles that are strictly verified and validated.

Results

Number of Publications

The number of published articles reflects the amount of research conducted over a specific period. Based on the graph displayed in Figure 1, articles discussing mathematical representation have been published from 2020 to 2024 in Scopus-indexed journals. From Figure 1, it can be seen that the highest number of publications occurred in 2024 within that time frame. The trend of increasing publication numbers on the topic of mathematical representation indicates a significant growth in researchers' interest in exploring this topic.

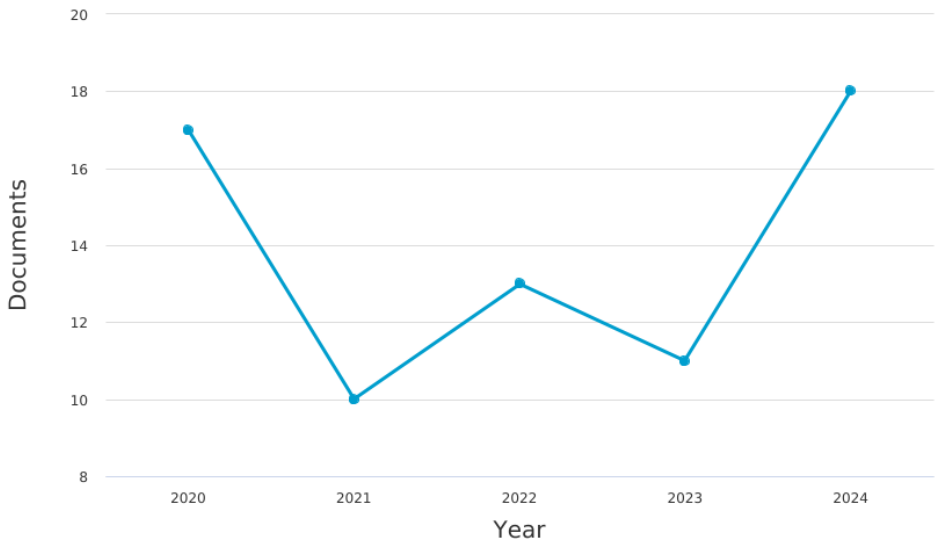

Figure 1. Trend in the Development of the Number of Research with Mathematical Representation as the Main Focus in Scopus over 4 Years

Most of the research conducted began with the identification by researchers that many students have limitations and difficulties in using mathematical representations in problem-solving (Bouck et al., 2024; Lewis et al., 2020; Mason, 2023; Rodrigues et al., 2024; Rojo & Wakim, 2023; Shumway et al., 2020; Verschaffel et al., 2020). Therefore, several researchers have made various efforts to enhance effective mathematical representation skills,

even using technology (Lee, 2021; Rocha, 2020; Tirkas & Panaoura, 2020; Vahey et al., 2020).

Research Methodology

Research methods and design are important aspects in determining the focus of a study. Based on Figure 2, qualitative research is the most dominantly used design by researchers to investigate mathematical representations.

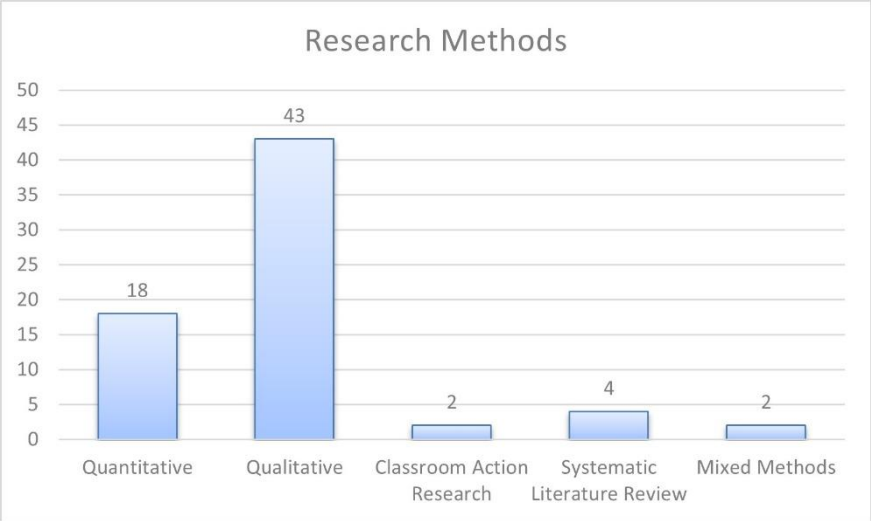

Figure 2. Distribution of Research with Mathematical Representation as the Main Focus Based on Research Method

The number of qualitative studies is higher compared to quantitative studies. This is in line with the research (Gavilán-Izquierdo & Gallego-Sánchez, 2024; Sealey et al., 2020; Thomas, 2021) that to observe students' ability to use mathematical representations in problem-solving, qualitative research is more likely to be used. In Figure 2, it is also indicated that the types of research such as Classroom Action Research, systematic literature, and mixed methods are very rarely used to uncover mathematical representations. This limitation does not mean that these types of research are not suitable for investigating mathematical representations. However, this can serve as a foundation for developing more complex research, especially in the application of mathematical representation in mathematics education. Of course, this is very difficult and has limitations if conducted using qualitative research methods.

Data Collection

Instruments In conducting research, researchers need tools that can support the data collection process. To assess students' mathematical representations, various tools have been developed by previous researchers. Based on the graph presented in Figure 3, it can be seen that the test sheet instrument is the most frequently used tool for collecting data on mathematical representation. In addition, more objective data collection instruments, such as observation sheets, have proven to be more effective in measuring mathematical representation compared to interview sheets and questionnaires. This emphasizes that the selection of the appropriate instruments is crucial for obtaining accurate and relevant data in this research.

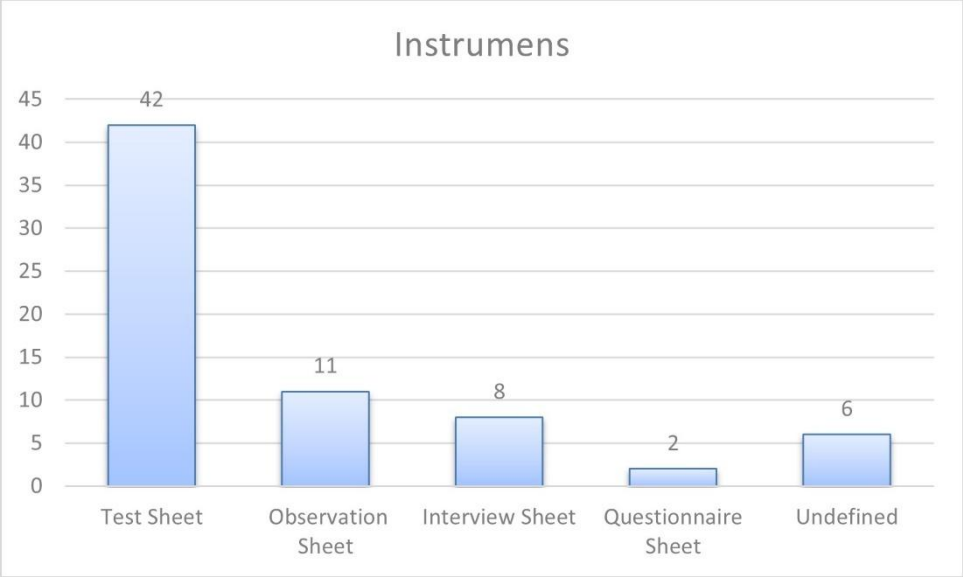

Figure 3. Distribution of Data Collection Instruments for Measuring Mathematical Representation

Several studies show that instruments using test sheets are capable of measuring mathematical representation well (Blanco et al., 2024; Khairunnisak et al., 2021; Newton et al., 2022; Urhan & Zengin, 2024). Additionally, there is something interesting in the research conducted using observation sheets (Bonafini & Lee, 2021; Cunningham et al., 2022; G. Fonseca & da Ponte, 2024; Moleko & Mosimege, 2021; Nelson & Carter, 2022; Radecki et al., 2020; Schliemann et al., 2022), which means that in these studies, direct observations were made during the research process. However, unfortunately, some researchers do not mention the instruments they used to collect data on mathematical representation in their publications. Among those who use tests as the primary instrument for data collection, not all provide information on whether the instrument has been tested for its validity and reliability.

Subject Area of Research

The distribution of documents based on the subject area of research over a four-year period, as shown in Figure 4, indicates that the social sciences dominate with a percentage of 58.4%, followed by mathematics with 33.6%, and psychology with only 8%. This data clearly reflects that the use of mathematical representations is more extensively researched in the context of social sciences, particularly in mathematics education. This phenomenon indicates significant attention to the issues that arise in the process of mathematics learning, especially those related to mathematical representation.

This condition may be caused by the complexity faced by students in understanding and applying mathematical concepts in real-life situations, which often requires the ability to represent information visually or symbolically (Flores & Hinton, 2022; Lockwood & Ellis, 2022; Purnomo et al., 2024). Thus, many researchers feel compelled to investigate further how mathematical representations can be optimized in learning, and how this can help students overcome the difficulties they face (Ekdahl et al., 2024). Moreover, the high percentage of research in the field of social sciences can also be interpreted as an effort to bridge the gap between theory and practice in

education, where mathematical representations are not only seen as tools to solve mathematical problems but also as means to understand broader social phenomena. These studies have the potential to provide new insights that can be used to design more effective learning strategies, which not only focus on the mastery of mathematical concepts but also on the development of students' critical and analytical thinking skills.

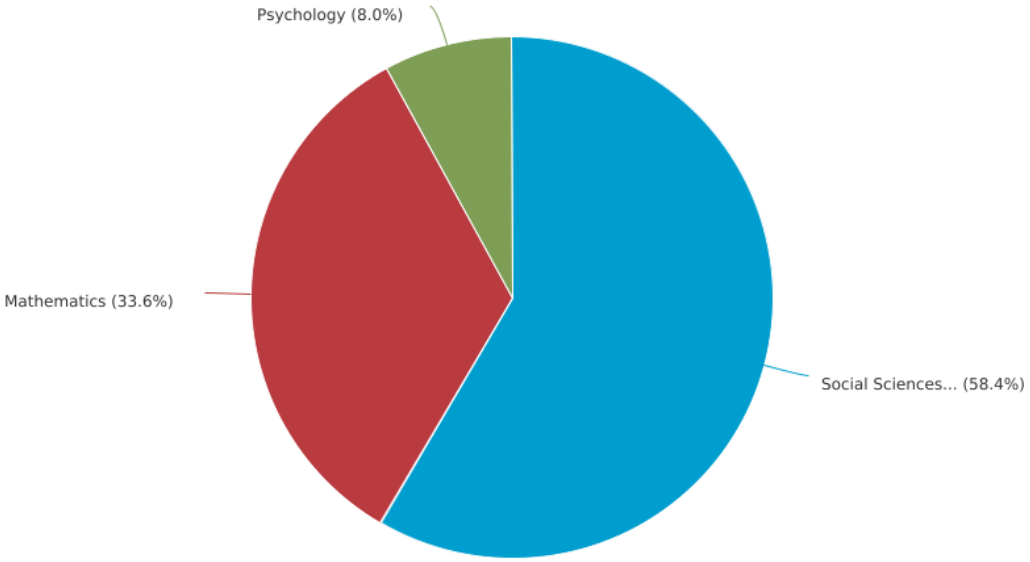

Figure 4. Document Distribution by Research Area Subject

Country-based Document

Referring to Figure 5, a comparison of the number of documents from up to 10 different countries or regions is visible. The United States occupies the top position with the highest number of documents, followed by Australia, Indonesia, Turkey, Germany, Portugal, Spain, Canada, China, and Colombia. This data reflects the contribution of academic publications from various countries or regions presented in the graph. This graph provides a clear visual representation of the comparison of the number of documents per country or region, allowing for the analysis of publication trends across different areas.

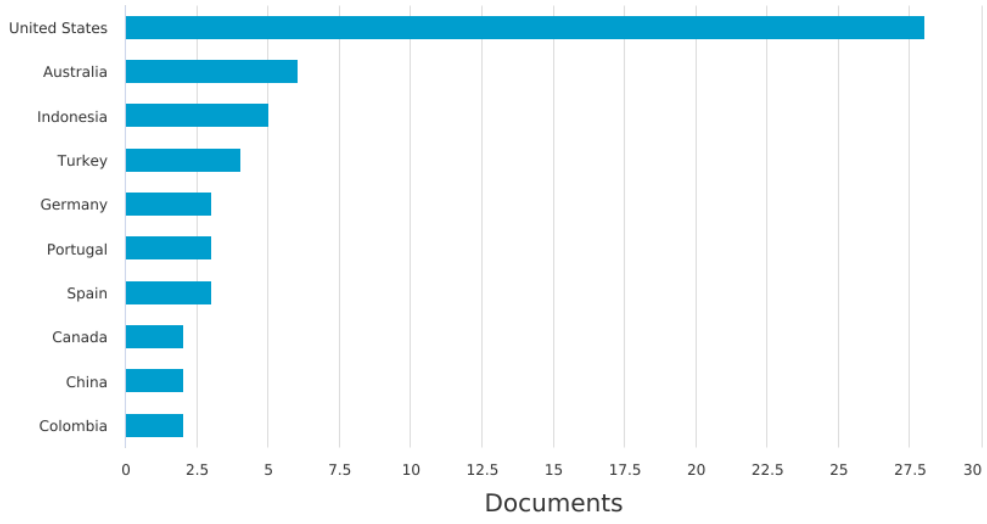

Figure 5. Distribution of Research Document Counts by Country

The graph presented in Figure 5 provides a clear visual representation of the comparison of the number of documents per country or region, allowing for the analysis of publication trends across various regions. With this data, researchers and educators can identify patterns and trends in mathematical representation research, as well as understand how various countries contribute to the development of knowledge in this field. Additionally, this analysis can also assist in formulating international collaborations, where countries with similar research focuses can work together to address the challenges faced in mathematics education.

Keywords in the Research

The keywords used in a study serve as important indicators that show the boundaries and focus of the research conducted. Based on Figure 6, the network of keywords reflects a complex and dynamic ecosystem of relationships between students, teachers, technology, and teaching methods. These relationships are interconnected and contribute to creating an effective educational environment. In this context, teachers and students become the main focus, which shows that in research in the field of mathematical representation, many researchers use teachers and students as research subjects. This emphasizes the importance of the roles of both parties in the learning process, where the teacher as a facilitator and the student as a recipient of information have crucial interactions in understanding mathematical concepts.

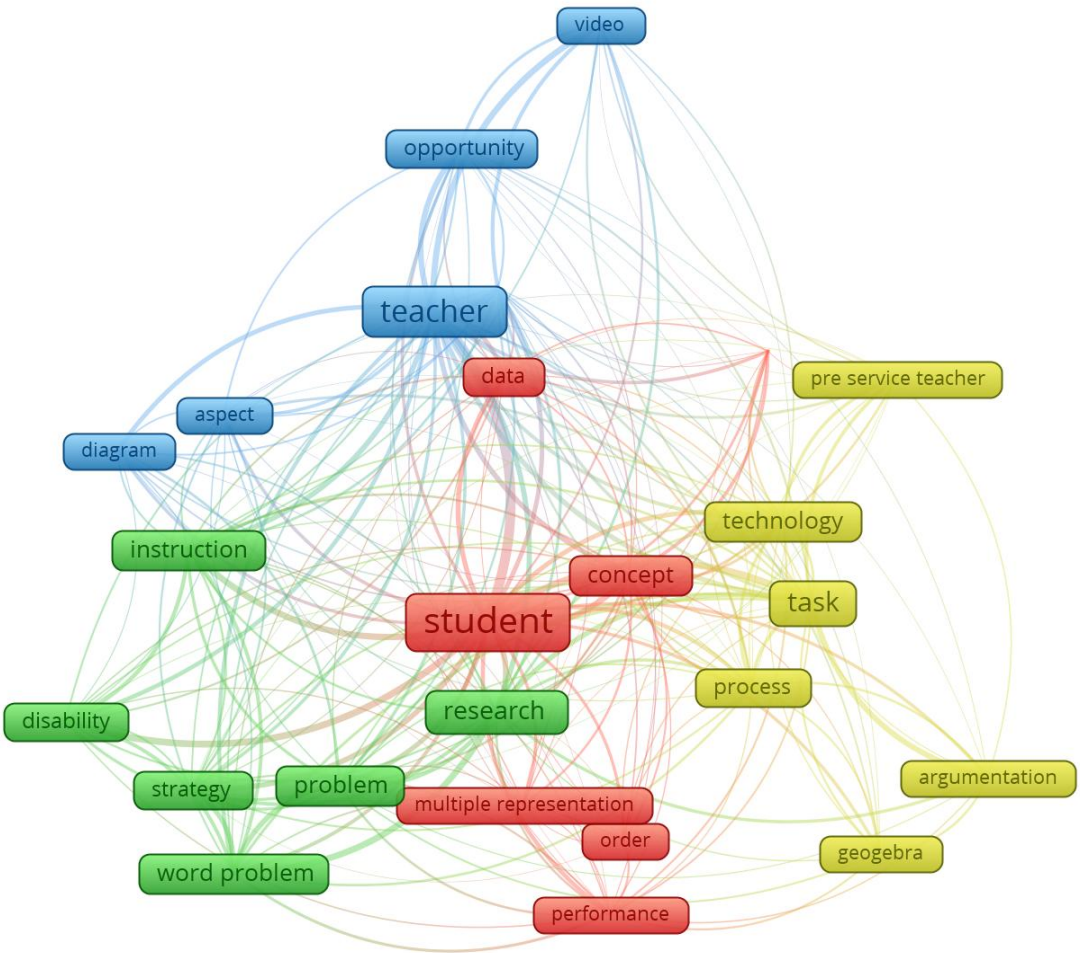

Figure 6. Keyword Network used in Research related to Mathematical Representation

This data is also supported by the distribution of keywords presented in Figure 7, which indicates that the variation in word sizes reflects the frequency of the research fields conducted. Larger keywords indicate that the topic is more frequently researched, while smaller keywords suggest a more specific or less common focus. Thus, this keyword analysis not only provides insights into ongoing research trends but also helps other researchers identify areas that may be underexplored or require further investigation. Through a better understanding of the relationships between keywords and their usage frequency, researchers can formulate more relevant and strategic research questions, as well as contribute to the development of knowledge in the field of mathematical representation and education in general.

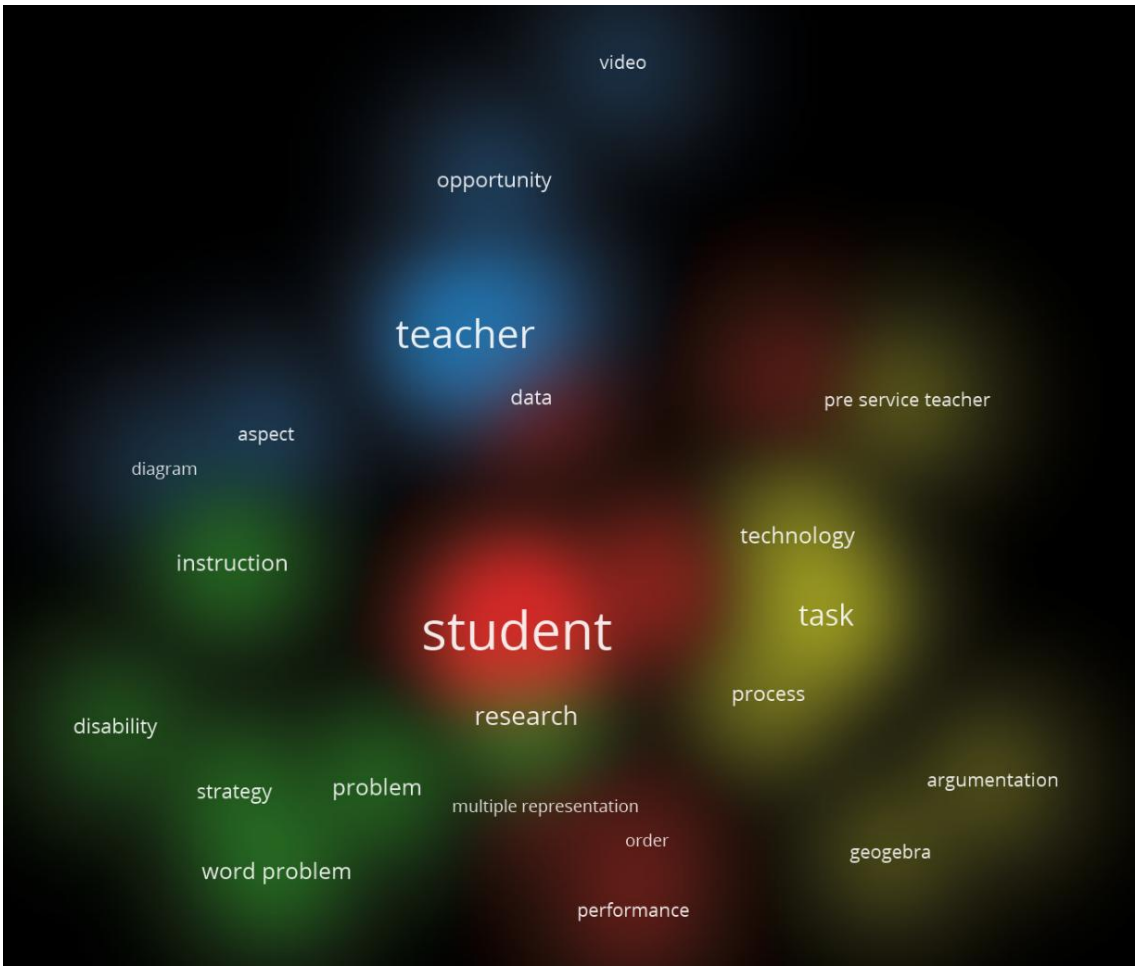

Figure 7. Distribution and Strength of Keywords Used in Mathematical Representation Research

Additionally, in Figure 8, it is clearly seen that the keywords frequently researched related to mathematical representation over the past year include several important terms, namely argumentation, GeoGebra, aspects, and tasks. The keyword "argumentation" indicates that much research focuses on how students can develop the ability to argue and explain their mathematical thinking. Argumentation in the context of mathematics learning is very important, as it not only helps students understand concepts but also communicate their ideas effectively to others(Blanco et al., 2024). Research focused on argumentation can provide insights into strategies that can be used to enhance students' critical and analytical reasoning skills (Ellis et al., 2024), as well as how they can interact with peers and teachers in the learning process.

Next, the keyword "GeoGebra" indicates that this software is increasingly being used in research related to mathematical representation. GeoGebra is a very useful tool for visualizing mathematical concepts, and its use in learning can help students understand the relationships between various elements of mathematics, such as algebra, geometry, and calculus (Carriazo-Regino et al., 2024; V. G. D. Fonseca & Henriques, 2023; Latsi & Kynigos, 2022). Research involving GeoGebra can explore how this technology can be integrated into the curriculum to enhance students' understanding of mathematical representations (Cullen et al., 2020; Rugh et al., 2020). Additionally, the keyword "aspects" indicates that the research also considers various dimensions or factors that influence mathematical representation, such as social, cultural, and pedagogical contexts (Hunter et al., 2022). Lastly, the keyword "tasks" reflects a focus on the types of tasks given to students and how these tasks can be designed to encourage better use of mathematical representations. Thus, this keyword analysis not only provides an overview of current research trends but also directs attention to important areas that can be further explored to enhance mathematics learning practices.

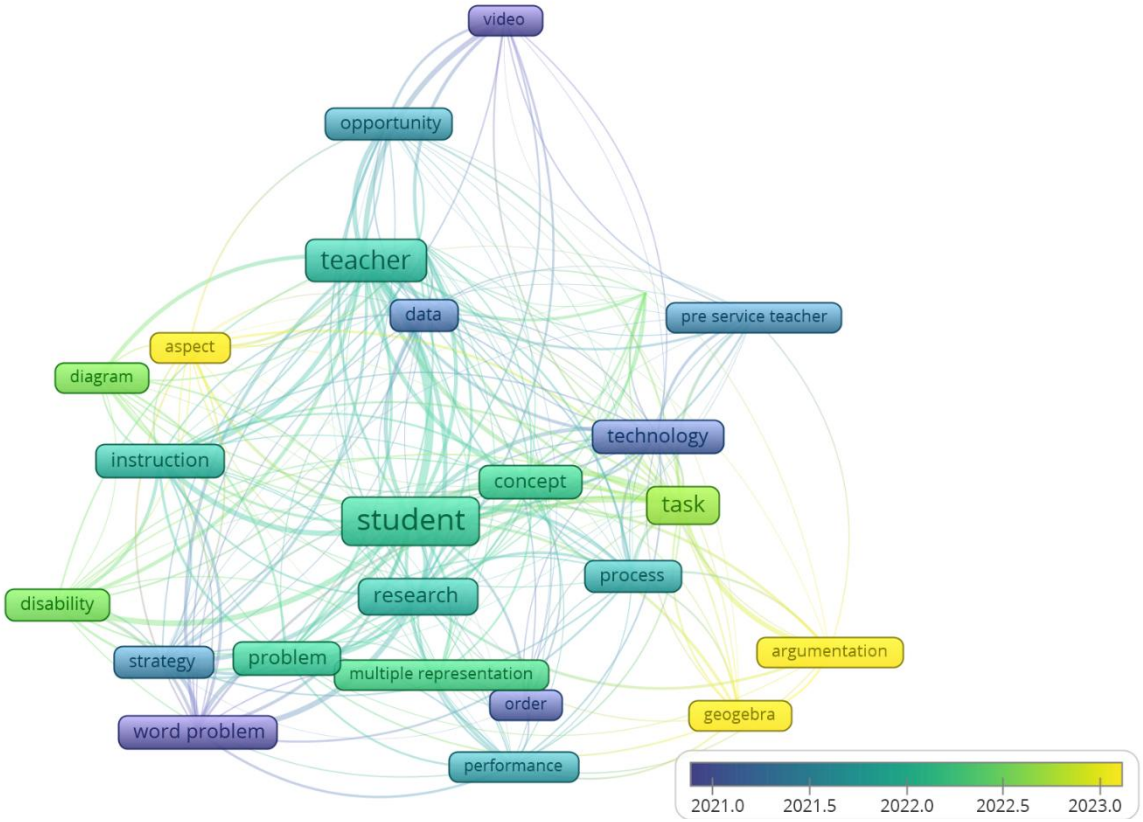

Figure 8. Trend of the Distribution of the Researched Keywords

Participants in Research

In conducting research, researchers need participants to test their hypotheses, and based on Figure 9, it is evident that the most commonly used participants in studies related to mathematical representation are students. Students play the main role as they are individuals directly involved in the learning process and can provide valuable insights into how they understand and apply mathematical concepts. However, it is important to note that in the data, the researchers did not directly mention the grade level of the students. This ambiguity can be a hindrance

in understanding the research context, as the characteristics and learning needs of students can vary significantly between different educational levels, such as elementary, middle, or high school.

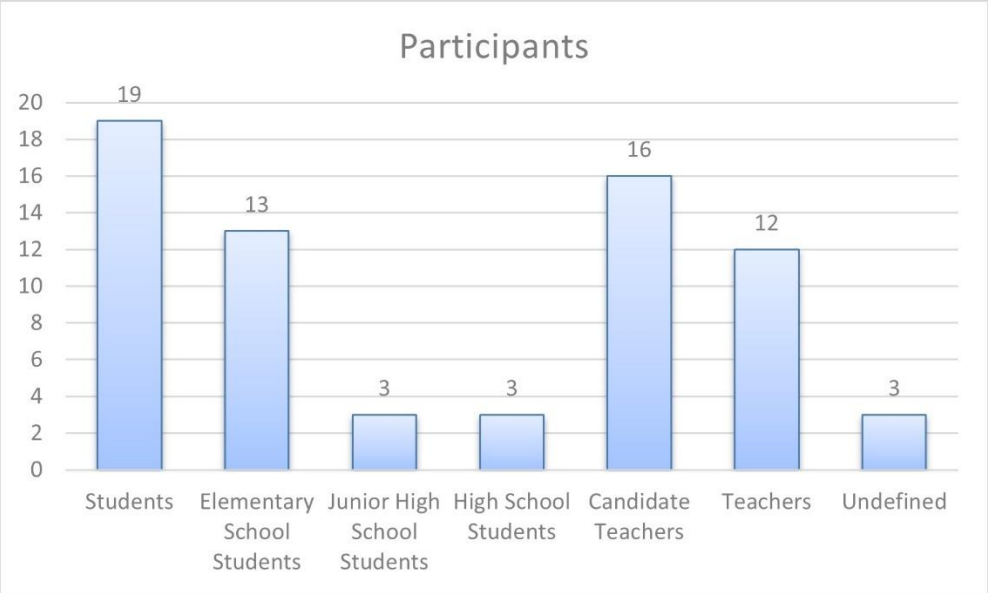

Figure 9. Distribution of Participants Involved in Research Related to Mathematical Representation

Besides students, other participants frequently used in the research include prospective teachers, elementary school students, and teachers. The presence of prospective teachers as participants indicates that this research not only focuses on students but also on how future educators prepare themselves to teach mathematical representations (Grenier-Boley & Robert, 2024; Newton et al., 2022; Prihandhika et al., 2022; Rahmawati et al., 2017; Tytler et al., 2020). This is in line with the data in Figure 7, which shows that the most frequently used keywords in research related to mathematical representation in mathematics education are students and teachers. By involving teachers in the research, the researchers can explore their perspectives and experiences in teaching mathematical representations, as well as the challenges they face in the classroom (McGraw et al., 2024; Weingarden & Heyd-Metzuyanim, 2024). This combination of participants provides a more comprehensive picture of the dynamics of mathematics learning and how various factors interact to influence students' understanding of mathematical representations. Research involving a diverse range of participants is expected to yield more in-depth and applicable findings, which in turn can contribute to the development of better educational practices.

Conclusion

In this study, articles focusing on mathematical representation in mathematics learning published in Scopus-indexed journals from 2020 to 2024 have been reviewed. The trend found is an increase in the number of studies focusing on mathematical representation in mathematics learning from 2023 to 2024. Based on those studies, qualitative research is the most commonly used by researchers in investigating mathematical representation. In addition, test sheets are widely used by researchers to measure mathematical representation. Meanwhile, the subject area of research related to mathematical representation is widely conducted in the field of social sciences.

The United States is one of the countries that has conducted the most research on mathematical representation in mathematics education over the past four years. The keywords most frequently used in the research are teachers and students. This is in line with the data showing that the majority of participants involved in the research were students. Referring to the findings of the research, several recommendations have been formulated for future studies. First, the frequency of classroom action research needs to be increased to investigate mathematical representation skills in mathematics learning. Second, research instruments need to be developed and collaborated on, for example, test sheets can be collaborated with observation instruments that observe the process of students using mathematical representations in problem-solving.

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