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Analytical Thinking in Mathematics: A Systematic Literature Review on Research Types and Content

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Analytical thinking is a crucial cognitive skill in mathematics, enabling learners to effectively decompose complex problems, evaluate relevant evidence, and propose reliable solutions. Despite its significance in mathematical learning, research on analytical thinking in mathematics education remains limited. To address this gap, the present study employs a systematic literature review to comprehensively analyze the current state of research on analytical thinking in the field of mathematics and categorizes the existing literature based on its types and content. Following the PRISMA standards, the study selected 21 relevant articles from major databases such as Web of Science, Scopus, and Google Scholar. The results indicate that the types of research predominantly focus on qualitative studies and quantitative descriptive studies. The content of the research primarily spans five key themes: Instruction and Development of Thinking, Research on Thinking Processes, Assessment and Evaluation of Thinking, Research on Thinking Styles, and Interdisciplinary Research. This study addresses the lack of a systematic synthesis of analytical thinking research in mathematics education. Theoretically, it providing a structured framework for future research. Practically, it identifies effective teaching strategies, guiding educators in fostering analytical thinking and supporting curriculum development.

Keywords: analytical thinking, mathematics education, systematic literature review, thinking processes, teaching strategies

INTRODUCTION

Analytical thinking is an essential cognitive skill that plays a critical role in mathematics education. It enables students to effectively decompose complex problems, assess relevant evidence, and propose feasible solutions (Hidayat et al., 2023).

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Mathematical problems are often highly abstract and complex, requiring not only strong computational abilities but also flexible and rigorous thinking skills (Corte & Verschaffel, 2007). Therefore, analytical thinking is indispensable in mathematics learning, particularly in advanced mathematics courses and applications, where it provides learners with frameworks and methods for problem-solving (Wang & Abdullah, 2024).

However, despite its crucial role in mathematics education, research on analytical thinking remains relatively scarce. In recent years, research in mathematics education has increasingly emphasized critical thinking, innovative thinking, and creative problem-solving abilities (Wahyudi et al., 2023; Ridwan et al., 2022; Yuningsih, Subali, & Susilo, 2022; Hobri et al., 2020). Yet, analytical thinking, a fundamental and essential cognitive skill in mathematics learning, has been more widely studied in fields such as science and philosophy, with less attention paid to its role in mathematics education (Nilimaa, 2023; Ida, Aziz, & Irawan, 2021; Ridwan, Retnawati, & Hadi, 2021). With the ongoing reforms in mathematics education, fostering students' analytical thinking has become a key goal in educational systems worldwide (Theabthueng et al., 2020). However, despite its recognized importance, there is no clear consensus on the definition, assessment, and instructional approaches related to analytical thinking in mathematics education. Additionally, previous studies have not systematically categorized or synthesized the existing research, making it difficult to develop a structured framework for understanding its role in mathematical learning. This lack of synthesis hinders the development of evidence-based teaching strategies and curriculum design.

Thus, conducting a systematic literature review on analytical thinking and addressing this research gap becomes crucial. This study aims to provide a comprehensive perspective on the application of analytical thinking in mathematics education through a systematic review and synthesis of existing literature, thereby guiding both educational practice and future research. The primary objective of this study is to comprehensively analyze the current state of research on analytical thinking in mathematics through a systematic literature review, revealing its theoretical framework and practical applications in mathematics education. Specifically, the goals include: first, organizing and screening existing literature on mathematical analytical thinking according to the PRISMA method; second, categorizing and summarizing the relevant literature based on content and type; and finally, exploring the gaps in the current research and proposing future directions, providing theoretical support and practical guidelines for both academics and educational practitioners.

Unlike previous research, which has primarily focused on critical thinking and problem-solving, this study systematically categorizes and evaluates analytical thinking in mathematics education. It is the first systematic literature review to identify key research themes, analyze methodological trends, and provide a structured theoretical framework for future studies. This study addresses a critical gap in analytical thinking research in mathematics education, offering both theoretical insights and practical applications.

Theoretically, it fills the gap in research on analytical thinking in mathematics education by systematically summarizing and evaluating the existing body of work and providing new perspectives and frameworks for future academic research. By reviewing research on analytical thinking in mathematics and categorizing it into five key themes—Instruction and Development of Thinking, Research on Thinking Processes, Assessment and Evaluation of Thinking, Research on Thinking Styles, and Interdisciplinary Research—this study classifies analytical thinking in mathematics education and provides a structured framework for future research.

Practically, this study provides mathematics educators with effective instructional strategies for fostering analytical thinking in students. By analyzing different teaching methods, such as inquiry-based learning, cognitive scaffolding, and metacognitive techniques, this study highlights approaches that help students develop problem-solving and reasoning skills. Additionally, the findings inform curriculum development and assessment design, guiding policymakers and educators in integrating analytical thinking into teaching standards and evaluation frameworks. The interdisciplinary focus of this study also promotes collaboration between mathematics education, cognitive science, and psychology, facilitating the development of more comprehensive and evidence-based teaching practices that enhance students' learning outcomes and analytical thinking abilities.

METHOD

Systematic Searching Strategies

This study employs a systematic literature review methodology, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure the transparency and scientific rigour of the literature selection process (Sarkis-Onofre, 2021). A systematic literature review is a comprehensive approach to analyzing existing research, aimed at summarizing relevant studies, assessing the current state of research in the field, and identifying existing gaps and future research directions (Linnenluecke et al., 2020). To ensure the breadth and representativeness of the review, this study selected relevant literature from multiple academic databases. Following the PRISMA guidelines, we first defined the scope of the research and then applied predefined criteria for literature selection, extracting key information from the included studies. The entire process, as shown in Figure 1, consists of four steps: identification, screening, eligibility, and inclusion (Rante et al., 2020; Almarzuki et al., 2024; Marzuki et al., 2023). Finally, the selected articles were classified according to research type and content.

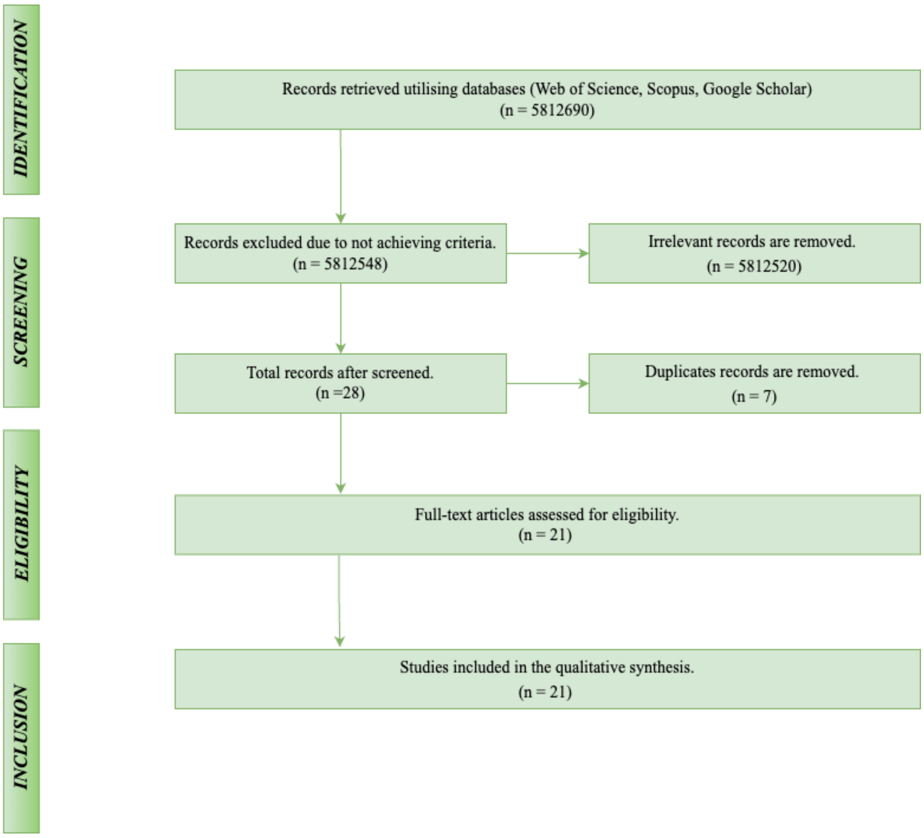

Figure 1
Flow diagram of the search strategies process

Identification

The key to literature identification lies in developing a systematic search strategy, which includes selecting appropriate databases, keywords, and search filters (Booth et al., 2021). For this study, three academic databases were chosen: Google Scholar, Web of Science, and Scopus, which encompass a large body of high-quality literature in the fields of mathematics education and cognitive science. The keywords used included "analytical thinking," "critical thinking," "mathematics," "students," "geometry," "algorithm," and others. These keywords ensure the retrieval of a diverse range of literature related to analytical thinking in mathematics education, including theoretical studies, experimental research, and the application of teaching methods.

Table 1
Search string applied in the selected database

Database	Search String
Google Scholar	TITLE-ABS-KEY (("Analytical thinking" OR "Analy* thinking" OR "AT" OR "Critical thinking" OR "Critic* thinking" OR "CT") AND ("Pupils" OR "Students") AND ("Math" OR "Mathematics" OR "Mathematical" OR "Geometry" OR "Algorithm" OR "Calculus" OR " Statistics" OR "Function" OR "Equation"))
Web of Science	TS= (("Analytical thinking" OR "Analy* thinking" OR "AT" OR "Critical thinking" OR "Critic* thinking" OR "CT") AND ("Pupils" OR "Students") AND ("Math" OR "Mathematics" OR "Mathematical" OR "Geometry" OR "Algorithm" OR "Calculus" OR " Statistics" OR "Function" OR "Equation"))
Scopus	Analytical Thinking AND mathematic*

Screening

The screening phase involves a preliminary examination of the identified literature (Liberati et al., 2009). In this process, the researchers first apply pre-established search string, followed by the removal of irrelevant and duplicate references.

Eligibility

In the eligibility phase, the researchers further examine the filtered literature based on predefined criteria such as article accessibility, type of document, language, and subject area. They review the titles and abstracts of the remaining articles to exclude those that are not relevant to the research questions. The aim is to ensure that only studies meeting specific standards are included in the systematic literature review (Khan et al., 2011).

The eligibility criteria strictly adhere to the PRISMA guidelines to ensure transparency and standardisation in the literature selection process. First, the articles must be accessible, and the types of literature selected are peer-reviewed journal articles or conference papers to ensure academic rigour and research depth. Second, the language of the literature is restricted to English to ensure the articles represent international-level research outcomes. Lastly, the scope of the research must be related to analytical thinking in mathematics. No time restrictions were imposed on the selected literature to ensure the breadth and comprehensiveness of the search and selection process.

Table 2
Criteria for inclusion and exclusion

Criterion	Inclusion	Exclusion
Article Accessibility	the article is available	the article is not fully accessible
Type of Document	it is a journal or a conference article	the article is not a journal or a conference article, e.g., a dissertation, etc.
Language	the writing language is in English	it is written in a language other than English
Subject area	it is relevant to analytical thinking in mathematics	it is irrelevant to analytical thinking in mathematics

Due to potential inaccuracies in the database, some literature may be incorrectly identified, requiring the researchers to manually conduct a second round of screening (Shaffril et al., 2020). During this process, the researchers conduct a full-text review of the remaining articles and exclude those that do not meet the established criteria (Hermont et al., 2022).

Inclusion

The Inclusion phase is the final step of the systematic literature review, where the researchers decide which studies will ultimately be included in the review (Aziz Marzuki, 2023).

Research Classification Process

Classification of Research Types

The classification of research types is an important process that allows researchers to better understand the methods employed and ensures that each study is categorized based on its design and purpose. The Mixed-Method Appraisal Tool (MMAT), proposed by Hong et al. (2018), is adopted in this study. MMAT enables scholars to systematically appraise mixed-method research and assess five types of studies: mixed-methods research, quantitative descriptive research, non-randomized studies, randomized controlled trials, and qualitative research (Hong et al., 2018). Therefore, this study selects five research design categories: quantitative descriptive (QN-DC), quantitative non-randomized (QN-NR), quantitative randomized controlled trials (QN-RCT), qualitative (QL), and mixed-methods (MX). Each category addresses different research questions. Mixed-methods research combines both quantitative and qualitative approaches to provide comprehensive insight. Quantitative descriptive research typically focuses on numerical data to describe phenomena, while non-randomized and randomized controlled trials are more focused on experimental and quasi-experimental designs to explore causal relationships. On the other hand, qualitative research emphasizes understanding phenomena through non-numerical data, gaining an in-depth understanding of participants' experiences and perspectives. Classifying research types allows for a clear observation of research designs, which not only helps to synthesize research findings but also aids researchers in evaluating the rigour and relevance of various research methods (Booth et al., 2016). By organizing studies based on methodology, scholars can identify the strengths and limitations of different types of research, facilitating clearer comparisons and determining areas for further exploration.

Classification of Research Content

The classification of research content refers to the process of categorizing studies based on their central themes, research questions, and subjects (Piepenbrink & Gaur, 2017). This classification helps to organize and synthesize the existing literature, ensuring a systematic understanding of the key contributions of the research and aiding in the identification of research gaps, emerging trends, and areas for future exploration (Booth et al., 2021). The classification process first identifies the central focus of each study, which may involve themes such as educational practices, psychological interventions, health outcomes, or social issues (Bengtsson, 2016). Once the main focus is identified, the research is categorized into thematic categories based on its research questions, objectives, and scope. For example, in the field of education, studies can be categorized into curriculum development, teaching methods, student engagement, or assessment practices (Cohen et al., 2002). This classification enables researchers to better understand the frontier research directions in a field while also identifying key areas for future research, thereby fostering broader academic inquiry.

FINDINGS

Types of Research on Analytical Thinking in Mathematics

Table 3
Results of the types of research on analytical thinking in mathematics

Research Design	Study	Total
QN (DC)	(Huincahue et al., 2021); (Godino et al., 2013); (Kesorn et al., 2020); (Kadir, 2017); (Suparman & Tamur, 2021)	5
QN (NR)	(Setiana & Purwoko, 2021); (Supriadi et al., 2022); (Anggoro et al., 2021); (Purba & Azis, 2022); (Syaiful et al., 2021);	5
QN (RCT)	(Belecina & Ocampo Jr, 2018);	1
QL	(Stein et al., 1996); (Abbas & Rasan, 2022); (Osman et al., 2016) (Reinke, 2019); (Ferri, 2003); (Faizah et al., 2020); (Wijaya et al., 2023); (Annizar et al., 2021); (Sam & Yong, 2006); (Mateus-Nieves & Díaz, 2021);	10

QN (DC) = Quantitative Descriptive; QN (NR) = Quantitative Non-Randomised; QN (RCT) = Quantitative Randomised Controlled Trials; QL = Qualitative; MX = Mixed-Methods; N/A = Not Applicable.

Table 3 presents the classification of research types on analytical thinking in mathematics, categorized into quantitative descriptive (QN-DC), quantitative non-randomized (QN-NR), quantitative randomized controlled trials (QN-RCT), qualitative (QL), and mixed-methods (MX). The results indicate that qualitative research (QL) dominates the field, with 10 studies (e.g., Stein et al., 1996; Faizah et al., 2020; Wijaya et al., 2023) focusing on in-depth exploration of analytical thinking processes, theoretical frameworks, and observational data. Quantitative non-randomized designs (QN-NR) and quantitative descriptive studies (QN-DC) each account for 5 studies, examining analytical thinking through surveys, assessments, and comparative analyses (e.g., Supriadi et al., 2022; Kesorn et al., 2020). A single study utilizes a quantitative randomized controlled trial (QN-RCT) approach (Belecina & Ocampo Jr, 2018), demonstrating the limited application of experimental methods in this area. Notably, no studies explicitly employed mixed-methods research (MX). These findings suggest a strong reliance on qualitative approaches, with quantitative methods mainly being non-randomized or descriptive, reflecting current trends and methodological preferences in analytical thinking research in mathematics.

Content Classification of Research on Analytical Thinking in Mathematics

Table 4
Results of the content of research on analytical thinking in mathematics

Theme	Explanation	Study	Total
Instruction and Development of Thinking	Explores various instructional strategies and educational approaches used to develop analytical thinking in mathematics.	(Setiana & Purwoko, 2021); (Stein et al., 1996); (Supriadi et al., 2022); (Anggoro et al., 2021); (Belecina & Ocampo Jr, 2018); (Reinke, 2019); (Purba & Azis, 2022); (Sam & Yong, 2006); (Mateus-Nieves & Díaz, 2021); (Abbas & Rasan, 2022); (Godino et al., 2013)	11
Research on Thinking Processes	Focuses on the cognitive development and transformation of students' thinking processes during mathematical learning.	(Faizah et al., 2020); (Wijaya et al., 2023); (Annizar et al., 2021)	3
Assessment and Evaluation of Thinking	Investigates methods for assessing and quantifying students' analytical thinking abilities in mathematics education.	(Kesorn et al., 2020); (Kadir, 2017); (Suparman & Tamur, 2021)	3
Research On Thinking Styles	Examines how different cognitive styles influence students' engagement in analytical thinking and mathematical reasoning.	(Ferri, 2003); (Huincahue et al., 2021)	2
Interdisciplinary Research	Explores how analytical thinking in mathematics is applied in interdisciplinary contexts, such as STEM and engineering fields.	(Syaiful et al., 2021); (Osman et al., 2016)	2

Table 4 categorizes the articles retrieved into five themes: Instruction and Development of Thinking, Research on Thinking Processes, Assessment and Evaluation of Thinking, Research on Thinking Styles, and Interdisciplinary Research. Specifically, the research on Instruction and Development of Thinking is the most abundant, encompassing 11 studies that explore various aspects of the cultivation and development of thinking in different educational contexts (e.g., Setiana & Purwoko, 2021; Supriadi et al., 2022). In the Research on Thinking Processes category, three studies focus on the dynamic development of students' thinking during mathematical learning (e.g., Faizah et al., 2020; Annizar et al., 2021). Regarding Assessment and Evaluation of Thinking, three studies investigate how to quantify and assess students' analytical thinking (e.g., Kesorn et al., 2020; Suparman & Tamur, 2021). In the Research on Thinking Styles theme, two studies are relevant (e.g., Ferri, 2003; Huincahue et al., 2021). Additionally, Interdisciplinary Research is represented by two studies that explore the application of analytical thinking from an interdisciplinary perspective (e.g., Syaiful et al., 2021; Osman et al., 2016). Overall, this table provides a clear overview of the current state of research on mathematical analytical thinking, highlighting the concentration of research in various directions and offering insights into potential future developments.

Comparison of Types and Content of Research on Analytical Thinking in Mathematics

Table 5
Comparison of types and content of research on analytical thinking in mathematics

Theme	Type	Methods	Author, Year
Instruction and Development of Thinking	QN (DC)	T-test, Pearson correlation coefficient, etc.	(Godino et al., 2013)
	QN (NR)	Quasi-experimental research design	(Setiana & Purwoko, 2021)
	QN (NR)	Quasi-experimental research design	(Purba & Azis, 2022)
	QN (NR)	Quasi-experimental research design	(Supriadi et al., 2022)
	QN (NR)	Quasi-experimental research design	(Anggoro et al., 2021)
	QN (RCT)	Randomized experimental design	(Belecina & Ocampo Jr, 2018)
	QL	Content analysis, classroom observation, coding	(Stein et al., 1996)
	QL	Grounded theory, framework development	(Reinke, 2019)
	QL	Literature review, phenomenological description	(Sam & Yong, 2006);
	QL	Literature review, phenomenological description	(Mateus-Nieves & Díaz, 2021)
	QL	Action research, coding	(Abbas & Rasan, 2022)
Research on Thinking Processes	QL	Exploratory research, descriptive methods	(Faizah et al., 2020)
	QL	Descriptive research with qualitative and quantitative elements	(Wijaya et al., 2023)
	QL	Case study, descriptive methods	(Annizar et al., 2021)
Assessment and Evaluation of Thinking	QN (DC)	Multidimensional modeling approach	(Kesorn et al., 2020)
	QN (DC)	Meta-analysis	(Kadir, 2017)
	QN (DC)	Meta-analysis	(Suparman & Tamur, 2021)
Research on Thinking Styles	QN (DC)	Normality test, spearman correlation, descriptive statistics, etc.	(Huincahue et al., 2021)
	QL	Grounded theory, case study	(Ferri, 2003)
Interdisciplinary Research	QN (NR)	Descriptive research (with group division)	(Syaiful et al., 2021)
	QL	Grounded theory, coding	(Osman et al., 2016)

Table 5 shows the distribution of research types and methods on analytical thinking in mathematics. The Research on Thinking Processes theme relies entirely on qualitative methods, such as exploratory and descriptive approaches. In contrast, the Assessment and Evaluation of Thinking theme is fully quantitative, utilising meta-analysis and multidimensional modelling. The other three themes—Instruction and Development of Thinking, Research on Thinking Styles, and Interdisciplinary Research—demonstrate a balanced mix of qualitative and quantitative methods, reflecting diverse approaches to exploring, measuring, and developing analytical thinking.

Under the Instruction and Development of Thinking theme, quantitative approaches are predominantly represented, with methods such as t-tests, Pearson correlation, and quasi-experimental designs (Godino et al., 2013; Setiana & Purwoko, 2021; Purba & Azis, 2022; Supriadi et al., 2022; Anggoro et al., 2021). A randomized controlled trial is also noted (Belecina & Ocampo Jr, 2018). Meanwhile, qualitative studies within this theme include content analysis, grounded theory, literature reviews, and action research (Stein et al., 1996; Reinke, 2019; Sam & Yong, 2006; Mateus-Nieves & Díaz, 2021; Abbas & Rasan, 2022).

In the Research on Thinking Processes theme, qualitative methods dominate, with studies employing exploratory, descriptive, and case-study approaches (Faizah et al., 2020; Wijaya et al., 2023; Annizar et al., 2021). The Assessment and Evaluation of Thinking focus on Quantitative Descriptive methods, including multidimensional modelling approaches and meta-analyses (Kesorn et al., 2020; Kadir, 2017; Suparman & Tamur, 2021). For Research on Thinking Styles, both quantitative and qualitative studies are present, with methods such as normality tests, Spearman correlation, descriptive statistics, and grounded theory (Huincahue et al., 2021; Ferri, 2003). Finally, in the Interdisciplinary Research theme, descriptive research with group divisions and grounded theory are highlighted (Syaiful et al., 2021; Osman et al., 2016).

DISCUSSION

Interpretation of Findings

This study systematically reviews how analytical thinking is researched in mathematics education, classifying studies by type and content to highlight key trends, gaps, and future needs. The existing literature was classified and organized based on research type and content. The findings regarding research types show that most studies focus on quantitative descriptive research (QN-DC) and qualitative research (QL). This suggests that research on analytical thinking in mathematics education tends to focus on using data to describe thinking processes and development, or on employing qualitative methods, such as in-depth interviews, to explore the specific manifestations of students' cognitive changes during the learning process. While quantitative research offers numerical data to support mathematics education, qualitative research plays an important role in revealing the details and underlying factors that contribute to students' development of analytical thinking.

Regarding the content of the research, the studies primarily focus on the following areas: Instruction and Development of Thinking, Research on Thinking Processes, Assessment and Evaluation of Thinking, Research on Thinking Styles, and Interdisciplinary Research. These areas reflect the various applications of analytical thinking in mathematics education and highlight the main research directions in this field. The results also show that the area of Instruction and Development of Thinking is the largest, with much of the research focusing on how teaching methods can support the development of students' thinking, particularly in areas such as mathematical problem-solving, concept understanding, and the promotion of critical thinking.

In comparing research types and content, the choice of research methods for different topics is closely aligned with their objectives. For example, "Research on Thinking Processes," which focuses on understanding the dynamic processes and strategies involved in students' thinking, typically uses qualitative methods like exploratory studies and case analyses to uncover the mechanisms of thinking. In contrast, "Assessment and Evaluation of Thinking," which focuses on measuring students' cognitive abilities, generally relies on quantitative methods such as multidimensional modelling and meta-analysis. For the topics of "Instruction and Development of Thinking," "Research on Thinking Styles," and "Interdisciplinary Research," a combination of qualitative and quantitative methods is often used to analyze the effectiveness of teaching interventions, while also exploring the impact of thinking styles and interdisciplinary influences. This mixed-methods approach ensures a well-rounded understanding of the issues.

Instruction and Development of Thinking

The significant focus on instructional methods underscores the essential role of teaching strategies in developing analytical thinking in mathematics. Research widely agrees that mathematical thinking involves students' ability to analyze and reason when solving complex problems, highlighting the importance of effective instructional approaches in fostering these skills (Setiana & Purwoko, 2021; Supriadi et al., 2022). These studies have found that students‘ mathematical thinking skills can be effectively promoted through appropriate learning models such as Problem-Based Learning (PBL) and the Realistic Maths Education (RME). Purba and Azis (2022) found through an empirical study that the PBL model significantly improved students’ mathematical problem-solving skills, which is in line with our findings indicating the role of analytical thinking in mathematical problem-solving's critical role.

In addition, the relationship between analytical thinking and 21st-century skills has gradually attracted the attention of researchers. Godino et al. (2013) suggested that analytical thinking is particularly significant among female students in influencing their performance in mathematical ability. Our findings are in line with theirs, further emphasising the importance of analytical thinking in the subject of mathematics.

Existing studies also point to the impact of different learning models on students' analytical and mathematical thinking skills. Setiana and Purwoko (2021) proposed in their study that students' critical thinking skills were significantly improved through the application of mathematical learning models. This was confirmed by our study which showed that appropriate learning models were effective in stimulating students' mathematical thinking. Meanwhile, Anggoro et al. (2021) further found that the open-ended learning approach promotes students' analytical thinking in mathematics more than the traditional lecture method, a finding that provides theoretical support for our study.

Nonetheless, Reinke (2019) poses a challenge, noting that contextual problems provide students with rich situations for mathematical thinking, but teachers often face some difficulties in implementing these tasks, especially in terms of how to balance the introduction of mathematical concepts with the practical application of the tasks. This observation suggests that when designing teaching tasks, teachers should pay more attention to the process of task implementation to ensure that students can gain a deeper understanding of mathematical concepts in problem situations.

Also, individual differences are an important factor that affects students' ability to think mathematically and analytically. Belecina and Ocampo Jr (2018) found through an experimental study that students' critical thinking skills showed different variations when faced with different problem situations. Our study also found that students‘ performance in problem-solving is influenced by their cognitive level and self-awareness (Anggoro et al., 2021). Supriadi et al. (2022) further showed that students’ level of analytical thinking can significantly influence their understanding of mathematical concepts. Therefore, we argue that individual differences are an important factor in the development of mathematical thinking and that educators should take into account students' cognitive differences when designing instruction and providing--personalised learning support.

Concerning the discussion of mathematical task design, both Stein et al. (1996) and Mateus-Nieves and Díaz (2021) emphasise the key role of task design in the development of students' thinking skills. Mathematical tasks are not only a tool to test students' mathematical knowledge, but also an important way to promote critical and analytical thinking. Research has shown that well-designed tasks can stimulate students' mathematical thinking skills, while the difficulty and design of the tasks also determine whether students can complete the tasks and develop analytical thinking in the process.

In this context, the contextual problem model proposed by Reinke (2019) provides a useful perspective on mathematical task design. Particularly in helping students apply mathematical concepts to real-life problems, contextual problems can enhance students' understanding and ability to apply mathematical knowledge. Therefore, the design of mathematical tasks should not only focus on the transmission of mathematical knowledge but also the development of students' critical and analytical thinking skills.

In addition to the design of mathematical tasks, the role of visual thinking in mathematical thinking should not be ignored. Mateus-Nieves and Díaz (2021) explored the synergy between visual language and analytical language in mathematical thinking, pointing out that visual thinking can complement analytical thinking and work together to promote students' mathematical understanding. In mathematics learning, visualisation tools and strategies (e.g., graphs, models, etc.) can help students better understand abstract mathematical concepts. Our study found that there is indeed some synergy between visual thinking and analytical thinking, especially in solving complex mathematical problems, where students can understand and express the problems more clearly through visualisation.

Although the roles of mathematical thinking and analytical thinking have been widely researched in educational practice, there are still many challenges to be faced. Sam and Yong (2006) pointed out that the promotion of mathematical thinking in the Malaysian mathematics classroom is faced with various challenges in terms of curriculum design, teacher training and classroom environment. In this study, we also found that although many theories and models support the development of mathematical thinking, in practice, factors such as teachers‘ pedagogical approaches, classroom interactions, and students’ attitudes towards learning may affect its effectiveness.

Therefore, future research should further explore how to effectively integrate different teaching models and strategies to promote the coordinated development of students' mathematical thinking and analytical thinking. Teachers‘ professional development and continuous improvement of teaching practice will have a profound impact on the improvement of students’ mathematical ability.

Research on Thinking Processes

Research on thinking processes provides crucial insights into how students develop analytical reasoning over time, especially in abstract algebra, convergence determination of real number series, and the application of the Lattice Method. (Faizah et al., 2020; Wijaya et al., 2023; Annizar et al., 2021). These studies reveal how students apply prior knowledge and analytical skills in different contexts to solve complex mathematical problems.

Faizah et al. (2020) investigated students' thought processes when performing mathematical proofs in abstract algebra and found that some students still relied on intuitive thinking to complete their proofs, even though mathematical proofs require strong analytical thinking. The study suggests that the intuitive thinking developed by students during the ‘attack’ and ‘review’ phases plays an important role in the proof process. Although this finding emphasises the importance of intuitive thinking, its long-term effects have not been fully explored.

Wijaya et al. (2023) studied students‘ analytical thinking in determining the convergence of real number series and found that students’ prior knowledge had a significant effect on the analytical thinking process. Students with higher a priori knowledge were able to differentiate more carefully, leading to better organisation and attribution. This suggests that a priori knowledge plays a central role in analytical thinking.

Annizar et al. (2021) investigated students' thought processes in understanding and applying the Lattice Method. It was found that some students were able to clearly understand and apply this new method, while others were unable to fully grasp it. This suggests that there are significant differences in students' cognitive strategies when learning the new method. Similar to Faizah et al.‘s (2020) study, Annizar et al. (2021)

emphasised the cognitive differences of students when confronted with new knowledge, suggesting that more attention should be paid to students' orientation towards new concepts to promote the development of analytical thinking.

In summary, the role of analytical thinking in students‘ mathematical problem-solving should not be overlooked; prior knowledge, intuitive thinking, and understanding of new approaches are all important factors that influence students' analytical thinking. Although these studies provide valuable insights, some shortcomings remain. For example, Faizah et al. (2020) failed to explore in depth the specific connection between intuitive thinking and analytical thinking; Wijaya et al. (2023) lacked strategies to enhance analytical thinking in students with low prior knowledge; and Annizar et al. (2021), although providing useful suggestions for learning the Lattice Method, still need to explore different students' cognitive strategies. Therefore, future research can further expand on these aspects to provide a more nuanced analytical thinking development programme for mathematics education.

Assessment and Evaluation of Thinking

Effective assessment of analytical thinking remains a key challenge in mathematics education. While tools such as rubrics and response models provide structured ways to measure students' skills, research highlights the need for more dynamic and adaptive assessment methods that reflect real-world problem-solving scenarios. In this context, studies have explored the impact of various assessment tools, learning interventions, and problem-based learning (PBL) on enhancing students' critical thinking skills in mathematics. In doing so, the validity of assessment tools, the effectiveness of learning interventions, and the enhancement of students' mathematical thinking skills by problem-based learning (PBL) emerged as central themes (Kesorn et al., 2020; Kadir, 2017; Suparman & Tamur, 2021).

Kesorn et al. (2020) developed an assessment tool to measure the mathematical reading, mathematical writing, and analytical thinking skills of fourth-grade students. The study showed that this instrument had high reliability and validity in the assessment of mathematical thinking. Validation of the assessment tool using the Multidimensional Random Coefficient Polynomial Item Response Model (MRC-MIRM) revealed that the tool was designed to accurately reflect students' abilities in these areas. Although the tool demonstrated good results in the assessment, it was limited by the fact that the sample was focused on fourth-grade students and did not address the applicability to students at different grade levels or in other cultural contexts. Therefore, future research could further explore the generalisability of the tool across grades and cultural contexts and its room for improvement.

Kadir's (2017) meta-analysis study revealed the positive impact of mathematics learning interventions on students' mathematical thinking skills. By analysing several student research papers, it was found that learning interventions had a significant effect in improving students' mathematical thinking, especially in some areas such as connectivity, communication, representation, problem-solving, logic and analytical thinking. This finding suggests that appropriate learning interventions are effective in enhancing students' mathematical thinking skills. However, the specific effects of different types of intervention methods on different groups of students were not explored in detail in the paper; therefore, future research should further refine the relationship between the type of intervention and individual student differences to ensure that the intervention strategies can be adapted to the needs of different students.

Suparman and Tamur (2021) evaluated the impact of problem-based learning (PBL) on students' mathematical critical thinking skills (MCTS) through meta-analysis. The results showed that PBL had a significant positive effect on students' mathematical critical thinking skills and that the characteristics of the year of publication significantly influenced the heterogeneity of the effect size. This study highlights the potential of PBL as an effective pedagogical approach to developing students' critical thinking. However, the study also shows that the effect of PBL can be affected by factors such as research context, level of education, and sample size, suggesting that differences in these variables should be taken into account when implementing PBL. In addition, the study's discussion of the effects of PBL on students at different educational levels was rather brief, and future research could explore in more depth the adaptation and effects of PBL at different educational levels.

Taken together, although the studies by Kesorn et al. (2020), Kadir (2017), and Suparman & Tamur (2021) validated the validity of the mathematical thinking skills assessment tool, the effectiveness of learning interventions, and the impact of problem-based learning on critical thinking from different perspectives, respectively, the results of these studies offer valuable experience. However, the current study still has some limitations, such as the universality of the instrument, the diversity of intervention methods, and the context-dependency of the effects of PBL. Therefore, future research should focus more on diversified intervention strategies and careful analysis of the adaptability of different student groups to provide more instructive practical solutions for the field of mathematics education.

Research On Thinking Styles

Research on thinking styles indicates that students with an analytical approach tend to excel in mathematics, highlighting the need for differentiated instruction that caters to individual cognitive preferences. This theme investigates the relationship between mathematical thinking styles (MTS) and student performance, with a particular focus on the benefits of an analytical thinking style in enhancing mathematical problem-solving and academic achievement. Huincahue et al. (2021) found through a quantitative study that there was a significant positive correlation between students' preference for mathematical thinking styles and their performance in mathematics. The study showed that students who preferred an analytical thinking style performed better in learning and solving mathematical tasks and there was also a strong link between this style and students' self-efficacy and achievement. This finding highlights the importance of analytical thinking styles in mathematics education and suggests that teachers can enhance students' mathematical performance by helping them to recognise and develop their analytical thinking styles. However, the article also points out that despite the advantages of analytical thinking in mathematics learning, mathematical thinking styles are not fixed and may be influenced by students' interests, emotions and beliefs. Therefore, future research could further explore how different types of mathematical thinking styles interact with each other to more fully understand their impact on student learning.

In contrast, Ferri (2003) in her study reviewed different classifications of mathematical thinking styles and explored how these classifications affect students' learning in mathematics. The article reviews classical categories such as ‘analytical’, ‘geometric’ and ‘philosophical’ thinking styles and demonstrates how these categories are used in practical teaching. Although the study provides a useful perspective on mathematical thinking styles, it focuses on a sample of mathematicians rather than students of mathematics, which may limit the generalisability of the findings. It is also mentioned in the paper that the categorisation of mathematical thinking styles is established more through experience or intuition and lacks systematic empirical support. Therefore, future research should focus more on how to refine and validate the characteristics of different mathematical thinking styles and their effects on students' academic performance through empirical studies.

Taken together, both Huincahue et al.‘s (2021) and Ferri's (2003) studies reveal the importance of mathematical thinking styles in mathematics learning. Huincahue et al.’s study highlights the advantages of analytical thinking styles in mathematics learning, while Ferri's study provides a theoretical basis for the classification and application of mathematical thinking styles. However, most of the existing studies have focussed on the relationship between specific thinking styles and learning performance, and there is a lack of exploration of the combined effects of multiple thinking styles. Future research could further explore the interactions between different mathematical thinking styles in actual teaching and learning, and how to personalise teaching according to students' thinking styles to maximise their mathematical ability.

Interdisciplinary Research

In science and engineering education, the development of critical and mathematical thinking has become an important aspect of enhancing students‘ ability to solve real-world problems. In their study, Syaiful et al. (2021) explored the effects of a problem-based learning (PBL) model on students’ analytical thinking skills and scientific process skills in the subject of mathematics. The results of the study showed that the PBL model significantly improved students' analytical thinking skills and scientific process skills, especially on the indicators of observation and classification. By using quantitative research methods, Syaiful et al. found that students who applied the PBL model significantly outperformed students who did not use the PBL model in these areas. This finding provides a theoretical basis for teachers to integrate PBL in mathematics teaching and learning, suggesting that PBL not only promotes students' mathematical knowledge acquisition but also develops foundational skills in scientific research, such as observation and classification. Although the study provided strong evidence to support the effectiveness of the PBL model in enhancing students' mathematical analytical skills and scientific process skills, its sample was limited to students in a specific district, which may affect the broad applicability of the findings. Therefore, future studies may consider further validating the effectiveness of the PBL model among students from different regions, disciplines and age groups.

On the other hand, Osman et al. (2016) explored the application of critical and mathematical thinking in civil engineering practice from an engineering education perspective. Through semi-structured interviews with eight civil engineers, the study identified 53 key elements of critical and mathematical thinking and proposed a substantive theoretical framework in conjunction with an improved rooted theory analysis method. The framework reveals the important role of critical and mathematical thinking in solving practical engineering problems, especially in making decisions and solving complex problems. Osman et al. emphasise that integrating critical and mathematical thinking into engineering education can effectively enhance students' problem-solving skills in their future careers. Although the study provided valuable empirical data for engineering education to support the application of critical and mathematical thinking in practice, its small sample of studies, covering only specific areas of civil engineering practice, limited the breadth of the results. In addition, the study did not adequately explore how these ways of thinking can be systematically integrated into classroom teaching and learning, and future research should further explore how the development of critical and mathematical thinking can be incorporated into the daily teaching and learning activities of engineering education.

In summary, the studies by Syaiful et al. (2021) and Osman et al. (2016) both emphasised the importance of thinking styles in different disciplines. Syaiful et al. highlighted the effectiveness of the PBL model in Mathematics education, whereas Osman et al. explored the application of critical and mathematical thinking in engineering education. Both studies provide theoretical support for educational practices in different fields, however, they have some limitations. Syaiful et al. failed to validate their results across regions, while Osman et al.'s study had a small sample and failed to elaborate on the details of the pedagogical implementation. Therefore, future research should consider expanding the sample size and delving into how these thinking skills can be effectively developed in the classroom and in practice to enhance students' comprehensive problem-solving skills.

Theoretical and Practical Implications

Theoretical Implications

This study provides a systematic literature review that categorizes and organizes existing research on analytical thinking in mathematics education, offering a structured framework for future theoretical development. By classifying research into five key themes—Instruction and Development of Thinking, Research on Thinking Processes, Assessment and Evaluation of Thinking, Research on Thinking Styles, and Interdisciplinary Research—this study contributes to multiple theoretical perspectives.

First, it expands the theoretical understanding of mathematical thinking by distinguishing analytical thinking as a distinct component rather than a subset of critical thinking or problem-solving. This contributes to theories of mathematical cognition (e.g., Corte & Verschaffel, 2007), which emphasize structured reasoning in mathematics learning.

Second, this review informs cognitive learning theories, particularly those related to metacognition and self-regulated learning in mathematics. By highlighting instructional strategies that develop analytical thinking, this study supports and extends models of cognitive scaffolding and inquiry-based learning.

Additionally, this study provides a basis for future theoretical integration by systematizing previously fragmented findings. It enables researchers to build more targeted models of analytical thinking development, linking it to curriculum design, assessment frameworks, and interdisciplinary applications. Future studies can explore how analytical thinking interacts with problem-solving frameworks and metacognitive strategies, further refining existing theories in mathematics education.

Practical Implications

This study provides practical guidance for mathematics educators by identifying effective teaching strategies that foster analytical thinking. The review highlights approaches such as inquiry-based learning, cognitive scaffolding, and metacognitive techniques, which have been shown to enhance students' problem-solving abilities and reasoning skills.

Additionally, this study informs curriculum development by emphasizing the need for instructional designs that integrate structured problem-solving tasks into mathematics education. Policymakers and curriculum designers can use these findings to develop teaching standards and assessment frameworks that better evaluate students' analytical thinking skills.

Beyond mathematics education, this study also has interdisciplinary applications. The classification of analytical thinking research highlights its relevance to cognitive science, psychology, and STEM education. By fostering collaboration between mathematics educators and experts in these fields, the study supports the development of more comprehensive, evidence-based teaching practices that enhance students' learning outcomes and analytical thinking abilities.

LIMITATIONS

Despite the comprehensive review of existing literature on analytical thinking in mathematics education, this study has several limitations. First, research on analytical thinking in mathematics education is relatively scarce, and the field is still in its early stages of development. As a result, some relevant studies may have been missed during the screening process. Second, the literature reviewed in this study primarily comes from three major databases (Web of Science, Scopus, and Google Scholar), and certain exclusion criteria were applied during the selection process, which may have led to the omission of some pertinent research. Furthermore, while the included studies provide valuable insights, relying solely on the data and conclusions from the existing literature still presents certain limitations. The selected studies employed a variety of research methods and differed in quality, which means that the conclusions drawn may be influenced by the varying research designs and data quality, thus complicating comparisons between different study outcomes.

FUTURE DIRECTIONS

In light of the findings and limitations discussed, future research on analytical thinking in mathematics education should address several key areas to advance both theoretical understanding and practical application. Firstly, there is a need for more expansive systematic literature reviews in this field, incorporating a broader range of studies to provide a more comprehensive understanding of the current state of analytical thinking in mathematics. This would help to identify gaps in the existing research and offer a clearer view of the evolution of this area.

Secondly, the volume of research focusing specifically on analytical thinking in mathematics should be increased. Future studies should examine how analytical thinking directly impacts students' performance and achievement in mathematical problem-solving. This will provide deeper insights into how analytical thinking influences mathematical learning outcomes, helping educators to design more effective instructional strategies.

Thirdly, the integration of emerging technologies, such as artificial intelligence, virtual learning environments, and adaptive learning systems, offers new avenues for enhancing analytical thinking in mathematics. Future research should explore how these technologies can be used to foster analytical skills in students and enhance the learning experience. Fourthly, it is important to examine the role of cultural context in shaping students' analytical thinking styles and problem-solving strategies, as cultural differences may influence cognitive development and learning approaches.

Finally, future research should investigate how various teaching models and strategies can be integrated to promote the development of both mathematical thinking and analytical thinking in students. Teacher professional development and continuous improvement in instructional practices will be crucial for advancing students' mathematical abilities and enhancing their analytical thinking skills. These areas provide valuable opportunities for future academic exploration and are essential for improving both the theoretical and practical aspects of mathematics education moving forward.

CONCLUSION

Analytical thinking, as a core cognitive skill in mathematics education, plays a crucial role in helping students analyze complex problems, evaluate evidence, and construct logical solutions. This study systematically classifies research on analytical thinking in mathematics education based on research type and content, providing a structured review of existing literature. The findings indicate that most studies focus on qualitative research and quantitative descriptive research, with five dominant themes emerging: instruction and development of thinking, research on thinking processes, assessment and evaluation of thinking, research on thinking styles, and interdisciplinary research.

This systematic review addresses a critical gap in analytical thinking research, offering new theoretical perspectives and a structured framework for mathematics education. It contributes to cognitive learning theories, metacognition, and problem-solving frameworks, emphasizing interdisciplinary connections with cognitive science and STEM. Practically, it supports educators in optimizing instructional strategies through inquiry-based learning, scaffolding, and metacognitive techniques.

Future research should expand systematic literature reviews, explore the direct impact of analytical thinking on mathematical problem-solving, and investigate the role of emerging technologies and cultural contexts in fostering analytical skills. Additionally, integrating diverse teaching models and enhancing teacher professional development will be crucial for advancing both theoretical understanding and practical applications in mathematics education.

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