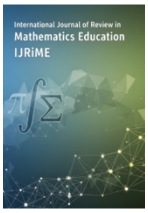

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Systematic Literature Review on Mathematical Representation: The Connection between Theories and Implementation

Amellia Putri, Imam Sujadi✉, Yuli Bangun Nursanti, Farida Nurhasanah
Faculty of Teacher Training and Education, Sebelas Maret University, Indonesia

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Abstract

Understanding and applying mathematical representations are essential in math education. However, many students face challenges in effectively using mathematical representation. Previous research has mainly focused on evaluating students' proficiency in mathematical representation rather than developing strategies to strengthen their skills. This has led to limited insights into research trends and information related to mathematical representation. Consequently, this systematic literature review is essential to address the deficiency in the literature by offering a thorough summary of research trends concerning mathematical representation. This study aims to analyze previous research related to mathematical representation, particularly the connection between the theories used, methodological features, the relationship between subjects and mathematical representation skills, and learning barriers and interventions to enhance these skills. At the end of the study, it was concluded that there is a relationship among all these variables. An examination of 52 scholarly papers on mathematical representation showed that most studies focus on assessing students' ability to use different types of mathematical representation to solve problems, drawing on theories proposed by Goldin and standards outlined by the National Council of Teachers of Mathematics (NCTM). The review also highlighted students' difficulties with mathematical representation and identified various methods for evaluating it, with written assessments and interviews being the most common approaches. Additionally, the review revealed numerous recommended activities to help students enhance their mathematical representation competency. In conclusion, the theoretical framework used in these studies significantly influences evaluation methods and recommended interventions in this field of study.

Keywords: mathematics teacher education research, mathematical representation, systematic literature review, measurement approaches, implementation design

✉***Corresponding Author:***
Imam Sujadi, Faculty of Teacher Training and Education, Sebelas Maret University, Indonesia
Email: imamsujadi@staff.uns.ac.id

1. Introduction

The field of mathematics undoubtedly holds significant importance by promoting logical thinking and serving as a potent tool for enhancing students' critical, creative, rational, and systematic thinking abilities, thereby positively influencing their everyday lives (Arnidha & Fatahillah, 2021; Rosdianah et al., 2019; Umam, 2018; Zaenuri et al., 2019). Mathematics learning in the context of the Merdeka Curriculum Learning Outcomes in Indonesia includes learning objectives, one of which is to develop students' ability to present situations in the form of symbols or mathematical conditions, which is often referred to as the ability to represent mathematics (Kemendikbud, 2023).

Mathematical representations are expressions of mathematical concepts and ideas students display to identify solutions to their problems (NCTM, 2000). The Principles and Standards for School Mathematics (NCTM, 2000) representation is the fifth process standard after problem-solving, reasoning, communication, and connection. NCTM (2000) sets the standards of representation that students are expected to master during the learning process, including (1) creating and using representations to organize, record, and communicate mathematical ideas; (2) choosing to use and translate between mathematical representations to solve problems; and (3) using representations to model and interpret physical, social, and mathematical phenomena.

Mastery of mathematical representation competency is essential for students to understand and use mathematical concepts in solving everyday problems (Sari & Sari, 2019). Teachers can also use certain representations to explain concepts and mathematical ideas in learning (Goldin, 2020). This shows that representation is crucial in mathematics learning, especially in understanding concepts, connections between concepts, and problem-solving (Lee & Lee, 2019). Mathematical representation can also be a sign that a person understands a concept well, according to Wiggins and Tighe's theory (2005), which states that a person who understands a concept can explain the idea in various forms. Behind the importance of mathematical representations that students and teachers must master, there are still many problems, one of which is that students still have to learn obstacles to using mathematical representations to solve mathematical problems (Safitri et al., 2023).

Although mathematical representation is crucial in mathematics learning, and there are still many related problems, previous studies tend to be limited to analyzing students' mathematical representation competency (Anwar et al., 2016; Asnawati & Dewi, 2020; Fadhilah et al., 2019; Gumilar et al., 2020; Hanifah et al., 2021; Minarni et al., 2016; Priyadi & Yumiati, 2021; Septian et al., 2020b; Istadi et al., 2017). Only a few previous studies aim to foster mathematical representation and dig deeper into the learning obstacles students experience in performing mathematical representation. In addition, although NCTM presents three leading indicators related to mathematical representation, most previous research has focused more on indicators of the use of mathematical representations to solve mathematical problems. This has led to limited insights into research trends and information related to mathematical representation.

Therefore, this systematic literature review will group previous studies related to mathematical representations into specific categories. The main objective of this analysis is to identify relationships and draw conclusions from various studies related to mathematical representations that have been carried out by previous researchers, primarily associated with the theory and indicators of mathematical representation, with learning obstacles in performing mathematical representations, their measuring tools, and strategies to improve them at different levels of education. By conducting this analysis, it is hoped that general patterns, trends, or joint findings can be revealed, which will provide more profound insights related to previous studies and support the development of research on mathematical representation.

1.1. Theoretical Framework of Mathematical Representation

This study will examine the relationship between the theories employed and the researcher's actions. This research focuses on two classifications: the Goldin classification and the classification of Lesh, Post, and Behr. Both were chosen because they are most used in research and have similar groupings. Additionally, this study will also explore the indicators of mathematical representation proposed by the NCTM more deeply. As mentioned earlier, most research still emphasizes the ability of mathematical representations to solve problems. Therefore, this study aims to track how these trends are evolving. Although it uses only three main theories, this study still allows for the consideration of other relevant classifications. The explanation for each theory includes the following.

1.1.1. Goldin Classification

According to Goldin (2020), mathematical representation is a configuration representing something else in several ways. According to Goldin, mathematical representation theory classifies mathematical representations into internal and external representations. Internal representation is a system of psychological representation of the individual itself. Internal representation is a set of images, ideas, and intellectual expressions that a person uses to relate information to a situation and assess and differentiate between primary and secondary information. Internal representation is related to mental processes or thoughts that occur in a person's brain so that the process cannot be observed directly.

External representation is closely linked to a person's external system, which includes signs, symbols, characters, or objects that symbolize, describe, code, or represent something other than themselves to convey an idea in various forms.

1. Mathematical symbol systems include formal algebraic notation, equations, function notation, number systems, derivatives, and integral calculus.
2. Visual or spatial, such as number lines, Cartesian graphs, polar coordinate systems, data box plots, geometric diagrams, and computer-generated fractal drawings; and
3. Words and sentences can be written or spoken.

1.1.2. Lesh, Post, and Behr Classification

Lesh, Post, and Behr (1987) constructed a mathematical representation model of several interrelated elements. The classification of mathematical representations presented by Lesh, Post, and Behr consists of five elements, including the following.

1. Written symbols are mathematical symbols and expressions formed by combining formal mathematical notations to express a mathematical concept.
2. Verbal (verbal representation) is a situation to understand a problem and express a mathematical concept using words.
3. Real problems, which refer to life situations, involve expressing everyday issues in mathematical terms.
4. A manipulative model consists of one or more objects that surround it, and
5. Picture representation is an image including diagrams, tables, and other forms to illustrate mathematical concepts.

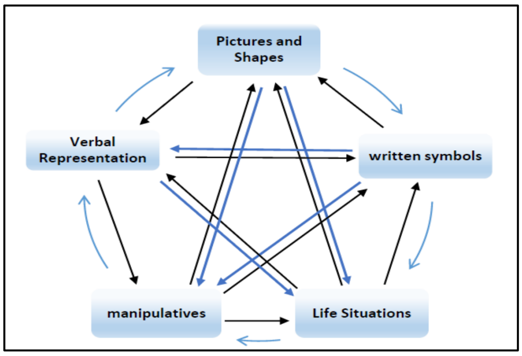

Figure 1. Lesh, Post & Behr Model for the Math Representations

1.1.3. NCTM Mathematical Representation's Indicators

Students display representations of mathematical concepts and ideas to discover solutions to their problems. In Principles and Standards for School Mathematics (NCTM, 2000) representation is the fifth process standard after problem-solving, reasoning, communication, and Connection. NCTM (2000) sets the standards of representation that students are expected to master during the learning process, including the following,

1. Create and use representation to organize, record, and communicate mathematical ideas.
2. Selecting, using, and translating mathematical representations to solve problems; and
3. We are using representations to model and interpret physical, social, and mathematical phenomena.

1.2. Research Question

A Systematic Literature Review (SLR) aims to understand the relationship between the theoretical framework underlying the research related to mathematical representation and students' learning barriers and methods to measure and improve them. In addition, to see the cumulative development of mathematical representation studies in the past decade, this study will answer and analyze some of the problem formulations below.

1. What are the characteristics of the research and the research methodology used (*year of publication, type of paper, geographical distribution, research method, subject, level of education of the subject, mathematical content used*)?
2. What theories are used to classify the mathematical representations and their indicators as defined by the NCTM that underlie this research?
3. What are the learning barriers students face when performing mathematical representations?
4. What are the methods used to measure mathematical representations?
5. What interventions are carried out to improve mathematical representation?

2. Method/Approach

2.1 Search Strategies and Manuscript Selection Procedure

This study is a systematic literature review to determine the latest research trends related to mathematical representation, especially about learning barriers in doing so, the process of measuring them, and interventions to improve them. The systematic literature review approach

Table 1. Inclusion and Exclusion Criteria

Inclusion criterion (IC)	Exclusion Criterion (EC)
IC1: Research in the field of mathematics education at all levels of education and in all fields of mathematics materials	EC1: Research in fields other than mathematics education
IC2: The research focuses on learning obstacles of mathematical representation, the concept of mathematical representation, the process of measuring it, and how to improve the mathematical representation of the research subject.	EC2: Research that does not address the matters mentioned in IC2
IC3: Research published in English	EC3: Research published in languages other than English
IC4: Types of documents: journal articles, book chapters, and conference proceedings	EC4: Document types: whole book, notes, book review
IC5: Research published in Scopus, ScienceDirect, SpringerLink, ERIC	EC5: Research published in addition to the IC5 database

identifies, evaluates, and interprets all available research relevant to formulating the problem or topic area being studied (Calderon & Ruiz, 2015). Systematic literature review (SLR) can also be defined as the process of identifying, assessing, and interpreting all available research evidence to provide answers to specific research questions (Kitchenham et al., 2009).

This study adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure a thorough and systematic approach. The final comprehensive search for relevant papers was conducted on April 2, 2024, across four reputable academic databases: (1) SpringerLink, (2) ScienceDirect, (3) ERIC, and (4) Scopus. The publications retrieved from these databases are recognized for their high quality and have earned a strong international reputation in the field of educational research. To identify papers that effectively address the specific problem formulations of this study, targeted keywords were employed. These keywords include "mathematical representation and education" and "mathematical multiple representation and education," focusing specifically on articles published from 2015 to 2024.

The keywords were chosen to focus on studies that specifically address mathematical representation in educational settings while excluding unrelated articles involving broader terms like "mathematical modeling" or "symbolic representation." The period 2015–2024 was selected to include recent developments in mathematical representation research, aligning with a global increase in studies on technology-based learning, RME/PMRI approaches, and modern cognitive models. This timeframe best reflects current trends and ensures that the findings stay relevant to contemporary mathematics education in the 21st century.

The scope of this research is limited to three types of academic contributions: peer-reviewed journal articles, conference proceedings, and scholarly book chapters, all published in the English language. To ensure the selection of appropriate and relevant research papers, a set of inclusion and exclusion criteria has been established, outlined in the following table. This systematic approach enhances the rigor and reliability of the findings in this research. The inclusion and exclusion criteria were established based on several considerations after consulting experts. This study focuses on research in mathematics education across all educational levels to examine differences in students' abilities to represent mathematical concepts (Table 1). Additionally, it aims to explore the aspects outlined in Table 2 to identify research trends and summarize various activities that can help students improve their representational skills.

Choosing English-language articles ensures consistent terminology, easier comparison across studies, and broader international access to research findings. English is the primary language of global scientific publication, so articles in English generally undergo more standardized editorial and peer review processes. Moreover, including four reputable publication sources was intended to ensure the overall quality of the studies analyzed.

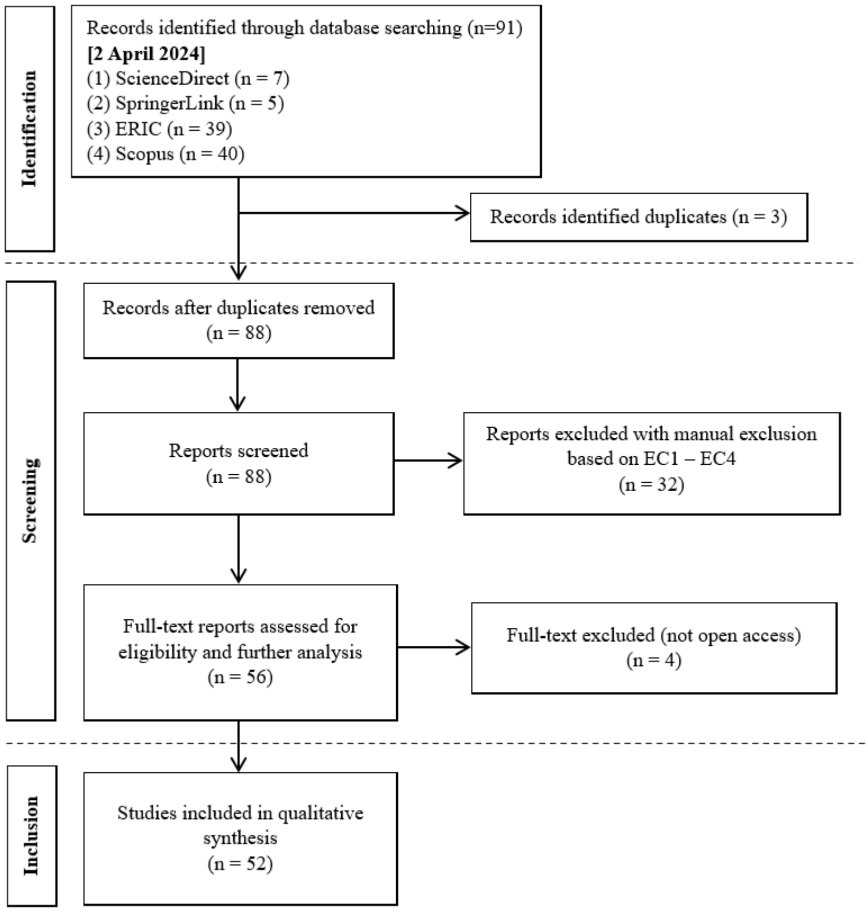

Figure 2. Flow Diagram of the Manuscript Selection Process

The researcher manually carried out the inclusion process, using an Excel program to obtain the papers for this review. The figure below shows the selection process in three stages: identification, screening, and inclusion (Figure 2)

At the identification stage, a paper search was carried out using predetermined keywords in the four databases to obtain as many as 91 papers. The Mendeley application was used to see the number of duplicate papers, and it was found that there were three duplicate papers from the Scopus and ERIC databases. Of the 88 papers obtained, a manual inclusion process was carried out for IC 1 to IC 4 using the help of Excel until 56 papers that met the inclusion criteria were obtained. However, four papers were inaccessible, so the researcher decided not to include them for further analysis. At the end of the selection process, 52 papers were obtained that will be used for further systematic literature review.

2.2 Data Analysis

The analysis is carried out one by one for each problem formulation. Related to the formulation of the first problem, the researcher classifies papers based on the characteristics of the research used with several sub-categories, namely the year of publication, type of documents, geographical distribution (location of research), research method, level of sample education, and mathematical content used. To answer the formulation of the second problem, the researcher initially analyzed several opinions related to the classification of mathematical representations and indicators of mathematical representation competency set by NCTM. Based on this, the researcher grouped the papers obtained into several theories and indicators that were used to underlie the research. The analysis for the third problem formulation identifies students' learning obstacles when performing mathematical representations, whether directly or implicitly. Finally, for the formulation of the fourth and fifth problems, how to measure and improve mathematical representations will be identified. To analyze data related to the development of the fourth and fifth problems, the researcher will identify the methods and types of interventions used in each analyzed article. Additionally, intervention was categorized into three main groups: (1) creation of representation tasks, (2) use of digital media, and (3) preparation of instructional strategies. The results of this categorization are then used to draw conclusions about the trends that have emerged recently.

3 Result and Discussion

3.1 Results

3.1.1. Result Concerning Study Characteristics and Research Methodologies of the Papers (Research Question 1)

Types of Paper and Publication Year

This study used 52 papers consisting of journal articles (56%, n = 29), conference proceedings (42%, n = 22), and one book chapter (2%). The journal articles were published in 22 journals (9 mathematics education journals, 9 educational journals, and 4 interdisciplinary journals focusing on social and technological phenomena). In addition, the conference proceedings obtained came from various mathematics education conferences, namely PME-NA, ICMSE, MISEIC, AD INTERCOMME, ICMETA, AICMSTE, NaCoME, SENATIK, ISAMME, MSCEIS, and ICMScE. The following diagram illustrates the distribution of the three types of papers used in this study.

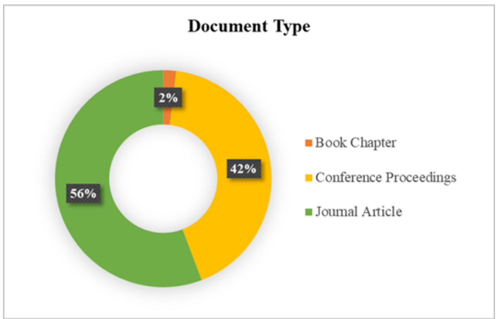

Figure 3. Types of Documents

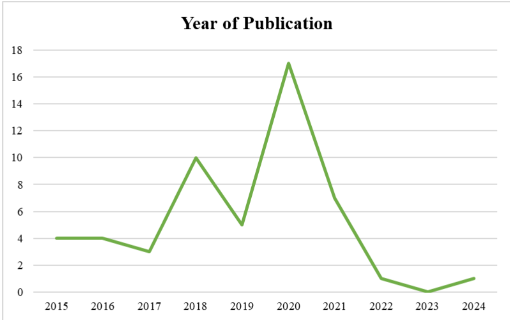

Figure 4. Number of Studies of Mathematical Representation

Table 2. Research Location

Continent	Country	n	%
Asia	China	1	2
	Indonesian	37	71
	Jordan	1	2
	Türkiye	2	4
Europe	Danish	1	2
	England	1	2
	Germany	1	2
	Netherlands	1	2
	Swedish	1	2
North America	USA	4	8
South America	Mexico	1	2
Australia	Australia	1	2

Regarding the year of publication, this study focuses on papers published during the last ten years, namely 2015–2024.

The visualization in the figure above shows that publications related to mathematical representations were not always stable during that time. Publications related to mathematical representation declined drastically after 2020.

Geographic Distribution

These results will show the geographical distribution related to the location of research conducted in previous studies. We carry out the systematic literature review process using an international database, which enables the retrieval of various research site-related data. The table below displays the locations of research on mathematical representations.

In Table 2 reviewing several research results, the region of origin of the research subject is crucial because it can reflect the quality of education in the country and the culture that grew up there. Based on the analysis results, many studies were conducted in Asia, especially Indonesia. In total, the studies were conducted in 12 different countries.

Most research on mathematical representation is conducted in Indonesia because the topic aligns with national curriculum priorities and efforts to enhance students' mathematical literacy. The abundance of local Sinta-indexed journals also supports context-based studies, making publishing easier. Additionally, researchers often focus on real classroom issues such as students' low representational skills and the adaptation of Realistic Mathematics Education (PMRI), which keeps this topic highly relevant.

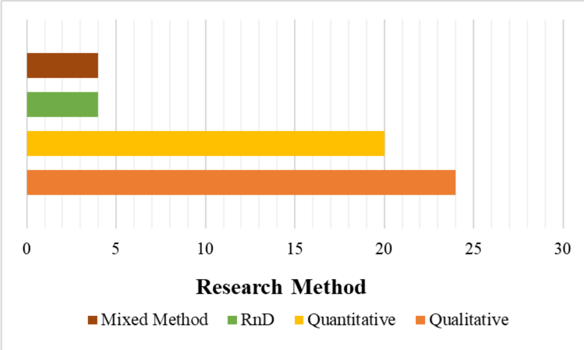

Figure 5. Research Methods

Table 3. Research Design

Research Method	Model/Design		n	%
Qualitative	Case Study		1	46
	Descriptive		10	
	Design Research		1	
	Literature Review		2	
	Observation		1	
	Survey		1	
	Systematic Literature Review		2	
	Not mentioned		6	
Quantitative	Quasi-Experimental	Non-Equivalent Control Group Pretest-Posttest	13	38
		Post-Test-Only Control Group Design	1	
		Not mentioned	5	
	Not mentioned		1	
R&D	4-D		1	8
	ADDIE		1	
	Not mentioned		2	
Mixed Method	Embedded		2	8
	Sequential Explanatory		1	
	Not mentioned		1	

Research Designs

Based on the analysis, almost half of the research (46%, n = 24) used qualitative methods, followed by quantitative methods (38%, n = 20), mixed methods, and research and development, consisting of only four papers. Please note that not all papers list the research design used in detail. Here is a summary of the research methods and design of the analyzed paper. (Figure 5)

The details of the research design for every method used can be shown in Table 3. Qualitative approaches prevail because studies on mathematical representation examine students' internal thinking processes, which are hard to measure quantitatively. Re-search in Indonesia often involves small classroom samples, making qualitative methods more practical and resource efficient. Additionally, national journals usually prefer qualitative studies that highlight contextual understanding and practical classroom implications.

Study Participants' Levels of Education

In this study, the researcher analyzed the characteristics of the sample. The researcher categorized the research participants based on their education level. In this study, the primary school education level covers grades 1 to 6, while the secondary school covers the junior high and high school education levels for grades 7 to 12. The analysis results show that most of the research was conducted on secondary school students (grades 7–12), and there were 24 research papers. Several studies (n = 12) were also performed on undergraduates, with most being prospective teacher students. Some papers (n = 4) found are also systematic literature review research, so the samples used are previous papers.

Table 4. Study Participants' Level of Education

Participant	Level of Education	Grade	n	%
Student	Pre-kindergarten		1	65
	Primary School	3rd grade	1	
		4th grade	1	
		5th grade	1	
	Secondary School	7th grade	6	
		8th grade	14	
		10th grade	2	
		11th grade	1	
		12th grade	1	
	Mixed Level		4	
	Vocational High School		1	
	Not mentioned		1	
Undergraduate Student	Prospective Teacher		10	23
	Other Major		2	
Mixed Participant			2	4
Paper			4	7

The researcher closely examined the types and characteristics of the four papers analyzed in the systematics literature review. Hanifah et al.'s (2020) paper does not focus on a specific education level but analyzes research involving subjects from various levels of education. Meanwhile, Pedersen et al. (2021) clearly stated that their research centered on primary and secondary school students. The other two papers, namely Putra et al. (2024) and Widakdo (2017), only reviewed research with student subjects at the secondary school level.

Some studies also use several samples from a series, such as those of junior high and high school students. A study also used research samples of mathematics teachers and junior high school students. These studies were categorized into mixed samples (Table 4).

Mathematical Content and Material

Mathematical representation must be included in all mathematical content, as it is essential for understanding and learning mathematical concepts. Therefore, the researcher also analyzed the materials that were the focus of previous mathematical representation studies. The results of the analysis indicated that one-third of the research focused on the domain content of measurement geometry (31%, n = 16) and algebra (29%, n = 15). The materials in geometry, measurement, and algebra used during the research also vary from basic materials to materials for higher education. Research on mathematical representation rarely focuses on domains such as numbers (15%, n = 8) and uncertainty data (4%, n = 2). Some studies either did not mention the specific mathematics materials used or they focused on all types of mathematics materials (15%, n = 8). In addition, three studies related to systematic literature review did not focus their research on one mathematical domain. The Table 5 shows the distribution of domains and mathematical materials used in mathematical representation research.

Table 5. Mathematical Content

Mathematics Content	Material	n	%
Algebra	Algebraic expression	1	29
	Calculus	1	
	An integral	2	
	Linear program	1	
	Logic mathematics	1	
	Number line, coordinate plane, and function graphs	2	
	Relation and function	1	
	Social arithmetic	1	
	Transformation geometry	1	
	Two-variable linear equation system	1	
	Vector space and eigenvalue-eigenvector	1	
	Not mentioned	2	
Data Analysis and Probability	Basic statistics	2	4
Geometry and Measurement	The area and perimeter of the rectangle	1	31
	Solid geometry	1	
	The surface area and volume of cubes	3	
	Three-dimensional shape	1	
	Trigonometric	1	
	Vector	1	
	Volume of pyramid	1	
	Not mentioned	7	
Number and Operation	Fraction operation	4	15
	Number	2	
	Sums, subtractions, and multiplication	2	
Not mentioned		8	15
Not applicable		3	6

3.1.2. Result Concerning the Theoretical Framework of the Studies on Mathematical Representation (Research Question 2)

Four categories make up this study's theoretical framework of mathematical representation. The Figure 6 shows the primary approach most widely used in previous studies.

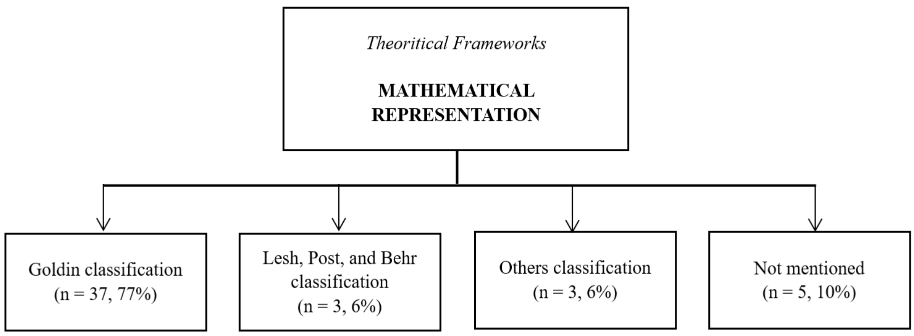

Figure 6. Theoretical Framework of the Study: Mathematical Representation

Table 6. NCTM's mathematical representation indicators

Indicators	n	%
Create and use representations to organize, record, and communicate mathematical ideas.	3	6
Select, apply, and translate among mathematical representations to solve the problem.	3	6
Use representations to model and interpret physical, social, and mathematical phenomena.	16	33
Combined/mixed	22	46
Not mentioned	4	8

Based on the results of the analysis of the papers obtained, it was found that the most widely used theoretical framework is the classification of mathematical representations presented by Goldin, which is a theory that classifies mathematical representations into two, namely external (symbolic, visual, and verbal) and internal. Only three studies used the Lesh, Post, and Behr classification (written symbols, words, real-life context, models, and pictures).

Goldin's classification of mathematical representation is widely preferred for its comprehensive and flexible approach, covering both internal (mental, affective, and cognitive) and external (symbolic, visual, verbal, and gestural) aspects. This framework effectively describes the link between students' conceptual understanding and their ways of representing ideas and is easy to use in various research methods. However, its limitation is the challenge of directly measuring internal representations, as data usually must be inferred from students' behavior or verbal responses, which can introduce subjectivity and affect reliability.

In addition to analyzing the theory used in classifying mathematical representations, this study also analyzes related mathematical representation indicators by NCTM, which are used to explore the mathematical representation competency of research samples.

In Table 6, the most widely used metric of NCTM mathematical representation in previous studies is the use of representation to model and solve phenomena. One-third of the research focused on that. This indicator is often used as a benchmark in measuring students' mathematical representation competency, even though mathematical representation is not always about solving problems in daily life. This is still something that previous research has not noticed, even though mathematical representation is one way to reveal students' understanding of mathematical material.

3.1.3. Result Concerning Students' Learning Obstacles When Carrying Out Mathematical Representation (Research Question 3)

Based on the results of the analysis of the papers obtained, it was found that epistemological obstacles dominated the learning obstacles of students presented in the study. Students' learning obstacles in performing mathematical representations include using verbal representations to express the steps to solve mathematical problems related to the geometry material (Fitrianna et al., 2018; Utami et al., 2019). Students in 8th-grade junior high school and 10th-grade high school feel these obstacles.

Students find it challenging to solve mathematical problems using mathematical or symbolic equations. According to research conducted by Fitrianna et al. (2018), various groups of students with multiple types of mathematics materials experience this difficulty; grade 10 high school students still have to learn obstacles in translating geometry problem situations into symbolic forms, in line with the research results of Sari et al. (2018), which also shows that 8th-grade students experience similar learning obstacles, especially in the surface area of the cube. Meanwhile, the research conducted by Istadi et al. (2017) shows that grade 12 has difficulty in bringing trigonometric problems into the form of symbols.

In addition, students also have difficulty expressing a mathematical idea in visual form, especially for the geometric material of the surface area of the cube, which requires a strong imagination from the students, and also for the fractional material, which is abstract for 3rd grade elementary school students who are getting the material for the first time (Purwadi et al., 2019; Sari et al., 2018). Students find it difficult to translate between forms of representation to communicate their mathematical ideas and solve mathematical problems (Fitrianna et al., 2018; Istadi et al., 2017; Utami et al., 2019). This problem occurs in various mathematics materials and is felt by high school students, both junior high and high school. In addition, pre-kindergarten students feel this difficulty as they are still introduced to the concept of numbers for the first time. They are used to using only one type of representation, so when directed to translate to other representations, students will experience learning obstacles (Björklund & Palmér, 2022).

A learning obstacle that often occurs is students' difficulty in translating, both between representations and from everyday problems to symbolic forms. This indicates that students still have a limited understanding of concepts. Students with a strong understanding of concepts are characterized by their ability to represent a concept in a variety of different forms (Wiggins & Tighe, 2005).

3.1.4. Result Concerning the Measurement of Mathematical Representation (Research Question 4)

This study will show various methods used to measure the mathematical representation competency of the research sample. The most widely used and often used methods to explore mathematical representation competency are written test instruments (50%, n = 26) and task-based interviews (21%, n = 11). This is natural because written tests can explore students' mathematical representation abilities in visual, verbal, and symbolic forms. Additionally, assignment-based interviews are often used to confirm students' answers, as some students understand concepts but struggle to write them down and can only explain them orally. However, the weakness of written tests is that they only assess the result without capturing the student's thought process, which might lead to missing conceptual understanding. While task-based interviews can be time-consuming and depend on the student's verbal ability, their results can also be subjective, based on the interviewer's interpretation.

Based on the analysis, eight different methods can be used to measure mathematical representation. Some studies also do not just use one method to measure mathematical representations (Tabel 7).

There are two papers that employ a new method, specifically eye-tracking technology. The main benefit of eye-tracking is its capacity to reveal hidden cognitive processes by illustrating where students focus and the sequence of their gazes when working on mathematical representations, helping researchers understand their thinking strategies. However, the drawback is that eye gaze does not always indicate comprehension, as a lingering gaze can simply signal confusion or interest; therefore, it must be combined with other data for accurate interpretation.

Table 7. Methods for Measuring Mathematical Representation Competency

Methods	n	%
Analysis question	1	2
Drawing task	1	2
Eye-tracking technology	2	4
Interview	11	21
Observation	5	10
Oral discussion	1	2
Worksheet	1	2
Written test	26	50
Not applicable	4	8

3.1.5. Result Concerning the Fostering of Mathematical Representation (Research Question 5)

The analysis results indicated that more than half of the papers (56%, n = 29) contributed to finding either the design or learning strategy, learning media, or other activities that improved the mathematical representation competency of the research sample. The recommended things to enhance mathematical representation are divided into several categories, as in the following Table 8.

Table 8. Activities Contributing to the Fostering of Mathematical Representation

Activities	n	%
Developing a mathematical representation task and gaining experience in mathematical representation	2	7
• Developing and using an image-rich problem		
• Using a task that requires the student to use multiple representations to communicate an idea		
Use of digital media tools	8	28
• Using Wingeom software		
• Learning using GeoGebra software		
• Learning using a website-assisted (math tutor)		
• Using the Android application		
• Geometer's Sketchpad program		
Designing or conducting instructional strategies	17	59
• Meta-level discussion		
• Use instruction material based on the joyful PBL model.		
• The Contextual Teaching and Learning (CTL) model incorporates an outdoor approach.		
• Concrete-Pictorial-Abstract Strategy		
• REACT strategy		
• Think-talk-write strategy		
• Using the IMPROVE method in mathematical learning		
• Learning based on RME		
• Jigsaw: cooperative learning with performance assessments		
• Cooperative learning type two Stay Two Stray with product assessment		
• Student facilitator explaining the (SFAE) cooperative learning model		
• Reciprocal teaching model		
• Indonesian version of Realistic Mathematics Education (PMRI) through Lesson Study for Learning Community (LSLC)		
• Learning Cycle 5E model		
• Giving student cognitive apprenticeship instruction (CAI)		
• Project-based learning (PBL)		
Others	2	7
• Using real tools		
• Using an accurate picture		

Of the studies that recommended ways to improve mathematical representation, more than half (59%, n = 17) suggested using multiple learning designs and strategies (e.g., discussion processes, learning models, cooperative learning, and projects). Some studies even specifically design learning processes that can improve mathematical representation competency. In addition, eight studies (28%) suggested using multiple learning media to improve mathematical representation competency. Research related to learning media focuses on digital media, such as GeoGebra and Wingeom software. Digital media-assisted learning has proven to be more effective in enhancing students' mathematical representation competency compared to classes without digital media. Similar improvements were also observed in classrooms that adopted new learning strategies. Combining new strategies with digital media leads to higher mathematical representation abilities.

Two studies suggest developing mathematical representation tasks to help students become familiar with their mathematical representation skills. These tasks relate to problems conveyed in pictures (not stories) and tasks that require students to translate between representations. Learning that requires students to translate between different forms of representation can enhance their mathematical representation skills, ensuring that students are not only accustomed to or restricted to one type of representation. In addition to using specific designs, digital media, and task development, some studies suggest using things such as student belongings or real images to bring students closer to mathematical representations. A real-world approach can help primary students understand math ideas more concretely. However, this method has limits because it mainly focuses on visual representations, which makes it hard for students to link different types of representations.

3.2. Discussion

Related to the formulation of the first problem, the results of this systematic literature review indicate that research related to mathematical representation has reached a satisfactory level even though there has been a significant decline since 2020. Mathematical representation is indeed an old topic and has been widely known by various parties, not only education practitioners, but the importance of mathematical representation in understanding students' concepts (Mainali, 2021). Research related to this topic must continue to be carried out with various new inspirations following the times. The studies reviewed in this systematic literature review mostly come from journal articles and conference proceedings. Of the 29 journal articles, only half were published in mathematics education journals, while the existing conference proceedings were seminars at various conferences, be it mathematics, science, or engineering. This shows that the urgency of mathematical representation is known by multiple parties, not only for teachers and students in mathematics education.

Most of the research was conducted in Asia, with 71% following the results of a research review conducted by Putra et al. (2024), especially Indonesia, performed in China, Turkey, and Jordan. Several studies were also conducted in Europe and North and South America (4 studies were conducted in the USA), and only one study was conducted in Australia. Research related to mathematical representation in the future can be carried out from the point of view of culture and the quality of education in a country. The culture and habits of learning in a country with good quality education can be adopted into the mathematics learning process (Widyastuti, 2021). This opens up the possibility that there are teaching cultures that may be able to make students better understand mathematical representations.

The analysis results also indicated that almost half of the research was qualitative. This follows the researcher's suspicion that most mathematical representation research only focuses on exploring the level of mathematical representation competency of the research sample. The rest of the research uses a quantitative and developmental approach. This suggests that many studies attempt to compare, prove, and develop several ways to improve mathematical representation. Significantly, these studies primarily focus on junior high and high school students, aligning with Lutfi and Juandi's research (2023). Several studies use samples of prospective teacher students and students of other majors. The results show that there is still little research on mathematical representation conducted at the early levels of education and elementary schools, so further research is needed at these levels of education.

Mathematical representation is closely related to "visualizing" mathematical concepts that are difficult for students to imagine, so it is very natural that many studies related to mathematical representation focus on the domain of measurement geometry. In fact, according to Kadunz and Sträßer (2001), geometry problems cannot be solved through visuals. In addition, mathematical representation is also used to translate everyday language into mathematical language, namely in the form of mathematical models. Mathematical models are very widely used in the algebraic domain. However, mathematical representation needs to be developed in various mathematical domain contents without exception (Pape & Tchoshanov, 2001), so it is necessary to conduct studies related to mathematical representation, especially in the domain of numbers and uncertainty data, to show that mathematical representation can be realized in any mathematical material.

Previous studies of mathematical representation have used various theoretical framework approaches as the basis of such research. Most of the theories used classify mathematical representations into several components, making them easier to explore more deeply. The theory most often used to underlie research related to mathematical representation is the classification by Goldin (external (visual, verbal, symbolic) and internal). This theory is the closest and most accessible because it divides the types of external representations into three very different things. In addition, almost all research focuses on the NCTM's mathematical representation indicators, which use representations to model and solve phenomena. This shows that mathematical representation is a tool for solving problems, whereas mathematical representation can also be considered a way to convey mathematical concepts.

Regarding students' learning barriers in performing mathematical representations, it is known that students experience learning barriers from various mathematical representation indicators. It was found that students had difficulty translating a problem into a mathematical (symbolic) model, stating the steps to solve it, and visualizing the given situation (Amir et al., 2021; Ningrum & Hw, 2022; Rohana et al., 2021; Rum & Juandi, 2023). It was also found that many students still had difficulty translating between forms of representation. The many learning obstacles show that mathematical representation is still far from students' habits of understanding mathematical concepts and far from the learning process conveyed by teachers.

The method to measure the mathematical representation competency of the research sample is in line with the purpose of the study. The number of studies that focus on exploring the level of mathematical representation competency aligns with the number of studies that use written test methods and task-based interviews to measure it. Even so, there are various other ways to measure it. However, remember that it is impossible to identify which method is the most effective or promising in measuring mathematical representation because each method has advantages and disadvantages. In addition, the selection of this measurement method is based on the objectives of each study (Williams, 2007). Further studies are expected to be able to use or produce new tools to measure mathematical representations, especially in using digital technology, which has rarely been done in previous research.

With many studies showings that 'students' mathematical representation competency is still low, various studies have emerged that aim to find solutions to improving mathematical representation. These studies recommend multiple strategies and learning models, such as the Concrete-Pictorial-Abstract and the REACT strategy. In addition, many studies recommend several models and strategies already widely known by educators, such as PBL, PMRI, think-talk-write, and some types of cooperative learning that support a fun learning approach. Many of these studies also recommend using digital media, such as geometry software, which is widely known as GeoGebra (Hevardani et al., 2024; Tamam & Dasari, 2020; Septian et al., 2020). The development of tasks that require students to use mathematical representations and the use of tools around students is also recommended as one of the solutions to improve mathematical representation competency.

4 Conclusion

The results of this systematic literature review (SLR) study show that research on mathematical representation has declined since 2021 and is mainly led by researchers from Indonesia. This decrease suggests a waning interest in topics that are crucial for deep understanding of mathematical concepts. Previous research has primarily focused on Goldin's classification and NCTM indicators that highlight the use of representations for problem-solving. This focus tends to overlook the role of representation as a means of communicating mathematical ideas, resulting in students' limited ability to express concepts through various forms of representation. Although there is a recurring pattern, the methods and interventions from earlier studies are quite diverse, including developing representation tasks, utilizing digital media, and applying instructional strategies. This indicates ongoing efforts to enhance students' understanding and skills in mathematical representation. Future research should emphasize the importance of mathematical representation as a means of communicating ideas and tailor learning activities to the material's characteristics and students' challenges. Teachers need to create activities that encourage students to use visual representations for problem-solving, especially for those who struggle to communicate ideas visually. Additionally, teachers should focus on tasks that require multiple forms of representation, helping students better grasp the process of using different representations to communicate mathematical ideas. Research in this area remains relevant because mathematical representation competency will continue to be essential for both students and teachers in mathematics learning.

Declarations

Author Contribution	:	Author 1: Conceptualization, Data Curation, Investigation, Visualization, Writing – Original draft, Writing – review & editing; Author 2: Supervision, Review & Editing, ; Author 3: Supervision; Author 4: Project administration; Supervision; Validation, Review & editing
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APPENDIX: Studies Included In The Systematic Literature Review

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