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Mathematical Creativity in Secondary Education: Conceptual and Assessment Evolution (2016-2025)

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ABSTRACT

Mathematical creativity is increasingly recognized as an essential competency in 21st-century mathematics education, as it underpins students' capacity for higher-order thinking and adaptive problem-solving. However, existing studies have examined it in isolation without integrating publication trends, conceptual evolution, and assessment methods within a unified analytical framework. This study addresses that gap through a systematic literature review of mathematical creativity in secondary education from 2016 to 2025. Following the PRISMA 2020 guidelines, searches were conducted in the Scopus and ScienceDirect databases. From 544 initial records, 23 articles met eligibility criteria and were analyzed through bibliometric analysis, thematic synthesis, and methodological categorization. Results revealed a substantial increase in publications, with 68.9% of studies published during 2023–2025, driven by curriculum reforms, technology integration, and post-pandemic pedagogical transformation. Conceptualization evolved from Torrance's traditional four-component framework toward more integrative models emphasizing collaborative processes and contextual problem-solving. Assessment methods showed balanced distribution: quantitative tests (39.1%), qualitative approaches (34.8%), and mixed methods (26.1%). Practically, the findings offer actionable guidance for curriculum developers, teachers, and policy makers to foster mathematical creativity more effectively, while theoretically, the holistic integration of three analytical dimensions provides a replicable model for future systematic reviews in mathematics education.

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1. INTRODUCTION

Mathematical creativity has emerged as a fundamental competency in 21st-century mathematics education. As technology and artificial intelligence continue to reshape the demands of the modern workforce, the ability to think creatively in mathematics has become essential for all learners. Mathematical creativity encompasses the dimensions of fluency, flexibility, originality, and elaboration [1], and has been recognized as a learning objective in various international curricula [2].

In Indonesia, the Merdeka Curriculum, implemented since 2022, explicitly positions creativity as a core competency in mathematics learning. However, international assessment results such as PISA indicate that Indonesian students' achievement in mathematics remains below the global average [3]. This suggests a gap between curriculum objectives and actual classroom achievement, necessitating further examination of how mathematical creativity is conceptualized and measured in learning practice.

From a pedagogical perspective, transforming learning approaches is key to optimizing the development of students' mathematical creativity. Mathematics education experts emphasize the importance of shifting from teacher-centered to more actively engaging models in knowledge construction. A meta-analysis conducted by Salgado and Salinas [4] examined the effectiveness of learning interventions in developing students' mathematical creativity across various educational levels. These findings confirm that mathematical creativity is a competency that can be systematically developed through planned, measured instructional design rather than an ability that forms incidentally.

Previous research has explored mathematical creativity from multiple perspectives, each contributing valuable yet partial insights. Maulidia et al. [5] investigated how problem-based learning facilitates the emergence of creative thinking among secondary students, finding that structured tasks effectively stimulate creative problem-solving. Norqvist et al. [6] employed eye-tracking methodology to compare algorithmic and creative reasoning strategies, revealing that students who engaged in creative reasoning demonstrated stronger long-term retention than those relying on algorithmic approaches. Zainudin et al. [7] focused on the psychometric dimension by developing and validating a mathematical creativity instrument using confirmatory factor analysis, resulting in a valid, unidimensional measurement tool. More recently, Yuliardi et al. [8] developed a STEM-based digital learning platform and demonstrated its effectiveness in enhancing students' mathematical creativity and autonomous learning, while Hidajat et al. [9] showed that guided discovery learning integrated with digital technology significantly improved creative outcomes.

Beyond individual empirical studies, several systematic reviews have also examined aspects of mathematical creativity. Joklitschke et al. [10] reviewed how mathematical creativity has been conceptualized across mathematics education research, revealing a shift from product-oriented toward process-oriented perspectives. Saefudin et al. [11] mapped bibliometric trends in mathematical creativity research over two decades, identifying Indonesia and Turkey as emerging contributors to the field. Bicer [12] reviewed instructional practices that foster mathematical creativity, demonstrating that student-centered approaches consistently yield stronger creative outcomes. Despite these efforts, none has simultaneously integrated publication trends, conceptual evolution, and assessment methods within a unified analytical framework. This study addresses that gap directly.

Major transformations in educational practice marked the decade from 2016 to 2025. Curriculum policy revisions across countries, increased use of technology in learning, and the

COVID-19 pandemic have significantly altered how mathematical creativity is understood, taught, and evaluated. These contextual shifts underscore the importance of a comprehensive and up-to-date review of how the field has evolved across all three dimensions.

This study aims to address this gap through a systematic literature review of mathematical creativity in secondary education during 2016-2025. The novelty of this research lies in the holistic integration of three analytical dimensions (publication trends, conceptualization, and assessment methods) that have not been undertaken in previous studies. Theoretically, this study contributes to understanding mathematical creativity as an evolving multidimensional construct. In practice, the findings are expected to guide curriculum developers and practitioners in designing more effective strategies to foster students' mathematical creativity. Three research questions are formulated: (1) What are the publication trends in mathematical creativity research in secondary education from 2016 to 2025? (2) How has the conceptualization of mathematical creativity evolved during this period? (3) What methods have been used to measure mathematical creativity during 2016-2025?

2. METHOD

This study employed a systematic literature review approach following the PRISMA 2020 guidelines to ensure a systematic, transparent, and replicable review process[13].

2.1 Search Strategy

Literature searches were conducted in December 2025 using two primary databases, Scopus and ScienceDirect, selected for their coverage of leading journals in mathematics education [14]. The search was limited to publications from 2016 to 2025 in accordance with the scope of this research.

To identify relevant articles, the search string used was TITLE-ABS-KEY ("mathematical creativity" OR "creative thinking in mathematics" OR "creativity in mathematics") AND ("secondary education" OR "high school" OR "middle school" OR "junior high school"), with filters for social sciences and mathematics subject areas, journal article document type, and English language. This search yielded 544 records: 344 from Scopus and 240 from ScienceDirect.

2.2 Inclusion and Exclusion Criteria

The criteria used to determine study eligibility for inclusion in this review are summarized in Table 1. Article selection followed the four stages of the PRISMA 2020 framework. In the identification stage, 544 records were retrieved from Scopus (n=344) and ScienceDirect (n=240). After applying database filters and removing 2 duplicates via Mendeley, 219 records were imported into Rayyan for screening. At the screening stage, 74 records were excluded based on title and abstract review, and 77 reports were inaccessible, leaving 68 reports for eligibility assessment. At the eligibility stage, 45 reports were excluded: inappropriate population (n=22), systematic reviews (n=12), not specifically addressing mathematical creativity (n=8), inappropriate outcomes (n=2), and not openly accessible (n=1). Finally, 23 studies met all inclusion criteria and were incorporated into the review.

Table 1. Inclusion and Exclusion Criteria for Literature Selection

Criteria Type	Description
	Inclusion Criteria (IC)
IC1	Journal articles that have gone through peer review
IC2	Focus on mathematical creativity as a primary topic.
IC3	Involves secondary education (age 12-18 years)
IC4	Published in English
IC5	Published between 2016 and 2025
IC6	Using empirical, substantial or conceptual data analysis
	Exclusion Criteria (EC)
EC1	Conference papers, books, book chapters, dissertations
EC2	Just briefly mentioning creativity without substantial focus.
EC3	Focus on non-secondary education levels.
EC4	Full text is not accessible.
EC5	Article type other than journal article (e.g., proceedings, book chapters)
EC6	*Literature review*, meta-analysis, and bibliometric analysis

2.3 Data Extraction

10

The overall article selection process followed the PRISMA 2020 flow diagram presented in Figure 1 below.

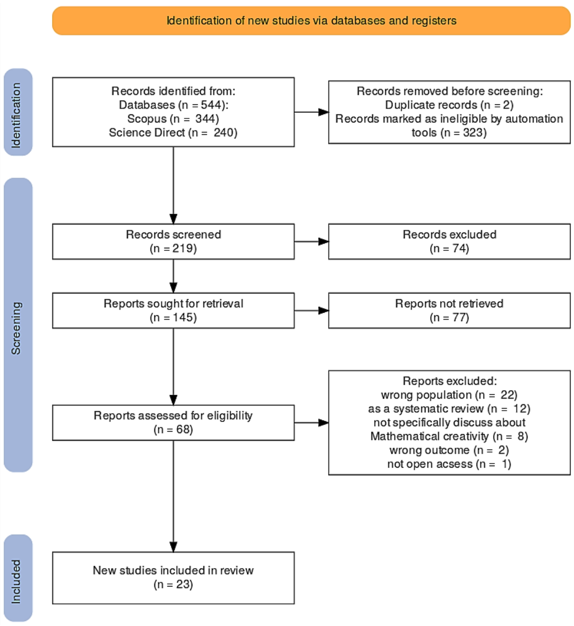

Figure 1. PRISMA 2020 Flow Diagram for Literature Selection

Upon inclusion, each of the 23 studies was read in full and analyzed individually to ensure a thorough understanding of its content, context, and findings. Data were then extracted using a previously developed standardized form that covered author identity, research country, research design, number of participants, conceptualization of mathematical creativity, measurement methods, main findings, and pedagogical implications. This extraction process was carried out systematically to ensure consistency and completeness across all included studies.

2.4 Data Analysis

Data analysis was conducted using content analysis and thematic synthesis approaches. Researchers read each article repeatedly to identify emerging patterns and themes, then conducted an inductive review and grouped them into broader themes. Analysis reliability was maintained through a coding process in which the primary author conducted initial coding, which was then reviewed and verified by the three other authors. Any disagreements were resolved through collaborative discussion among all four authors, and findings were triangulated with existing mathematical creativity theory. To answer RQ1, descriptive analysis using frequency and percentage calculations was applied to examine publication trends and year-by-year distribution, as well as the geographic distribution of research. To answer RQ2, a thematic synthesis was used to identify the evolution of the conceptualization of mathematical creativity over time. To answer RQ3, content analysis was applied to classify and analyze the assessment methods used in each study.

3. RESULTS AND DISCUSSION

3.1. Results

Based on the analysis of 23 studies that met the inclusion criteria, several key findings were identified that address the three research questions.

3.1.1. Publication Trends in Mathematical Creativity Research (RQ1)

Publication Distribution

The publication distribution shows an increasing trend, with fluctuations, over the last decade (2016-2025). The year-to-year publication distribution pattern is shown in Figure 2.

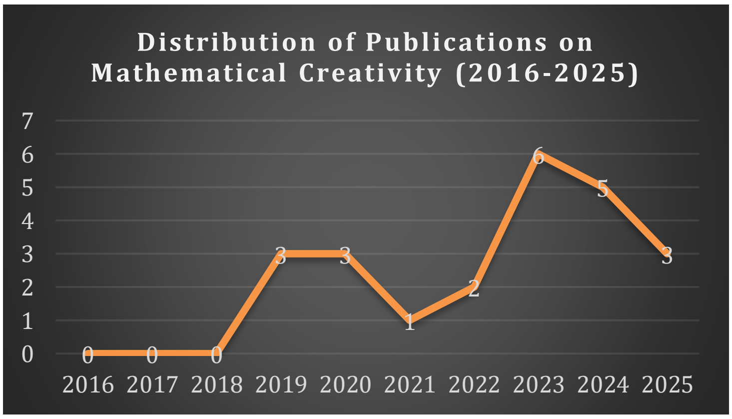

Figure 2. Distribution of Publications on Mathematical Creativity (2016-2025)

Publication trends during the 2016-2025 decade show an interesting pattern. The early period (2016-2018) yielded no publications meeting the strict criteria of this review, indicating that research on mathematical creativity in secondary education remained limited during that period.

Significant growth began in 2019 with 3 publications (13.0%). The 2019-2020 period showed consistency, with 3 publications per year. In 2021, publications declined to 1 (4.3%), possibly due an the COVID-19 pandemic, which disrupted research and publication processes.

The publication peak occurred in 2023 with 6 publications (26.1%), reflecting the post-pandemic period where innovative learning approaches became a priority. The year 2024 maintained high momentum with 5 publications (21.7%), and 2025 shows 3 publications (13.0%) through the end of December.

Geographic Distribution

The analyzed studies originated from various countries, with the highest concentration in Asia. The geographic distribution of research is shown in Table 2.

Table 1. Geographic Distribution of Mathematical Creativity Studies (2016-2025)

Region	Country	Number of Studies	Percentage
Asian	Indonesia (4), Malaysia (2), Japan (1), Turkey (2), Thailand (1)	10	43,5%
Europe	UK(2), Germany (2), Spain (1), Netherlands (1), Czech Republic (1)	7	30,4%
Americas	United States (2), Brazil (1), Chile (1)	4	17,4%
Middle East	Jordan (1), Israel (1)	2	8,7%

Based on Table 2, the 23 included studies originated from 14 countries across four regions. Asia accounted for the highest proportion, with 10 studies (43.5%), led by Indonesia (4 studies), followed by Turkey, Malaysia, Japan, and Thailand. Europe ranked second with 7 studies (30.4%), primarily from the UK and Germany. The Americas contributed 4 studies (17.4%), and the Middle East contributed 2 studies (8.7%). The dominance of research from the Asian region (43.5%) reflects serious attention to mathematics education reform in developing countries seeking to increase competitiveness by developing higher-order thinking skills. Europe ranks second with 30.4% (7 studies), indicating that mathematical creativity research is also a priority in countries with strong educational research traditions.

3.1.2. Evolution of Mathematical Creativity Conceptualization (RQ2)

Thematic analysis identified three phases of conceptual evolution of mathematical creativity during the last decade (2016-2025). The development of conceptualization shows a significant shift from classical to more integrative models, summarized in Table 3.

Table 2. Evolution of Mathematical Creativity Conceptualization in Three Phases (2016-2025)

Phase	Period	Main Focus	Emphasized Dimensions	Key Studies
Phase 1	2016-2020	Classical Theoretical Foundation	Cognitive (Fluency, Flexibility, Originality, Elaboration)	[5], [6], [7]
Phase 2	2021-2022	Affective & Contextual Integration	Cognitive + Affective (Motivation, Attitude, Confidence) + Contextual (Culture, Teacher)	[15], [16], [17]
Phase 3	2023-2025	Integrative & Technological Model	Cognitive + Affective + Metacognitive + Social + Technological	[8], [18], [19], [20], [21]

Based on Table 3, the conceptualization of mathematical creativity underwent three distinct phases of evolution between 2016 and 2025. In Phase 1 (2016–2020), studies predominantly adopted Torrance's classical four-component framework, focusing on cognitive dimensions such as fluency, flexibility, originality, and elaboration. Phase 2 (2021–2022) marked a shift toward affective and contextual integration, incorporating dimensions such as motivation, attitude, confidence, and sociocultural factors. Phase 3 (2023–2025) saw the emergence of fully integrative and technological models that simultaneously encompass cognitive, affective, metacognitive, social, and technological dimensions. This progression reflects a broadening understanding of mathematical creativity as a multidimensional construct shaped by context, interaction, and technology.

3.1.3. Assessment Methods for Mathematical Creativity (RQ3)

Analysis of the 23 studies identified significant evolution in mathematical creativity assessment methods, which can be categorized into three main approaches. The classification of assessment methods is shown in Table 4.

Table 3. Classification of Mathematical Creativity Assessment Methods

Assessment Approach	**Number of Studies**	**Methods Used**	**Key Studies**
Traditional Quantitative	9	Standardized instruments, rubrics, creativity tests, statistical analysis (t-test, ANOVA, regression, CFA)	[6], [7], [16], [17], [22]
Exploratory Qualitative	8	Case studies, content analysis, interviews, observations, eye-tracking, stimulated recall	[5], [15], [23], [24], [25]
Integrative Mixed Methods	6	SNA, design research, DDR, combined qualitative-quantitative approaches	[8], [9], [20], [26]

Based on Table 4, mathematical creativity assessment methods across the 23 studies were distributed across three main approaches. Traditional quantitative methods were the most commonly used, applied in 9 studies (39.1%), and included standardized instruments, rubrics, and statistical analyses such as t-tests, ANOVA, regression, and CFA. Exploratory qualitative approaches were used in 8 studies (34.8%), utilizing case studies, interviews, observations, and eye-tracking. Integrative mixed-methods were applied in 6 studies

2

(26.1%), combining social network analysis, design research, and qualitative and quantitative approaches. This distribution indicates that while quantitative approaches remain dominant, there is a growing recognition of the need for more exploratory and integrative methods to capture the full complexity of mathematical creativity. The analysis identified several emerging trends in mathematical creativity assessment over the last decade, summarized in Table 5.

Table 4. Emerging Trends in Mathematical Creativity Assessment (2016-2025)

Trend	Description	Technology/Methods Used	Implications
Technology-Based Assessment	Use of digital tools to capture and analyze creative processes	Digital platforms [8], Eye-tracking [24], SNA [26]	More comprehensive data collection, real-time process tracking
Authentic Task-Based Assessment	Use of real-world and contextual tasks to elicit creativity	STEAM activities [21], Open tasks [25], Fermi problems [27]	Higher ecological validity, meaningful engagement
Process-Oriented Assessment	Focus on creative thinking processes rather than just final products	Qualitative analysis, think-aloud protocols, stimulated recall interviews	Deeper understanding of cognitive mechanisms
Multidimensional Assessment	Measuring cognitive, affective, metacognitive, and social dimensions simultaneously	Mixed methods design, integrated frameworks	Holistic understanding of mathematical creativity

Based on Table 5, four major emerging trends were identified in mathematical creativity assessment. First, technology-based assessment is increasingly adopted through digital platforms, eye-tracking, and social network analysis, enabling real-time process tracking and more comprehensive data collection. Second, authentic task-based assessment uses contextual and real-world tasks, such as STEAM activities, open-ended tasks, and Fermi problems, offering greater ecological validity and meaningful student engagement. Third, process-oriented assessment shifts the focus from final products to creative thinking processes, employing qualitative methods such as think-aloud protocols and stimulated recall interviews to uncover cognitive mechanisms. Fourth, multidimensional assessment integrates cognitive, affective, metacognitive, and social dimensions simultaneously through mixed methods designs, providing a holistic understanding of mathematical creativity. Together, these trends reflect a paradigm shift toward more authentic, contextual, and comprehensive approaches to assessing mathematical creativity. To provide a comprehensive overview of all studies examined, Table 6 presents detailed summaries of the 32 23 studies that met the inclusion criteria. The table covers each study's author, year, method, main results, and conclusion, offering a systematic basis for the thematic and methodological analysis discussed in subsequent sections.

Table 5. Summary of Included Studies on Mathematical Creativity (2016-2025)

No	Author	Year	Method	Main Results	Conclusion
1	[23]	2024	Qualitative	Students showed variation in creativity aspects; the majority had a preference for problem-solving	Structured tasks are effective in stimulating creative thinking. Task diversification is needed.
2	[26]	2023	Mixed methods	Digital tools recorded the creative design process; social creativity was identified; SNA metrics operationalized four Torrance dimensions.	SNA is effective in depicting social creativity. This methodology expands research perspectives.
3	[27]	2023	Quantitative	Strong correlation between Fermi problems and mathematical creativity (r=0.76); moderate correlation with psychology (r=0.47)	Fermi problems are effective tools for measuring creativity.
4	[9]	2023	Quantitative	Learning has significant effect (F=34.897; p=0.000); self-regulated learning (t=2.782); guided discovery (t=2.566)	Digital technology learning has a significant positive impact on creativity.
5	[22]	2024	Quantitative	Only 5.9% of students had high creativity; moderate positive correlation (r = 0.504); students with music training were more creative.	Music training has a positive impact. Integration of music into the curriculum is needed.
6	[15]	2021	Qualitative	Teachers' beliefs influence practice; 6 approaches were identified; creativity assessment becomes a barrier.	Teachers need support in creativity assessment.
7	[24]	2020	Qualitative	Students identified 3 solutions from 7 approaches; existing models do not fully capture students' processes.	Existing creative process models have not captured the nuances of students' processes.
8	[8]	2024	Mixed methods	STEM-based DLS well validated; moderate improvement (Ng=0.554); learning autonomy has significant effect	The DLS platform is effective in enhancing creativity and autonomous learning.
9	[25]	2025	Qualitative	Students showed variation in 4 components; collaboration influences knowledge expression.	Open-ended tasks are effective for students with learning disabilities.
10	[28]	2020	Qualitative	Students developed recursive rules; 2 algebraic generalization rules were constructed.	The PMMT model integrates ATD and mathematical creativity.
11	[29]	2023	Qualitative	9 connection tools identified; students who made connections were more creative	Mathematical connection tools are effective in enhancing creativity

No	Author	Year	Method	Main Results	Conclusion
12	[20]	2025	Mixed methods	Learning barriers in quadrilaterals identified; puzzles are effective; 7 frameworks developed.	Interactive manipulatives are effective in overcoming barriers.
13	[21]	2025	Mixed methods	STEAM-geometry activities validated as effective; enhanced critical thinking and creativity	STEAM-geometry activities with EDP are effective in enhancing creativity.
14	[5]	2019	Qualitative	3 highly creative groups (level 4); variability in problem-solving ideas	The PBL model is effective in fostering creativity
15	[6]	2019	Quantitative	CMR group superior in post-test; AR group better during practice	Creative tasks are more effective than algorithmic tasks
16	[16]	2022	Quantitative	Gifted students scored higher on 5 sub-dimensions; gifted female students excelled.	Educational environment and family support play important roles.
17	[30]	2023	Quantitative	The majority of students struggled to conclude that there is a relationship between cognitive flexibility and figure understanding.	Auxiliary lines are effective in stimulating geometric creativity.
18	[18]	2024	Quantitative	Creative self-confidence explained 20% of variance; self-assessed creativity is a significant predictor.	Only self-assessed creativity is a significant predictor.
19	[19]	2024	Quantitative	A positive attitude has a significant effect ($\beta = 0.10$); ethnic identity mediates the relationship.	Cultural factors and identity need to be considered.
20	[17]	2022	Quantitative	General ability has a significant effect; mathematical expertise has a lower effect; contextual representation is effective.	Task representation influences the creativity level.
21	[7]	2019	Quantitative	15 instrument items valid and unidimensional; model fit (RMSEA=0.059)	Valid instrument for measuring mathematical creativity
22	[31]	2025	Qualitative	Understanding of creativity improved; teachers still struggle to promote originality and elaboration.	Continuous support for teachers is needed.
23	[32]	2020	Qualitative	Lack of creativity among Malaysian students; inconsistent TIMSS performance	The education system needs to shift from rote learning to creative learning.

As shown in Table 6, the 23 included studies span a range of methodological approaches, geographic contexts, and conceptual frameworks. The diversity of findings across these studies forms the empirical basis for the thematic analysis presented in the Discussion section below.

3.2. Discussion

3.2.1. Publication Surge as Response to Curriculum Reform

The concentration of publications in the 2023-2025 period (68.9%) indicates a significant shift in research on mathematical creativity in secondary education. This finding differs from the even distribution pattern reported by Salgado and Salinas [4] for the 2010-2020 period, suggesting that mathematical creativity at the secondary level has only become a primary research focus in the last three years.

This surge in publications can be understood as a collective response from the research community to waves of curriculum reform occurring almost simultaneously across various countries. The implementation of Indonesia's Merdeka Curriculum (2022), Malaysia's Education Blueprint revision (2018), and Thailand's curriculum renewal (2021) share a fundamental commonality: a shift from procedural learning toward the development of higher-order thinking skills. The time gap between policy implementation and the publication peak in 2023 reflects the natural cycle of educational research. Researchers need time to design interventions, collect data, and publish findings.

The dominance of research from Asia (43.5%) reveals dynamics that go beyond mere publication numbers. Countries in this region face dual challenges: improving the quality of mathematics learning while addressing achievement gaps with developed nations. PISA results consistently place Southeast Asian students below the OECD average. This context creates urgency to identify learning approaches that can systematically develop mathematical creativity.

Meanwhile, research from Europe (30.4%) tends to explore more fundamental cognitive and metacognitive aspects. This reflects a more established research tradition and access to a more complete research infrastructure. There is an interesting difference in research orientation between the two regions. Studies from Asia generally test the effectiveness of specific learning models, media, or strategies in enhancing creativity. Conversely, European research is more exploratory, seeking to understand cognitive mechanisms and the factors influencing creativity. This difference reflects not only research priorities but also the developmental stage of mathematical creativity research in both regions.

3.2.2. Expanding Understanding: From Cognitive Ability to Multidimensional Construct

The evolution of the conceptualization of mathematical creativity over the last decade has been gradual and systematic. The early phase (2016-2020) was dominated by classical perspectives viewing creativity as an individual cognitive ability. Torrance's framework, with its four components (fluency, flexibility, originality, and elaboration), became the primary reference. Although this framework provided a clear structure for measurement, it ignored the complexity of mathematical creativity as a phenomenon that occurs in specific contexts.

Criticism of this overly narrow view triggered a shift in Phase 2 (2021-2022) by incorporating affective and contextual dimensions. Bereczki and Kárpáti [15] demonstrated that intrinsic motivation and confidence are not merely supporting factors but inseparable parts of mathematical creativity itself. Students with high cognitive ability but low creative confidence often fail to demonstrate their potential. Keleş's [16] finding that family support and educational environment significantly contribute to creativity reinforces the argument that creativity cannot be understood apart from its sociocultural context.

Phase 3 (2023-2025) marks the emergence of integrative models that synthesize previous developments. These models recognize mathematical creativity as a multidimensional construct that involves dynamic interactions among cognitive abilities, affective attitudes, self-regulation, social processes, and technology use. Yuliardi et al. [8] demonstrated that digital learning platforms are not merely tools but can fundamentally shape interaction and exploration patterns distinct from those in conventional learning.

25 Suherman and Vidákovich's [19] findings on the role of ethnic identity as a mediator of the attitude-creativity relationship reveal a previously neglected dimension. How students' sociocultural identity shapes their understanding and expression of mathematical creativity becomes an important question. This challenges assumptions that creativity is universal and raises questions about the validity of existing measurement instruments when used cross-culturally.

This transformation of understanding has important implications. If mathematical creativity is understood as the result of interaction between individuals and their environment, then development efforts cannot be conducted by focusing solely on cognitive aspects. Learning needs to be designed as a system that simultaneously develops cognitive competencies, builds positive attitudes, trains self-regulation, encourages collaboration, and integrates technology meaningfully.

3.2.3. Diversity of Assessment Methods and Validity Challenges

Mathematical creativity assessment methods exhibit diversity, reflecting a tension between standardized measurement traditions and authentic assessment demands. The persistence of traditional quantitative approaches (39.1% of studies) indicates that written tests remain the primary means of measuring mathematical creativity. Instruments such as those developed by Zainudin et al. [7] offer practical advantages that cannot be ignored: standardization, assessment objectivity, and the ability to compare across groups.

However, the validity of written tests is increasingly questioned. If mathematical creativity involves exploration, iterative refinement, and collaboration (as demonstrated by qualitative research), then tests that measure final results in a limited time capture only a small portion of what should be measured. Moreover, written tests tend to favor students who think and write quickly, while students with different thinking styles, such as those who need more time for deep thinking or who are more creative when working in groups, may not be identified.

Exploratory qualitative approaches (34.8% of studies) offer access to dimensions that written tests cannot measure. Eye-tracking technology used by Schindler and Lilienthal [24] showed that open-ended group tasks enable students with learning disabilities to express mathematical creativity undetected through conventional tests.

The strength of qualitative approaches lies in their ability to capture thinking processes rather than just final results. However, challenges of inter-rater reliability and generalization remain serious limitations. Although some studies report Cohen's kappa values between 0.72 and 0.85, achieving this requires significant investment in assessor training and in the development of detailed assessment protocols. Zioga and Desli's [31] finding that teachers struggle to recognize and facilitate students' mathematical creativity shows that large-scale implementation of qualitative assessment faces significant human resource capacity constraints.

Mixed methods (26.1% of studies) emerge as an answer to the limitations of both previous approaches. Mathematical creativity, as a complex construct, requires multiple methods to be fully understood. Yuliardi et al. [8] demonstrate that combining pre-post tests to measure improvement, observations to track processes, and interviews to uncover the reasoning behind answers produces a far richer understanding than using a single method alone.

Digital technology integration opens new opportunities in creativity measurement. Bokhove et al. [26] used social network analysis to map creative collaboration patterns. This research revealed that students' positions in collaborative networks can predict their creative contributions. Digital platforms enable highly detailed data recording. Every click, every attempt, every revision is recorded and provides information about cognitive processes that were previously unobservable. However, using this technology needs to be balanced with awareness of equity issues. Differences in access to technology can create assessment biases that actually widen existing gaps.

3.2.4. Shift to Authentic Assessment and Implementation Challenges

The shift from standardized tests to authentic assessment is not merely a technical change but a reflection of changing perspectives on mathematical creativity itself. The increased use of contextual tasks, such as Fermi problems, as applied by Okamoto et al. [27], recognizes that mathematical creativity cannot be separated from its application context. The higher correlation between performance on Fermi problems and mathematical creativity ($r=0.76$) than on general creativity tests ($r=0.47$) demonstrates the importance of using domain-specific mathematical tasks.

Pramasdyahsari et al. [21] went further by integrating art, technology, and mathematics in STEAM-geometry activities. This approach not only increases alignment with real-world contexts but also creates space for various ways to express creativity. Students who may not excel in conventional tests can demonstrate mathematical creativity through visual representations, physical constructions, or combinations of various methods.

Recognition that mathematical creativity is often collaborative challenges the tradition of individual assessment dominating formal education. Ron-Ezra and Levenson [25] found that collaboration not only helps students express creativity but also transforms the nature of creativity itself. Creativity is no longer seen merely as individual achievement but as a process involving social interaction. This means that the mathematical creativity assessment needs to accommodate this collaborative dimension rather than treating it as an interference to be eliminated.

The use of formative assessment with repeated feedback reflects the view that creativity is not a fixed trait merely measured, but a capability that can be developed. Meier et al. [18] demonstrated that creative self-confidence, developed through sustained engagement with creative tasks, is the strongest individual predictor of mathematical creativity scores, underscoring the importance of assessment as part of the learning process rather than merely a measurement tool.

However, the gap between pedagogical ideas and field realities remains quite large. Zioga and Desli [31] uncovered a concerning situation. Although teachers' understanding of creativity improved, their ability to facilitate originality and elaboration (the two most complex components) remains very limited. This is not merely an issue of individual teacher capacity but also indicates that the system has not provided adequate support.

Muhammad Hafizi and Kamarudin [32] identified a more structural root cause. Education systems that are still focused on rote memorization remain the main obstacle. As long as examinations determining graduation continue to measure memorization and procedural imitation rather than creative thinking, efforts to develop mathematical creativity will continue to face barriers. Changing assessment practices requires not only teacher training but also more fundamental policy reforms regarding how educational success is measured and evaluated.

3.2.5. Theoretical and Practical Implications

The findings of this study carry significant implications at three levels. First, in terms of creativity theory, this study confirms and extends the view that mathematical creativity is not a static, singular entity but a construct that evolves with shifting social, technological, and cultural contexts. The progression from Torrance's four-component model to integrative multidimensional models reflects important theoretical maturation in mathematics education scholarship. Second, for mathematics education research, integrating three analytical dimensions (publication trends, conceptualization, and assessment methods) offers a new methodological framework for systematic reviews in this field, enabling a more holistic understanding than single-dimension reviews allow. Third, for educational assessment frameworks, the findings support a paradigm shift from summative, test-based assessment toward multidimensional, authentic, and technology-enhanced formative assessment systems, aligning with the demands of 21st-century education and the realities observed across the included studies.

4. CONCLUSION

This systematic review addressed three research questions concerning mathematical creativity in secondary education between 2016 and 2025. The integration of publication trend analysis, conceptualization evolution, and assessment method classification within a single analytical framework represents the primary theoretical contribution of this study, an approach not previously undertaken in the literature. The findings collectively demonstrate that mathematical creativity research has undergone a significant transformation across all three dimensions during this decade, driven by curriculum reform, technological advancement, and post-pandemic pedagogical innovation.

The key implication of these findings is that mathematical creativity cannot be treated as an individual cognitive trait measurable by a single test. It is a multidimensional construct shaped by cognitive, affective, metacognitive, social, and technological interactions. Educational practice must respond by designing comprehensive learning systems and shifting toward authentic, multidimensional assessment that captures the full breadth of creativity. This study also acknowledges important limitations: the search was restricted to two databases and English-language publications, potentially missing high-quality studies in other languages or databases.

Future research should prioritize empirical validation of the creativity assessment models identified in this review, cross-cultural comparisons of how sociocultural identity shapes the expression of mathematical creativity, and the development of teacher professional development programs to facilitate and assess originality and elaboration.

In practice, the findings offer actionable guidance for curriculum developers, teachers, and policymakers to foster mathematical creativity more effectively. At the same time, theoretically, integrating three analytical dimensions into a single framework provides a replicable model for future systematic reviews in mathematics education.

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