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METHODOLOGICAL GAPS AND NEW DIRECTIONS OF CREATIVE MATHEMATICAL REASONING RESEARCH: A SYSTEMATIC LITERATURE REVIEW

Titin Masfingatin[1*], Ika Krisdiana[2], Reza Kusuma Setyansah[3]
[1,2,3]Departement of Mathematics Education, Universitas PGRI Madiun, East Java, Indonesia

*Correspondence: titin.mathedu@unipma.ac.id

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ABSTRACT

Creative Mathematical Reasoning (CMR) emphasizes students' ability to generate reasoning that is novel, plausible, and grounded in mathematical foundations. This study aims to identify research trends, methodological patterns, and research gaps in CMR through a systematic literature review following the PRISMA framework. Articles were retrieved from Scopus, Web of Science, SpringerLink, Google Scholar, and SINTA-indexed journals using predefined inclusion and exclusion criteria. An initial search identified 57 records from the selected databases, of which eleven studies met the eligibility criteria and were included in the final synthesis. The review revealed three major gaps: (1) methodological fragmentation between outcome-oriented quantitative studies and process-oriented qualitative studies; (2) limited population diversity, with research dominated by Scandinavian contexts and few cross-cultural investigations; and (3) assessment instruments that primarily measure learning outcomes rather than the creative mathematical reasoning process itself. In addition, evidence from Indonesian studies suggests that Argument-Driven Inquiry and Discovery Learning are promising instructional approaches for fostering CMR. These findings highlight the need for integrative research designs, such as Design-Based Research, and process-based digital assessment instruments to capture the dynamics of CMR more authentically, thereby contributing to the advancement of quality mathematics education in support of Sustainable Development Goal 4 (SDG 4: Quality Education).

Keywords: Creative Mathematical Reasoning, Systematic Literature Review, Methodological Gaps.

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PRELIMINARY

The ability to think and reason creatively is one of the main goals of modern mathematics education. Creative thinking allows students not only to reuse existing knowledge, but also to develop new ways of understanding and solving mathematical problems. In this context, Creative Mathematical Reasoning (CMR) has become a central concept that has received a lot of attention in the last two decades (Lithner, 2008, 2017). CMR emphasizes the construction of new solutions (novel), mathematically plausible, and

based on valid mathematical principles (mathematical foundation). This approach is the opposite of Imitative Reasoning (IR), where students simply replicate a procedure that has been exemplified without really understanding the mathematical reasoning behind it.

Various studies have shown that learning that stimulates CMR contributes to improved conceptual understanding, knowledge transfer, and long-term learning resilience (Granberg & Olsson, 2015; Jonsson et al., 2020; Lithner, 2017). However, the research landscape on CMR is still dominated by homogeneous and limited methodological approaches. Most studies use quasi-experimental designs to compare learning outcomes between the CMR group and the algorithmic group, focusing on learning outcomes such as test scores or transfer outcomes (Jonsson et al., 2016, 2020). This design is indeed effective in demonstrating the superiority of CMR over the final result, but it has not been able to reveal how the creative thinking process itself occurs during learning.

Qualitative research, as conducted by (Granberg & Olsson, 2015; Hershkowitz et al., 2017) have sought to fill this gap through the analysis of classroom interaction and student knowledge shifts. However, such studies are still descriptive and have not been accompanied by quantitative validation that allows for generalization of findings. Meanwhile, (Sjaastad, 2025) who applied the CMR framework to elementary school students found that the adaptation of novelty and plausibility concepts at an early age poses its own challenges, especially in the assessment process. These facts confirm the existence of a methodological gap in CMR research, namely the absence of a research approach that is able to explain the relationship between process and product of creative reasoning in an integrated manner.

In addition to the limitations of the research approach, the measuring tools used in CMR studies are also still oriented towards the final product. Assessment of creative reasoning is generally carried out through the results of a transfer test, without observing how students' mathematical ideas develop in real time. In fact, the essence of CMR lies in the process of constructing, justifying, and evaluating mathematical ideas (Hansen, 2022; Lithner, 2017). Various researchers have called for the importance of developing process-oriented instruments that can monitor the course of creative reasoning, for example through think-aloud protocols, learning analytics, or digital trace data from applications such as GeoGebra (Granberg & Olsson, 2015; Jonsson et al., 2022).

In addition, most CMR research has been conducted in European countries, particularly Sweden, involving secondary school students and focusing predominantly on algebraic topics. Although several studies have recently emerged in Indonesia, they mainly investigate the implementation of instructional models or explore students' CMR in specific

learning contexts (Hidayat, 2017; Masfingatin et al., 2020; Masfingatin & Murtafiah, 2020). However, the methodological characteristics, research trends, and gaps of CMR studies across Indonesian educational contexts have not yet been systematically mapped. This limited evidence highlights the need to broaden CMR research across educational levels, learner populations, and mathematical domains, while also examining how contextual and pedagogical characteristics may shape the development of creative mathematical reasoning.

To address these methodological and contextual gaps, this study conducts a Systematic Literature Review (SLR) to identify methodological trends and research gaps in Creative Mathematical Reasoning (CMR) research. An SLR was selected because it provides a systematic, transparent, and reproducible approach to synthesizing evidence from previous studies, enabling a comprehensive identification of methodological trends, recurring limitations, and research gaps across the existing body of CMR literature (Booth et al., 2016). This review examines research designs, analytical approaches, participant characteristics, and assessment practices reported in CMR studies published between 2014 and 2025. The findings are expected to provide a comprehensive methodological map of CMR research and offer evidence-based recommendations for future studies aimed at developing more integrated and process-oriented approaches to mathematics education, thereby contributing to the advancement of evidence-informed mathematics education research in support of Sustainable Development Goal 4 (SDG 4): Quality Education.

METHODS

This research is a systematic literature review which aims to identify directions, methodological patterns, and research gaps in the field of CMR. This study follows the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020), which includes four main stages: identification, screening, eligibility, and synthesis (Ramadhany et al., 2025). A systematic approach was chosen so that the literature review process is transparent, replicable, and scientifically accountable, as well as to build a complete knowledge map regarding the development of CMR research.

Literature searches were conducted using Publish or Perish to retrieve records from Google Scholar, while Scopus, Web of Science, SpringerLink, and SINTA 1- or SINTA 2-indexed journals were searched directly. The search strategy employed the following search strings: "creative mathematical reasoning" OR "creative reasoning in mathematics" OR "mathematical creativity and reasoning". The search was limited to articles published in English or Indonesian between 2014 and 2025, including empirical and theoretical studies

related to CMR published in peer-reviewed journals. Records retrieved from all sources were exported, merged, and subsequently screened according to the predefined inclusion and exclusion criteria following the PRISMA 2020 framework.

Inclusion criteria were established to ensure the relevance of the article to the focus of the study. Articles are included when they meet the inclusion criteria: mention or refer to the CMR concept according to the Lithner framework (2008; 2017); present clearly identifiable objectives, methods, and research results; contain a formal mathematics learning context (school or college); and are available in full text. An article is excluded if it is only in the form of a conference abstract or editorial note, does not mention the dimensions of novelty, plausibility, and mathematical foundation, and does not focus on the context of mathematics learning. The article selection process follows the PRISMA stages as presented in Figure 1.

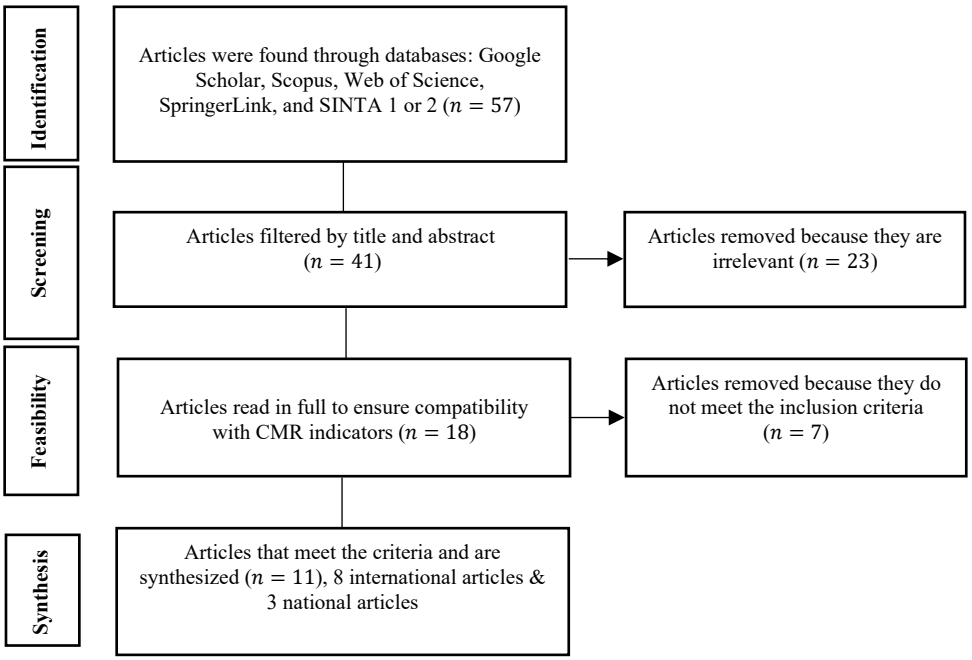


Figure 1. PRISMA Flow Diagram of Systematic Literature Review on CMR

Figure 1 shows the systematic stages of the literature review process. A total of 57 initial articles were identified from four main databases. After removing 16 duplicate articles and selecting 41 articles by title and abstract, 18 full-text articles were obtained and thoroughly reviewed. Of these, 7 articles were excluded because they did not explicitly discuss CMR or did not have empirical data. Finally, 11 articles were declared to meet the inclusion criteria and were further analyzed to identify methodological patterns and research gaps related to CMR.

1. Data Analysis and Synthesis Techniques

The analysis is carried out with two main stages, namely data extraction and verification.

a. Data Extraction

Each article that passed the selection was extracted based on nine categories of information: the author's name and year of publication, research design and the purpose of the research, population/context, the main variable or focus, measuring instruments, research limitations, key findings, and research implications.

b. Verification

The extraction process is done manually and verified twice to ensure consistency.

2. Thematic Synthesis

The extracted data were analyzed using a thematic content analysis approach to identify methodological patterns, research contexts, and directions for CMR development. Furthermore, the research gap is categorized into six dimensions: knowledge, practical knowledge, evidence, empirical, methodological, population, and theoretical gap, as stated by (Booth et al., 2016).

3. Validity and Reliability of the Study

To ensure the validity of the study, selection and extraction were carried out by researcher triangulation, which is a double reading by two researchers independently.

The difference in results is discussed until an agreement is reached. The reliability of the process is maintained by documenting all stages in the review log using a spreadsheet that records the sources, selection decisions, and reasons for inclusion/exclusion.

RESULT AND DISCUSSION

1. General Profile of CMR Research

A total of eleven articles that met the inclusion criteria were analyzed to identify the methodological characteristics and key findings of CMR research. Eight articles came from reputable international journals such as ZDM Mathematics Education, Frontiers in Psychology, and International Journal of Mathematical Education in Science and Technology, while three articles were national publications (Sinta 2) relevant to the context of mathematics education in Indonesia. Eleven articles that met the inclusion criteria in this study are summarized in Table 1.

Table 1. Summary of Articles on CMR

No.	Author (Year)	Research Design	Population/ Context	Research Focus	Main Findings

1	Jonsson et al. (2022)	Quasi-experiments	Swedish High School Students	CMR vs Algorithmic Reasoning (AR)	CMR improved learning outcomes and transfer through productive struggle.
2	Jonsson, Kulaksiz & Lithner (2016)	Quasi-experiments	Swedish High School Students	Post-workout performance	Effortful struggle enhanced transfer and retention.
3	Lithner (2017)	Conceptual studies	Conceptual/ Theoretical	Task design principles	Proposed novelty, plausibility, and mathematical foundation as core principles.
4	Granberg & Olsson (2019)	Qualitative observational	Prospective Teacher	Proses reasoning kreatif	GeoGebra facilitates the exploration of creative reasoning.
5	Hershkowitz, Tabach & Dreyfus (2017)	Class-based qualitative	Junior High School Students	Knowledge shift	Social interaction supports CMR.
6	Jonsson & Lithner (2020)	Quasi-experiments	Swedish High School Students	Learning outcomes & retention	CMR results in better retention.
7	Sjaastad (2025)	Qualitative exploratory	Elementary students (7–8 years old)	Implementasi CMR	Children show plausibility reasoning.
8	Jonsson et al. (2014)	Experiment Laboratory	Swedish High School Students	Transfer capability	CMR improves transfer, especially in students with high memory.
9	Masfingatin, Murtafiah & Maharani (2020)	Descriptive qualitative	Indonesian Prospective Teacher	CMR process in troubleshooting	Students show novel and plausible reasoning.
10	Masfingatin & Murtafiah (2020)	Qualitative exploratory studies	Indonesian Prospective Teacher	CMR in *Discovery Learning*	CMR arises through discovery activities.
11	Hidayat (2017)	Quasi-experiment	Indonesian High School Students	CMR (novelty, plausibility, mathematical foundation)	ADI improves CMR; significant interaction with AQ.

To complement the information presented in Table 1, Figure 2 provides an aggregated summary of the reviewed studies, enabling a clearer comparison of the overall research characteristics.

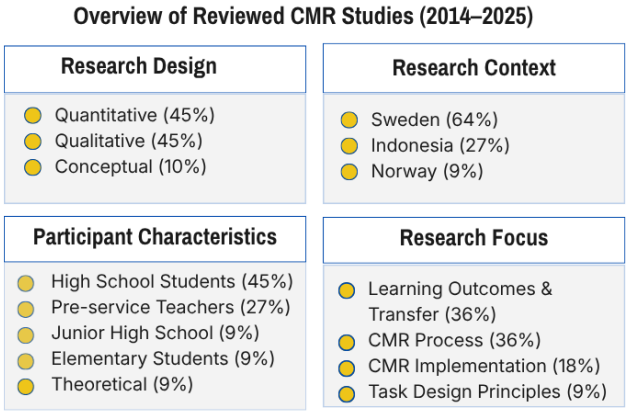


Figure 2. Distribution of Research Characteristics in Reviewed CMR Studies

Table 1 and Figure 2 reveal several consistent patterns in the current landscape of CMR research. First, the reviewed studies demonstrate a balanced methodological distribution between quantitative and qualitative approaches, whereas conceptual studies remain scarce. Second, CMR research is geographically concentrated in Scandinavia (Sweden & Norway), reflecting the historical development of the theory by Lithner (2008, 2017), while Indonesian studies primarily emphasize pedagogical implementation through instructional approaches such as Argument-Driven Inquiry (Hidayat, 2017) and Discovery Learning (Masfingatin & Murtafiah, 2020). Third, the existing literature focuses predominantly on high school students and learning outcomes or students' reasoning processes, with comparatively limited attention given to other educational levels, diverse cultural contexts, and instructional design. Overall, these patterns suggest that although CMR research has developed across different methodological traditions, its empirical evidence remains concentrated within specific geographical, educational, and research contexts, providing the foundation for the methodological, population, and instrument gaps discussed in the following sections.

2. Design Patterns and Research Approaches

The analysis shows two main orientations of the research design:

a. A quantitative-experimental approach, used to measure the influence of assignment design or learning models on the improvement of CMR (e.g. (Jonsson et al., 2016; Lithner, 2017).

b. A qualitative-descriptive approach or case study is used to understand students' creative reasoning processes in depth through classroom interaction and technology-assisted exploration (Masfingatin & Murtafiah, 2020; Sjaastad, 2025).

In addition, the integration of mixed methods has begun to emerge, that combines quantitative analysis of learning outcomes with process-based qualitative data. This pattern shows a shift from validating effectiveness to understanding the creative thinking process, marking the development of a new direction in CMR research.

3. Focus and Variables Studied

All studies refer to the three main indicators of CMR developed by Lithner (2008), namely novelty, plausibility, and mathematical foundation. However, the context of the research focus varies:

a. Individual level: examines the differences in CMR skills between students.
b. Task level: researching the design of a problem or mathematical task that encourages the emergence of CMR.
c. Pedagogical level: reviewing teacher-student interaction and technology-based learning design that supports CMR.

National research tends to add affective aspects, such as adversity (Hidayat, 2017; Hidayat et al., 2018), thereby expanding the scope of dimensions that have not been widely studied in the global literature.

4. Key Findings

a. The synthesis shows that CMR can thrive when students engage in open-ended tasks, have moderate cognitive challenges, and are given space for reflection on non-algorithmic solutions.
b. Teachers play an important role in balancing the provision of instruction and student autonomy.
c. Technology-supported research confirms that dynamic visualization can trigger novel reasoning paths and help validate solutions through multiple representations.

Indonesian studies show that the integration of project-based learning and ADI is effective in encouraging students to take intellectual risks, which is a core characteristic of CMR.

5. Methodological Gap

This review identifies a major methodological gap in CMR research, namely the fragmentation between quantitative and qualitative research traditions. International studies (Jonsson et al., 2016, 2020, 2022) are predominantly characterized by experimental and quasi-experimental designs that evaluate the effects of CMR on learning outcomes, retention, and knowledge transfer. In contrast, qualitative studies such as Hershkowitz et al. (2017) and Granberg & Olsson (2015) provide rich descriptions of

students' reasoning processes, classroom interactions, and the role of technological support in facilitating CMR.

This methodological divergence reflects two complementary but largely disconnected research orientations: one seeks to determine whether CMR improves learning outcomes, whereas the other aims to understand how CMR emerges during mathematical activity. The predominance of these separate approaches has limited the development of comprehensive evidence capable of simultaneously explaining learning effectiveness and the mechanisms underlying students' reasoning. Similar concerns have been raised in mathematics education research, where instructional effectiveness and learning processes have often been investigated independently rather than within an integrated research framework (Cobb et al., 2003).

The findings of this review therefore suggest the need for more integrative methodological approaches that connect instructional interventions, students' reasoning processes, and learning outcomes within a coherent research design. Such approaches should combine iterative refinement of instructional practices with process-oriented analyses and rigorous empirical evaluation, enabling researchers to investigate not only whether CMR is effective but also how and why CMR develops across different learning contexts (Cobb et al., 2003; McKenney & Reeves, 2019).

Notably, none of the eleven reviewed studies adopted such an integrative methodological perspective. Most studies focused either on evaluating post-intervention outcomes or on describing students' reasoning processes without systematically linking these dimensions. Consequently, future CMR research should move beyond methodological dichotomies by integrating outcome evaluation with analyses of cognitive, social, and contextual processes that shape the development of CMR.

6. Population Gap

The limitations of the study population are also evident. Most international research focuses on secondary school students in Sweden (e.g., Jonsson et al., 2016-2022), while local contexts outside of Europe are still underrepresented. National research in Indonesia (Hidayat, 2017; Masfingatin et al., 2020; Masfingatin & Murtafiah, 2020) has expanded the scope of the subject to prospective teachers and high school students, but the number is still limited, and the cultural context has not been widely compared.

In fact, as stated by Lithner (2008), the novelty and plausibility nature of reasoning are very contextual, depending on the background of the learning experience and discursive norms in the classroom. In the Indonesian context that tends to emphasize

proceduralism, the opportunity to foster creative reasoning can differ from the more constructivist Scandinavian context. Therefore, cross-cultural and cross-level research (from primary school to higher education) is important to explore the validity of CMR indicators in diverse learning situations.

In addition, there has been no research involving prospective teachers as CMR facilitators, even though Leikin (2014) emphasized that mathematical creativity in learning does not only lie in students, but also in the ability of teachers to design and assess non-conventional ideas. Thus, the study in the context of mathematics teacher education will be a strategic step to expand the scope of the population and deepen the understanding of the ecology of CMR learning.

7. Instrument and Measurement Gap

Most studies use outcome-based instruments such as written tests, transfer tests, or retention (Jonsson et al., 2016, 2020). This kind of approach assesses the CMR product, not the reasoning process itself. This is a fundamental limitation because CMR is dynamic, evolutionary, and contextual.

Researchers such as (Kanlı, 2020; Mumford et al., 1997; Suherman & Vidákovich, 2022) have emphasized the need for process-based assessments to understand CMR. Recent research by (Liljedahl et al., 2016) even shows that indicators of mathematical creativity are often seen in non-linear activities such as exploration, revision of ideas, and spontaneous reflection-aspects that cannot be captured through conventional tests.

In this context, several national studies (Masfingatin et al., 2020; Masfingatin & Murtafiah, 2020) have taken important steps by using observation, student work, and self-reflection as alternative instruments to observe the CMR process. This strategy is in line with the process-oriented assessment approach recommended by (Leikin & Tovli, 2014).

Furthermore, technology integration is a strategic opportunity to overcome the limitations of process-based assessment for CMR skills (Granberg & Olsson, 2015; Santos-Trigo, 2023). In line with Granberg & Olsson (2015), the use of GeoGebra can serve a dual function: as a learning medium and at the same time a tool to document students' thinking processes (digital trace data). This approach is also supported by Blikstad-Balas & Sørvik (2015), who state that digital data is able to record the dynamics of students' thinking in real-time and authentically, thus potentially producing more accurate and contextual CMR evaluation instruments.

8. Implications of Further Research

The findings of this review suggest several priorities for advancing CMR research.

a. Methodological implications. Future studies should adopt more integrative research approaches that connect instructional interventions, students' reasoning processes, and learning outcomes within a coherent research framework (Cobb et al., 2003; McKenney & Reeves, 2019).
b. Instrument implications. More process-oriented assessment instruments are needed to capture the dynamics of creative mathematical reasoning through multiple sources of evidence, such as think-aloud protocols, classroom observations, video analysis, and digital learning traces (Granberg & Olsson, 2015; Lithner, 2017).
c. Population implications. Future research should expand to more diverse educational levels, learner populations, and cultural contexts to examine the applicability of CMR across different educational systems.
d. Pedagogical implications. Future studies should further investigate how inquiry-oriented instructional approaches and innovative classroom practices can foster students' CMR in authentic learning environments.

Overall, these recommendations reinforce the need for more integrated, process-oriented, and context-sensitive CMR research to strengthen both theoretical understanding and educational practice.

9. Final Synthesis

Overall, the reviewed studies indicate that CMR research has evolved along two complementary yet fragmented trajectories. International studies predominantly employ rigorous quantitative and quasi-experimental designs to evaluate the effectiveness of CMR on learning outcomes, retention, and knowledge transfer, whereas Indonesian studies contribute richer descriptions of instructional implementation and students' reasoning processes through qualitative and exploratory approaches. Although these two research traditions provide valuable insights, they have largely developed independently, resulting in limited integration between evidence of learning outcomes and explanations of how CMR develops during mathematical activity.

The geographical concentration of CMR research in Scandinavia is closely related to the historical development of the CMR framework itself. The theoretical foundations of CMR were established and extensively developed by Lithner and his research group in Sweden (Lithner, 2008, 2017), making Scandinavia the primary center for both conceptual development and empirical validation. Furthermore, mathematics education in Nordic countries has long emphasized conceptual understanding, problem solving, mathematical justification, and inquiry-oriented learning, creating an educational

environment that supports the implementation and evaluation of CMR (Niss & Højgaard, 2019; OECD, 2023). Consequently, most Scandinavian studies have focused on experimentally examining the effectiveness of CMR through standardized learning outcomes and transfer measures, thereby producing strong empirical evidence regarding its instructional benefits.

In contrast, Indonesian research has primarily focused on adapting CMR to local educational contexts through innovative instructional models such as Argument-Driven Inquiry (Hidayat, 2017) and Discovery Learning (Masfingatin & Murtafiah, 2020). This tendency likely reflects the relatively recent adoption of the CMR framework in Indonesian mathematics education research, where greater attention has been devoted to understanding students' reasoning processes and exploring classroom implementation before conducting large-scale empirical validation. Consequently, Indonesian studies provide important contextual and pedagogical insights but generally involve limited samples and exploratory designs, restricting the generalizability of their findings.

The synthesis also reveals that the identified methodological, population, and instrument gaps are closely interconnected. The predominance of quantitative studies has generated substantial evidence regarding the effectiveness of CMR but has provided limited explanations of how students construct novel, plausible, and mathematically grounded reasoning during learning. Conversely, qualitative studies have successfully documented the dynamics of students' reasoning processes but often lack broader empirical validation. Similarly, the geographical concentration of studies within Scandinavian contexts limits the applicability of existing findings across different educational systems and cultural settings, while the continued reliance on outcome-based assessments restricts understanding of the reasoning processes that constitute the essence of CMR.

These findings suggest that future CMR research should adopt more integrative methodological approaches capable of linking learning processes, instructional contexts, and learning outcomes within a coherent research framework. Rather than examining these dimensions separately, future studies should integrate iterative refinement of instructional interventions with process-oriented analyses and rigorous empirical evaluation (Cobb et al., 2003; McKenney & Reeves, 2019). Such integration would enable researchers not only to determine whether CMR is effective, but also to explain how and why CMR develops across diverse educational contexts.

Ultimately, the methodological fragmentation identified in this review should be viewed not merely as a technical limitation but as an epistemological challenge concerning how CMR is conceptualized, investigated, and assessed. Addressing this challenge requires future studies to integrate methodological rigor, contextual diversity, and process-oriented assessment so that a more comprehensive understanding of CMR can be developed. Such efforts are expected to strengthen both the theoretical foundation of CMR research and its contribution to achieving equitable and high-quality mathematics education in line with Sustainable Development Goal 4 (Quality Education).

CONCLUSION

This systematic literature review aimed to identify research trends, methodological patterns, and research gaps in Creative Mathematical Reasoning (CMR) studies published between 2014 and 2025. Through a PRISMA-guided review of eleven eligible studies, the findings reveal that CMR research has developed along two complementary yet fragmented trajectories. International studies are predominantly characterized by quantitative and quasi-experimental approaches focusing on learning outcomes and knowledge transfer, whereas Indonesian studies primarily emphasize the exploration of students' creative reasoning processes through qualitative and pedagogical investigations.

The synthesis identified three major research gaps. First, a methodological gap remains evident due to the separation between outcome-oriented quantitative studies and process-oriented qualitative investigations. Second, a population gap persists because empirical evidence is concentrated in Scandinavian contexts, with limited representation from other educational systems and cultural settings. Third, an instrument gap was identified, as most studies continue to assess learning outcomes rather than the dynamic processes through which students construct novel, plausible, and mathematically grounded reasoning. These findings indicate that, despite the well-established theoretical foundation of CMR, its empirical investigation remains methodologically and contextually fragmented.

This review contributes to the CMR literature by providing a comprehensive synthesis of methodological characteristics, research contexts, and assessment practices across previous studies. Rather than merely summarizing existing evidence, this review demonstrates how methodological orientation, participant characteristics, and assessment approaches collectively shape current knowledge of CMR. The findings highlight the need for more integrative research approaches capable of linking instructional contexts, reasoning processes, and learning outcomes while expanding investigations across diverse educational

and cultural settings. Such efforts are expected to strengthen both theoretical understanding and practical implementation of CMR in mathematics education.

Several limitations should be acknowledged. The review synthesized eleven studies that met the predefined eligibility criteria, which may limit the generalizability of the findings. In addition, the reviewed literature was dominated by studies conducted in Scandinavia and Indonesia, leaving many educational contexts underrepresented. Future research should therefore involve broader cross-cultural investigations, develop process-oriented assessment instruments, and employ integrative methodological approaches that capture both the development and effectiveness of creative mathematical reasoning. These directions are expected to support more inclusive and high-quality mathematics education, consistent with Sustainable Development Goal 4 (Quality Education).

DECLARATIONS

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