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Creativity as Cognitive Ability and Thinking Process: A Narrative Review of Two Interrelated Perspectives

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Abstract: The development of 21st-century education demands strengthening mathematical creative thinking as part of higher-order thinking. However, the literature shows a conceptual fragmentation that positions mathematical creativity as both a cognitive process and a measurable ability. This study aims to synthesize and integrate these two perspectives through a systematic literature review (SLR) guided by the PRISMA 2020 guidelines, resulting in a more comprehensive conceptual framework. The review process was carried out through the stages of identification, screening, eligibility, and inclusion of literature from the Scopus database with strict selection criteria. Of 124,278 initial documents, 34 scientific articles were identified that met the criteria for the main unit of analysis. The analysis was conducted through a cross-study conceptual synthesis to identify the characteristics of creativity as a process and an ability, and to examine the relationship between the two. The results of the study indicate that the process approach emphasizes the dynamics of the stages of creative thinking (e.g., preparation, incubation, illumination, and verification). In contrast, the ability approach emphasizes measurable indicators such as fluency, flexibility, originality, and elaboration. The main finding of this study is the development of an integrative conceptual framework of process–ability, which positions mathematical creativity as a multidimensional construct that simultaneously connects cognitive dynamics with measurable performance. The contribution of this study is not only a critical synthesis but also an attempt to offer a new conceptual flowchart that integrates creative thinking as a process and as an ability, and is expected to serve as the basis for developing more holistic learning and assessment designs. The implications of this study indicate the importance of developing assessment instruments that can capture both process and product simultaneously. Thus, this study expands theoretical understanding while providing new methodological directions in mathematics education research and practice.

Keywords: creative thinking process, creative thinking ability, mathematics, mathematics education.

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INTRODUCTION

The rapid changes of the first two decades of the 21st century have driven fundamental transformations across education, the economy, and the world of work. Developments in digital technology, artificial intelligence, and globalization have shaped a new landscape that demands individuals possess adaptive and flexible higher-order thinking skills. In this context, creative thinking skills are an essential competency for navigating the complexities and uncertainties of the future.

In line with these demands, mathematics education plays a strategic role in equipping students with relevant competencies. Mathematics is no longer viewed solely as a procedural discipline but as a means of developing higher-order thinking skills, including creativity. Recent research confirms that strengthening mathematical competencies is crucial in preparing students to face future challenges (Bakker et al., 2021; Gravemeijer et al., 2017; Riera et al., 2024)

One competency that has received significant attention in mathematics education is creative thinking. This ability enables students to generate original ideas, develop diverse problem-solving strategies, and construct flexible and meaningful conceptual understanding (Dilekçi & Karatay, 2023; Lu & Kaiser, 2022; Newton et al., 2022; Oknaryana et al., 2025; Sosna et al., 2025; Thornhill-Miller et al., 2023; Zulkifli et al., 2022)

Creative thinking offers individuals a significant opportunity to adapt to new challenges and tackle tasks that do not yet exist (Smare & Elfatihi, 2023). This ability enables individuals to respond to change innovatively and develop alternative solutions to complex problems. Thus, creativity is a crucial foundation for building individual competitiveness in the global era.

Furthermore, creative thinking is crucial for solving complex problems that conventional approaches cannot. Real-world problems are generally open-ended and unstructured, and require divergent thinking. Therefore, creativity is an essential element in generating original, context-specific solutions.

In an organizational context, creativity contributes to increased effectiveness and service quality. Creative individuals tend to make innovative and adaptive decisions, thereby impacting organizational performance (Cheraghi et al., 2021). This statement demonstrates that creativity has systemic implications that extend beyond the individual.

Creative thinking not only impacts professional aspects but also provides intrinsic meaning for individuals by fostering motivation, self-satisfaction, and a sense of social connectedness (Oppert et al., 2023). Thus, creative thinking serves not only as a tool for problem-solving but also as a means to achieve psychological well-being and self-actualization.

Furthermore, in education and the world of work, creative thinking is a key asset for fostering flexible, in-depth learning that is relevant to real-life needs. Learning processes that foster creativity have been shown to improve students' adaptability to increasingly dynamic social and technological changes (Samaniego et al., 2024), thereby strengthening the relevance of education to real-life needs.

This ability also encourages organizations to innovate, collaborate across disciplines, and create a competitive advantage amidst global competition (Kottwitz et al., 2024). Furthermore, an environment that fosters new ideas strengthens individuals' cognitive flexibility, enabling the creation of original solutions with broad impact (Ruiz-del-Pino et al., 2022). Therefore, developing creative thinking is a real need that not only supports academic and professional success but also fosters an adaptive, innovative, and creative generation across various aspects of life.

Since its inception in the previous decades, many experts have researched creative thinking. Some of these are well-known and have contributed to international mathematics education and served as references for other researchers, including Aizikovitsh-Udi & Amit (2011), Leung (1997), Leung & Silver (1997), Paul (1993), and Runco & Acar (2012).

In the past five years, the study of creative thinking has undergone significant conceptual and methodological developments. Research no longer focuses solely on the products of creativity but also examines the underlying cognitive processes. This shift indicates an effort toward a more comprehensive and integrative understanding of creativity.

This development is rooted in classic contributions that have shaped creativity studies, such as research on divergent thinking and mathematical problem-solving. However, contemporary research seeks to reinterpret these concepts in a more contextually grounded manner, drawing on current empirical evidence to make them relevant to the dynamics of 21st-century education.

Recent bibliometric studies and reviews confirm that creativity research, particularly in education and mathematics, is evolving and shifting in focus. Publication trends increased steadily from 2019 to 2024, with a significant peak in 2022–2023 (Nga, Thu, & Huyen, 2025). During the same period, conceptualizations of creativity increasingly emphasize processes and cognition, rather than end products. For example, Dilekçi & Karatay (2023) describe creative thinking as a multifaceted cognitive process. Similarly, Joklitschke, Rott, & Schindler (2022) note that some scholars focus on creative products, while others focus on creative processes, and they call for a more integrative framework. Systematic reviews echo this shift. Schoevers et al. (2019) found that mathematics education research on creativity increasingly addresses both the cognitive foundations and the practical tasks that foster creativity, and Fauzi, Wuryandani, & Supartinah (2025) proposed a holistic framework that bridges the cognitive, socio-emotional, and cultural dimensions of creative thinking. Methodologically, new studies often use mixed methods (e.g., think-aloud protocols, design tasks, and interviews) to capture how creativity emerges, not just what it produces.

As attention to creative thinking increases, the complexity of understanding its nature grows. The literature indicates two dominant perspectives: creativity as a cognitive process and as a measurable individual ability (Joklitschke et al., 2022; Suherman & Vidákovich, 2022) as a final product. This dualism is not only theoretical but also has practical implications in education.

Real-world classroom conditions demonstrate that assessments that overemphasize students' final products often overlook the complexity of the creative process. For example, Marangio et al. (2024) noted the experience of science teachers who felt "constantly tense … not to lose the integrity of the creative process and its value in the final product." This means that if assessments focus solely on the final product, creativity as a product does not equate to freedom or limitless possibilities, leading to the failure of many original ideas. Beghetto (2021) even observed that overly structured learning can make it difficult for students to engage in the creative process and develop their own original ideas. These findings reinforce concerns that rubrics that assess only students' final answers tend to obscure their creative process and reward predetermined answers, thereby neglecting divergent creativity and early exploration.

Conversely, assessment approaches that focus on the creative process face challenges with reliability and standardization. Long & Wang's (2022) study of 84 consensual studies showed that although the Consensual Assessment Technique (CAT) generally demonstrated good reliability and validity, some levels of unreliability and invalidity remained in its assessments. Mirzaei et al. (2025) also highlighted that the CAT method, which relies heavily on expert judgment, can pose challenges for standardization and scalability. In other words, process assessment is often subjective and difficult to consistently institutionalize across contexts. These limitations of both product- and process-based methods underscore the urgency of synthesizing the findings of these studies to develop a more balanced assessment of mathematical creativity.

Furthermore, this dualism raises pressing issues, particularly in assessment and curriculum development. When creativity is positioned as a process, assessment focuses on the stages of student thinking. Conversely, when viewed as an ability, assessment tends to focus on the final product. This inconsistency has the potential to introduce evaluation bias and lead to inaccurate learning strategies.

Furthermore, this dualism also impacts the learning design implemented by teachers. Curricula that lack conceptual clarity about creativity can lead to fragmented learning practices. Therefore, a conceptual study is needed that can systematically bridge these two perspectives.

Furthermore, there are differing views regarding whether creativity is domain-general or domain-specific. Some researchers view creativity as the ability to think divergently across domains, while others emphasize that creativity must be understood within specific contexts, such as mathematics (Sipahi & Bahar, 2025). This distinction further reinforces the conceptual complexity of mathematical creativity.

Based on these problems, this research aims to answer the following questions: (1) How can mathematical creativity be understood simultaneously as a cognitive process and an ability? (2) What are the implications of this dualism for assessment practices in mathematics learning?

Therefore, this study aims to elaborate on the duality of creative thinking as both a process and an ability, and its implications for mathematics education. This study is expected to provide theoretical contributions to clarify the construct of mathematical creativity and practical contributions to the development of more comprehensive learning and assessment methods.

Although research on creativity in mathematics education continues to grow, contemporary literature still shows a strong tendency to treat creativity as both a cognitive process and a measurable ability. This conceptual fragmentation has led to a lack of a theoretical framework capable of comprehensively explaining the relationship between the dynamics of the creative thinking process and its manifestation in student performance. Furthermore, the dominance of partial approaches in empirical studies over the past five years has led to inconsistent assessment practices, with the instruments developed often capturing only one dimension of creativity. This situation not only undermines the validity of interpretations of learning outcomes but also affects curriculum design that is not aligned with the comprehensive development of mathematical creativity. Therefore, a conceptual study is needed to bridge this gap through a systematic, integrative approach.

METHOD

Research Design

This study uses a systematized narrative review approach. This approach was chosen because the purpose of the study is not to conduct a quantitative meta-analysis, but rather to synthesize and conceptually integrate two perspectives on creative thinking, namely (1) creative thinking as a gradual cognitive process, and (2) creative thinking as a cognitive ability that can be measured through certain indicators, both in the general context and in mathematics education.

To avoid a methodologically weak, reflective-subjective design, this study employed explicit, traceable selection procedures, thematic coding, and synthesis strategies. The study procedures were adapted from the narrative synthesis framework developed by Sukhera (2022), with an emphasis on analytical transparency and coherence between data and research claims.

Search Strategy, Inclusion and Exclusion Criteria

Search Strategy

The initial search process was conducted through Elsevier's Scopus database using the keywords "TITLE-ABS-KEY((creative* OR "creative thinking") AND ("thinking process" OR process OR cognition OR ability OR skill* OR competence*))". Subsequent literature selection was conducted in accordance with the PRISMA 2020 guidelines to ensure transparency and reproducibility of the research process.

The search process using these keywords was deliberately and methodologically chosen to accommodate the conceptual complexity of the construct of creative thinking, which is indeed multidimensional and cross-perspective. In the literature, creative thinking is positioned not only as a cognitive process but also as an ability, competence, and even as a higher-order cognitive function. Therefore, using more general terms such as "process," "cognition," and "ability" helps avoid terminological bias and ensures that the full spectrum of relevant literature, both process- and ability-oriented, is identified early in the search. This approach aligns with the principle of a high-recall search strategy in systematic and narrative reviews, prioritizing search sensitivity to minimize the risk of missing important studies due to overly narrow keyword constraints.

Nevertheless, to avoid including irrelevant articles given the broad scope of the search, this study employed a rigorous multi-stage screening process. After the initial identification stage, articles were selected using inclusion-exclusion criteria that explicitly required a direct link to creative thinking as a cognitive process or as a cognitive ability. Furthermore, an in-depth review of the articles' titles, abstracts, and content was conducted to ensure conceptual alignment with the study's focus. Thus, the broad search strategy does not aim to compromise selection quality, but rather to ensure comprehensive coverage of the literature, which is then refined through a systematic, transparent screening process. This approach ensures that relevant articles are not prematurely eliminated, while maintaining the conceptual validity of the resulting synthesis.

In the initial identification stage, 124,278 documents were obtained from the initial search results. To focus the search results on relevant literature, an automated database tool (database limiters) was applied with the following criteria: (1) publication year 2020–2025, (2) subject area of mathematics education, (3) document type (journal article), (4) final publication status, (5) English language, and (6) open access. Applying these criteria excluded 123,699 documents, leaving 579 articles for the subsequent selection process.

In the screening stage, 579 articles were selected based on their titles and abstracts. The screening results indicated that 429 articles were excluded for being irrelevant to the research focus. This condition left 150 articles for which full manuscripts were sought. However, five articles were inaccessible, leaving only 145 to proceed to the eligibility assessment stage.

At the eligibility and inclusion stage, 145 articles were fully reviewed to assess their suitability for the study's inclusion criteria. The review revealed that 111 articles were excluded for failing to meet the criteria. These included 65 articles that did not specifically address a conceptual framework or indicators of creative thinking, 26 that did not focus on the context of mathematics education, and 20 that had inadequate methodology. Thus, 34 scientific journal articles were deemed to meet all criteria and were designated as the primary unit of analysis in this study. The complete flow of the identification process leading to the final article selection is presented in Figure 1 (Haddaway, Page, Pritchard, & McGuinness, 2022).

Inclusion and Exclusion Criteria

Inclusion criteria included: (1) Scopus-indexed journal articles, (2) published between 2020 and 2024, and (3) containing a conceptual framework, process model, or indicators of creative thinking. Exclusion criteria included: (1) studies that only discuss creativity as an affective or personality aspect, (2) studies that focus on artistic products without a cognitive dimension, and (3) studies without a clear conceptual framework.

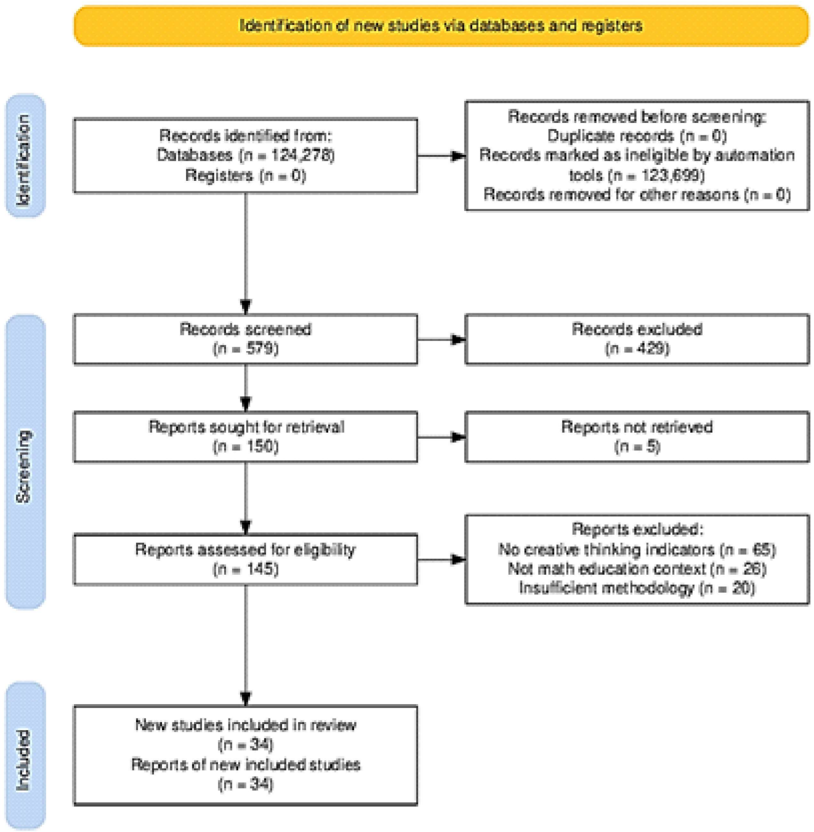

Figure 1. Literature selection PRISMA diagram

In addition, this study drew on several foundational works published before 2020 as its historical-theoretical foundation. These sources were not included as the primary unit of analysis. However, they were used only to explain the early development of concepts that are still referenced, revised, or criticized in contemporary literature. These historical references consisted of 5 journal articles and 5 books.

Data Analysis

Data analysis was conducted using a conceptual synthesis approach rather than statistical aggregation. The analysis phase began with the development of initial categories based on the research objectives, namely: (1) analysis of mathematical creativity as a cognitive process and as an ability, (2) analysis of the implications of dualism for assessment practices, and (3) analysis of an integrative conceptual framework.

Each selected article was mapped to these categories and then analyzed to identify patterns, consistencies, and conceptual differences between studies. This process aimed to build a coherent, evidence-based synthesis.

The final phase was conceptual integration and justification, in which the synthesis results were interpreted through explicit theoretical reasoning. The researcher's perspective was used as a reflective tool to strengthen conceptual integration but not as the basis for empirical claims, thereby maintaining the study's scientific validity.

■ RESULT AND DISCUSSION

Synthesis Findings of 34 Articles Meeting All Selection Criteria

Based on the synthesis of the 34 articles that served as the primary unit of analysis (detailed data can be found in the synthesis table in the appendix), the findings indicate that the definition of mathematical creative thinking generally focuses on two main orientations: the ability to generate novel ideas and the cognitive process of problem-solving. Most studies, such as those by Bicer et al., Meier et al., and Rahayuningsih et al., emphasize creativity as the ability to generate original and meaningful mathematical solutions. In contrast, others, such as those by Burakgazi & Reiss and Thoring et al., emphasize creativity as a process involving both divergent and convergent thinking stages. This demonstrates that the literature does not have a single definition of creativity, but rather develops along a spectrum connecting the product (outcome) and the process (mechanism of thinking).

Furthermore, regarding theoretical frameworks, most studies still draw on classical theories such as Guilford, Torrance, and Wallas, albeit with various modifications and integrations with modern theories. For example, several studies combine Guilford's divergent thinking theory with constructivist approaches, Piaget's cognitive theory, and STEM and computational thinking frameworks. In fact, some studies, such as those by Corcuera and Vuichard et al., have developed nonlinear and multivariate models, indicating a shift from traditional linear models to a more complex, dynamic approach to understanding creativity.

In terms of creative thinking ability indicators, almost all studies consistently use four main indicators: fluency, flexibility, originality, and elaboration, derived from the Torrance Test of Creative Thinking (TTCT). However, there are variations in indicator development, such as the addition of connection and redefinition aspects, as well as problem-posing and problem-solving abilities. This indicates that although classic indicators remain dominant, there are adaptations to accommodate more complex mathematical contexts, particularly those that require higher-order thinking.

Regarding the stages or processes of creative thinking, it was found that although the Wallas model remains widely used, most studies no longer employ it linearly. Several studies have developed more dynamic processes, such as the Creative Problem Solving (CPS) model, the PCAH model, and approaches based on experimentation and iterative reflection. In fact, several studies have shown that the creative thinking process involves the simultaneous interaction of idea exploration, evaluation, and reflection, which cannot be represented in a rigid sequence of stages. This strengthens the argument that creativity is better understood as a nonlinear, cyclical process.

In terms of research methodology and context, the findings indicate a predominance of quantitative and quasi-experimental approaches, particularly for measuring the effectiveness of learning interventions such as PBL, PjBL, STEM, and technology use. However, there are also qualitative and mixed-method studies that explore students' thinking processes in greater depth through interviews, observations, and think-alouds. The research contexts are diverse, ranging from elementary school to higher education, with a trend toward increasing use of digital technology as a medium for developing creativity. Overall, these findings indicate that research on mathematical creativity continues to evolve toward a more integrative approach across concepts, processes, and measurement methods.

Creative Thinking as a Cognitive Process and Cognitive Ability

Creative Thinking as a Cognitive Process

The first approach views creativity as a hierarchical cognitive process. Mathematical creative thinking is defined as a process that yields new and unusual answers and ingenious solutions to given or similar problems, raising new questions or approaches to old problems from new, more imaginative perspectives (Sriraman, 2004).

Table 1. Synthesis of 34 articles, which are the main unit of analysis

No	Article Title & Author	Definition of Creativity	Reference Theoretical Framework	Creative Thinking Ability Indicators	Stages / Process of Creative Thinking	Research methodology	Educational Context
1	Mathematical creativity in upper elementary school mathematics curriculum (Bicer et al.)	The ability of students to produce new, original mathematical ideas, processes, or products through the selection of acceptable mathematical patterns and models.	The Four C Model & Creativity (Kaufman & Beghetto), the Creativity Systems Model (Csikszentmihalyi), and the Actiotope Model.	Fluency, flexibility, and originality were adapted from the Torrance Test of Creative Thinking (TTCT).	Involves cognitive flexibility through cognitive variability, cognitive noveity, and cognitive framing.	Content/curriculum analysis of 1,000 mathematics assignments in 5 curricula.	Upper-grade students in an elementary school in the United States.
2	Exploring creative thinking skills in PISA (Burakgazi & Reiss)	Attitudes towards life and work include cognitive, effective, motivational, and environmental components, as well as the ability to generate original and effective ideas.	Bronfenbrenner's ecological systems theory (microsystem, masosystem, exosystem, macrosystem, and chronosystem).	Generating diverse ideas, generating creative ideas, and evaluating and improving ideas (based on PISA 2022).	Focuses on convergent and divergent cognitive processes: idea generation, evaluation, and idea refinement.	Exploratory comparative/qualitative correlational study (PISA 2022 data from various countries).	15-year-old students in secondary school (Singapore, Canada, Finland).
3	Creativity in Designing Virtual STEAM Tasks (Cahyono et al.)	The capacity to think imaginatively and innovatively in solving mathematical problems, connecting ideas, and identifying patterns beyond common methods.	Brousseau's concept of didactic situations and Henriksen's creative product evaluation framework.	Novel (new/unique), Effective (useful relevant), and Whole (organic sesthetic) aspects.	Following the four-stage Gestalt model: preparation, inciıbation, illumination, and verification.	An exploratory study through observation, interviews, and project-based assignment evaluation.	Prospective mathematics education teacher students in a virtual learning environment.
4	The Houses of Creativity (Corcuera)	Quality depends on the capacity and attitude to do new things that can provide value or evoke emotions.	Wallas" "The Art of Thought" model (1926), Rhodes' 4P framework (1961), and the Octahedral Creativity Framework.	Fluency, flexibility, originality, and elaboration (from the divergent thinking test), as well as novelty and appreprіateness.	Formed in a non-linear honeyeveeb pattern; selecting, observing questioning, seeking information, seeking ideas, verification, and communication.	Theoretical research/lberature study comparing various models of creativity since 1926.	The general context of creativity theory for evaluation and training programs.
5	Analysis of Mathematical Creative Thinking Skill (Gunawan et al.)	The ability to generate new and unique ideas in solving mathematical problems.	Siswona's (2010) level of creative thinking, Guilford's (1961) concept of divergent thinking, and the concept of self-confidence.	Fluency, flexibility, originality, connection, and elaboration.	Conceptual or constructive stage: information exploration, knowledge association, concept identification, and idea analogy.	Descriptive qualitative (purposive sampling, questionnaires, written tests, and interviews).	College students taking a Differential Calculus course.
6	Effectiveness of virtual reality application technology (Hidajat)	High-level thinking skills to generate original and imaginative ideas through technology flexibly.	Constructivist approach through the use of virtual reality (VR) technology.	Flexibility of ideas and originality of ideas in mathematical problem solving,	Constructing abstract knowledge through spatial interactions, imaginative simulations, and focused attention in virtual spaces.	Quantitative using multiple linear regression analysis and questionnaires.	College-level students majoring in Mathematics Education.
7	Unplugged activities in the elementary school mathematics classroom (Hu & Wang)	Identification and selection of mathematical patterns to produce new products for individuals; a combination of problem posing.	Piaget's theory of cognitive development (the concrete operational stage) and the embodied cognition theory.	Fluency, flexibility, and elaboration, as well as creativity in problem posing and creativity in problem solving.	Problem identification, problem solving, and observation and development of new relationships between concepts.	Messd methods: quasi-experimental design (pre-test and post-test) and semi-structured interviews.	Third-grade elementary school students.
8	Integrating problem-based learning and computational thinking (Ji & Wong)	The ability to generate new and valuable ideas beyond traditional problem-solving frameworks.	Constructivist learning theory, Problem-Based Learning (PBL), and Computational Thinking framework (Angeli et al., 2016).	Fluency, flexibility, originality, elaboration, and redefinition.	Intersects in four aspects: problem solving, abstract generalization, transfer of thought, and evaluation and reflection.	Quantitative Experiment with descriptive statistics and the Wilcoxon signed rank test (pre-test and post-test).	Upper-grade students (grades 5-6) in elementary school.
9	The Effectiveness of Problem-Based Learning (Maskur et al.)	The ability to think creatively and mathematically to solve problems in a detailed, flexible, fluent, and original manner.	Problem-Based Learning (PBL) model and Aptitude Treatment Interaction (ATI) model.	Original, detailed (elaboration), fluent (fluency), and flexible thinking.	Following the PBL stages: analyzing/collecting data, discussing to develop arguments, and finding solutions to problems.	Quasi-experimental with posttest-only control-test and t-test design.	School environment with reference to the 2013 Curriculum in Indonesia.
10	Mathematical Creativity in Adults (Meier et al.)	The process of producing unusual, new, and useful solutions to a mathematical problem.	Threshold theory of intelligence and domain-specific vs. domain-general theories of creativity.	Fluency (mathematically correct answers), flexibility (number of categories), and originality (novelty of the solution).	Produce responses in mathematical divergent thinking tasks for numerical and figural aspects.	Quantitative/Exploratory study with psychometric evaluation and confirmatory factor analysis (CFA).	University students and adult individuals.
11	The Effect of the Blended Project-based Learning... (Mursid et al., 2022)	An original and detailed way of producing complex products (divergent thinking); the ability to formulate new, surprising, and valuable ideas.	The integrated Project-Based Learning (PjBL) model and Mahanal & Zubaidah's creative thinking concept.	Fluency, flexibility, originality, and elaboration.	Following the PjBL model: opening with challenging questions, project planning, scheduling, project supervision, product assessment, and evaluation.	Quasi-experimental with pre-test and post-test design; using a two-way ANOVA test on a sample of 80 students.	Engineering students taking technical drawing courses in Indonesia.
12	Project-Based Learning in Fostering Creative Thinking... (Ndiung & Menggo, 2024)	The ability to effectively address challenges, broaden perspectives, and generate unexpected ideas through non-algorithmic reasoning.	Constructivist theory (Piaget on assimilation/accommodation) and Revised Bloom's Taxonomy (Higher-Order Thinking Skills/HOTS).	Fluency, flexibility, adaptability, and originality.	Initiate fundamental questions, create project planning guidelines, develop schedules, monitor progress, assess work, and evaluate experiences.	Quasi-experimental with control group design, MANOVA data analysis, sample of 43 students.	Sixth-grade elementary school students in Indonesia.
13	The impact of brain science literacy on creative thinking... (Peng et al., 2025)	High-level cognitive abilities that dynamically involve brain networks (default mode network, central executive, and salience).	Brain science literacy (educational neuroscience) and the mechanisms of neuroplasticity.	Fluency, flexibility, originality, and elaboration (based on Torrance's structural model).	Influenced by the stage of educational intervention: optimization of teaching strategies, regulation of student behavior, and childhood intervention.	Meta-analysis integrating 35 experimental studies (Total N = 14,688).	General education spans various stages (from early childhood education through elementary, secondary, and university).
14	Using Open-Ended Problem-Solving Tests... (Rahayuningsih et al., 2021)	The individual's tendency to find novelty in solving open mathematical problems.	Gestalt creativity model (Wallas/Sriraman) and cognitive flexibility.	Cognitive flexibility (cognitive variation, novelty of ideas, changes in thinking frames) and cognitive fluency.	The four-stage Gestalt model: Preparation, incubation, illumination, and verification.	An exploratory study with a qualitative approach through written tests (OEPST) and in-depth interviews.	Seventh-semester prospective mathematics education teacher students at Indonesian universities.
15	Exploring how students with learning disorders engage... (Ron-Ezra & Levenson, 2025)	A form of divergent thinking that produces various dimensions of thought and unique ideas that are different from those of peers.	Guilford's (1967) Intellectual Structure Model and Torrance's (1974) framework.	Fluency, flexibility (overcoming fixation), originality, and elaboration.	Interact in collaborative pairs when solving mathematical problems with open and multiple strategies.	Qualitative/observational through video recording analysis of 26 students in pairs.	Third-grade students with learning disabilities in special education classes at regular schools in Israel.
16	Exploring creativity's complex relationship with learning... (Rubenstein et al., 2022)	The development of new, useful products or ideas, ranging from innate creativity in the learning process ("mini-c") to everyday creativity.	Threshold theory, cognitive theory (Kintsch), and Torrance's structure of creative thinking.	Fluency, originality, elaboration, abstraction of the title, and resistance to premature closure.	Mentally constructing knowledge through games or strategies generates many ideas.	Quantitative study using Generalized Additive Models (GAMs) with academic scores (growth) as the measure. Sample: 141 students.	Early elementary school students (Kindergarten and Grade 1) in the United States.
17	Creative thinking in students of mathematics... (Sbaih, 2023)	Complex, directed mental activity driven by a strong desire to find solutions and produce original products that have never existed before.	Framework of reference for the Torrance Test of Creative Thinking (TTCT).	Fluency, flexibility, originality, sensitivity to problems, and elaboration.	Organizing existing experience and information to respond to requirements from a new perspective, then generating ideas or alternatives.	Descriptive and inferential quantitative analysis (multiple linear regression, t-test, ANOVA). Sample: 166 undergraduate students.	Student of the Mathematics Study Program at Al-Balqa Applied University, Jordan.
18	Mathematical Creativity in Elementary School Children... (Shaw et al., 2022)	Generating new ways to solve new problems or various strategies to solve existing problems (containing novelty and meaningfulness values).	Haylock's mathematical creativity framework and Wallas' incubation gap theory.	Fluency (number of strategies/ideas) and originality of ideas in problem solving.	The problem-solving process is interspersed with incubation breaks (time breaks) to eliminate mental fixation and activate solutions from the subconscious.	Experimental study (1 minute vs continuous incubation rest condition) on 211 elementary school students.+3	Elementary school students (Grades 1-5) in the United States use the Cognitively Guided Instruction method.
19	Teaching creativity through mathematical lateral thinking... (Shodiq et al., 2025)	Related to the creation of new mathematical ideas, processes, or products for students through the process of lateral analytical thinking.	De Bono's (2018) lateral thinking process and orientation components in Pedagogical Content Knowledge (PCK) Theory.	Fluency (multiple solutions), flexibility (multiple approaches), and novelty of ideas (novelty).	The dynamic PCAH process includes the stages of perception, challenge, alternative solutions, and harvesting/conclusion.	A qualitative descriptive case study (purposive sampling). Data collection was conducted through interviews and learning observations with two high-	The context of mathematics education teachers at the junior high school (SMP) level in East Java, Indonesia.

20	Mathematical Creativity: A Systematic Review… (Sipahi & Bahar, 2025)	Synthesized into three definitional clusters: divergent thinking, problem solving/problem posing, and motivational/affective components that produce original mathematical responses.	Domain-general (Guilford, Torrance), Domain-specific (Silver, Leikin), and various multidimensional and sociocultural models.	The components of divergent thinking are dominated by fluency, flexibility, originality, and elaboration.	Operationally varied, many are dominated by problem formulation, heuristic problem-solving, and unusual idea-evaluation strategies.	A systematic review (Systematic Review) through thematic analysis following PRISMA standards by synthesizing 80 empirical studies.	Education levels from kindergarten to high school (K-12 population) globally.
21	Assessment of mathematical creative thinking… (Suherman & Vidakovvić, 2022)	The creation of something new from mathematical ideas, concepts, or experiences through	Guilford Intellectual Structure, Lateral Thinking (De Bono), and Torrance	Fluency, flexibility, originality, and elaboration.	Problem-solving approach in the process: divergent thinking (generating ideas), then	Systematic literature review (PRISMA) by analyzing 70 journal articles.	General mathematics education, with a focus on the need for measuring
22	Creative processes in visual arts in education... (Swanzy-Impraim, 2025)	Human competencies are grounded in domain-specific skills for generating new knowledge, solving problems, and producing original ideas.	The 8P Creativity Model, Wallas' 4-stage Model, and the Swanzy-Impraim Panoramic Creative Process Model (SI PCPM).	Focused on artistic/aesthetic product results or problem-solving ideas.	Consists of 7 phases (SI PCPM): immersion, problem identification, ideation, production, results, evaluation, and response.	Conceptual/theoretical paper (review and synthesis of the creative process model literature).	Fine arts in education (classroom and studio environments) crosses the mini-c to Big-C levels.
23	Exploring the effects of interactive digital picture books... (Tang et al., 2025)	Essential 21st-century skills to foster creative thinking and imagination through the integration of digital technologies.	Torrance Tests of Creative Thinking (TTCT).	Score-based evaluation on TTCT instruments (usually includes fluency, flexibility, originality, and elaboration).	Involves engaging with and activating interactive digital features to spark creative thinking.	Triangulation/quasi-experimental approach: interviews, observations, and TTCT. Sample: 44 students.	Sixth-grade elementary school students.
24	The Architecture of Creativity... (Thoring et al., 2021)	As a result (original, useful, and surprising product, and as a process (sequential problem solving).	Wallas' (1926) problem-solving model, cognitive theory (focused vs. diffuse mode), and Guilford's divergent-convergent mode.	Fluency, flexibility, synthesis, fixation, priming, and serendipity.	Preparation, incubation, illumination, elaboration (adding details), and verification (critical validation).	Grounded-theory / Qualitative approach through 9 expert interviews from various design fields.	Creative work/study spaces in educational institutions (design/art schools) and corporations.
25	Parental involvement in STEM... (Tunceli et al., 2025)	The capacity to generate new and useful ideas, solve problems in innovative ways, and express thoughts/emotions.	Torrance's (1965) creativity framework, Lee & Lee's (2002) framework, and Social Learning Theory (Bandura).	Measured in two main domains: language (verbal) and drawing (visual) creativity.	Play, explore, identify problems, make predictions/hypotheses, and experiment until you find a solution.	Quasi-experimental with intervention & control group design (Wilcoxon & Mann-Whitney test). Sample: 28 children.	Early childhood education (students aged 5 years) involves parental intervention at home.
26	Exploring the creative potential of mathematical tasks... (Vale & Barbosa, 2024)	A mental process that involves the formation of new ideas/concepts or the discovery of connections between mathematical problems.	Problem-solving and problem posing approaches (Polya, Silver), as well as multi-solution tasks (Leikin).	Fluency, flexibility, and originality in submitting/completing assignments.	Explore, experiment, make conjectures, generalize, and create muitiple solution paths.	Qualitative and interpretative exploration using analysis of written production from 19 students.	Pre-service teachers at the elementary education level.
27	Creative problem solving in primary school students (Van Hooijdonk et al., 2023)	Real-life strategies where creativity and domain knowledge are combined to solve problems in an original and useful way.	Creative Problem Solving / CPS Model (Isaksen, Treffinger) and Rhodes' 4P Creativity (Process & Product).	Fluency, originality, completeness, and practicality.	4 elements of the CPS Model: (1) understanding the challenge, (2) generating ideas, (3) preparing to act, and (4) planning the approach.	Mixed methods: Study 1 (qualitative think-aloud with 13 students) & Study 2 (quantitative with 594 students).	Upper elementary school students (grades 4, 5, and 6).
28	Creative Process and Multivariate Factors... (Vuichard et al., 2023)	A sequence of thoughts and actions that leads to work/production that is both original and adaptive.	Multivariate approach (Lubart, 2015), 7C Model of creativity, and Botella's 16-step model (2011).	Cognitive, conative, emotional factors, and environmental factors (collaboration).	14 adapted stages: problem definition, asking, documentation, illumination, association, experimentation, evaluation, and resolution.	Pilot/Qualitative study using creative process diary analysis and semi-structured interviews (N=10).	Master's level students in the teacher education program at the university.
29	Enhancing Creative Mathematical Thinking with GeoGebra... (Wahyuni et al., 2025)	Ability to generate multiple solutions, adapt to different approaches, and find detailed, original solutions.	A framework for mathematical problem solving based on technology and general creative thinking.	Fluency, flexibility, originality, and elaboration.	Interact directly and manipulate mathematical concepts visually/dynamically to find innovative solutions.	Quasi-experimental method with pre-test and post-test design without a control group. T & Wilcoxon test. (N=90)	Senior high school students (grade 11) in Padang, Indonesia.
30	Creativity: Exploring Factor Structure... (Xu et al., 2025)	A multifaceted concept involving perception, cognition, and emotion that plays a vital role in unlocking the potential of an individual's cognitive functions.	Adaptive-Innovative Theory (Kirton, 1976) and the Torrance Tests of Creative Thinking (TTCT) instrument.	Fluency, originality, elaboration, abstraction of the title, resistance to premature closure, and creative power.	Focusing on the figural aspect: drawing, enriching ideas, producing unique responses, and delaying premature closure of the drawing.	Quantitative using Confirmatory Factor Analysis (CFA) and the gender invariance test. Sample: 256 children.	Early childhood education (Kindergarten, 4-6 years old) in Shanghai, China.
31	The effect of creative thinking on academic performance... (Yang & Zhao, 2021)	The ability to detect previously unidentified relationships, generate new experiences, and evaluate and refine thinking to create innovative solutions.	The concept of divergent and convergent thinking (Hadar & Tirosh; Sternberg & Lubart; Volle) and Torrance's (1972) views on higher-order thinking skills.	Understanding of key concepts, synthesis, ability to explain concisely, evaluation, association, originality, future orientation, and insight.	Involves two thought processes: divergent thinking (generating many ideas for one problem) and convergent thinking (integrating different ideas to find a specific solution).	Quantitative: Ordinary Least Squares (OLS) regression, centered influence function (RIF) regression, and mediation effects model. Sample: 2,355 students.	Senior high school (SMA) students in grades 10-12 in China.
32	Creativity development through questioning activity... (Yu, Wang, & Yuizono, 2023)	The activity, process, and ability to produce new (novel) and effective ideas or solutions in dealing with a problem.	The National Advisory Committee on Creative and Cultural Education (NACCCE) report, the Revised Bloom's Taxonomy (Anderson & Krathwohl), and the theory of Guilford and Torrance.	Fluency (fluency of ideas), flexibility (variety of idea categories), originality (uniqueness of ideas), and high-level cognitive abilities in asking (analyzing, evaluating, and creating).	Through the pedagogy of asking: (1) Brainstorming questions in groups, (2) Refining and sharing high-level questions, and (3) Individual reflection.	Pre-experimental with pre-test and post-test design using the Wilcoxon signed-rank test. Sample: 80 students.	A second-year university student majoring in a second language (Japanese) in Dalian, China.
33	The Creative Problem-Solving Skills Test... (Yurt, 2025)	The capacity to generate original ideas and systematically transform them into practical solutions through the dynamic integration of creative thinking and problem-solving skills.	Torrance's theoretical framework of creativity (four dimensions), Guilford's theory of convergent/divergent thinking, and the dual pathway model of creativity.	Fluency, flexibility, originality, and elaboration (detailedness) are assessed from various problem-solving scenarios.	The dynamic interaction between generating ideas innovatively (divergent thinking) and then analyzing and evaluating them into viable solutions (convergent thinking).	Quantitative (Instrument/Test Development): Testing content validity, construct validity (Confirmatory Factor Analysis), and reliability (Cronbach's alpha). Sample: 1,007 students.	Higher-education students (bachelor's programs) at various universities in Türkiye.
34	Addressing the creativity gap... (Zioga & Desli, 2025)	A process that goes beyond the speed or accuracy of algorithms; it involves generating new solutions, identifying patterns, and approaching problems from multiple perspectives.	Guilford and Torrance's creativity index, Hadamard's (1945) mathematical discovery model, and Silver's (1997) concept of mathematical problem posing.	Fluency (multiple solutions), flexibility (different approaches), originality, elaboration, overcoming fixated thinking, and the ability to pose problems.	Emulate the way mathematicians work: formulate problems from curiosity, make conjectures, try solutions, revise approaches, and solve problems.	Qualitative Exploratory (Thematic Analysis): Direct classroom observation and semi-structured interviews before and after the intervention program. Sample: 7 teachers.	Primary school education teacher (teaching grades 1, 4, and 5) in Greece.

In another research study, Gunawan et al. (2022) define creative thinking as the ability to connect related concepts to discover new ideas. They state that "creative thinking is the process of finding new ideas obtained from correlations between concepts." In other words, creative thinking is the process of discovering new ideas through correlations or by linking pre-existing concepts. This emphasis on conceptual relationships suggests that creativity can emerge when individuals integrate old information in new ways.

Creative thinking, as a process, is largely derived from the concept proposed by Graham

Wallas (1926) in his book The Art of Thought. He proposed a model of creative thinking consisting of four stages: preparation, incubation, illumination, and verification. In the preparation stage, individuals gather information, understand the problem, and intensively consider various possible strategies. This stage is followed by the incubation stage, a period in which the prepared problem is left for a while; the individual consciously distances themselves from the problem, while the subconscious mind continues to develop ideas. Next comes the illumination (insight) stage, marked by the sudden emergence of a new idea or solution, known as an "aha moment," often seen when individuals are not directly considering the problem. Finally, the verification stage is carried out to test and evaluate the emerging solution, such as examining proof of a discovered mathematical formula or validating the idea within the context of the problem (Wallas, 1926). Wallas's model became the conceptual foundation for much subsequent research on creativity and remains relevant today (Corcuera, 2024; Swanzy-Impraim, 2025; Vuichard et al., 2023).

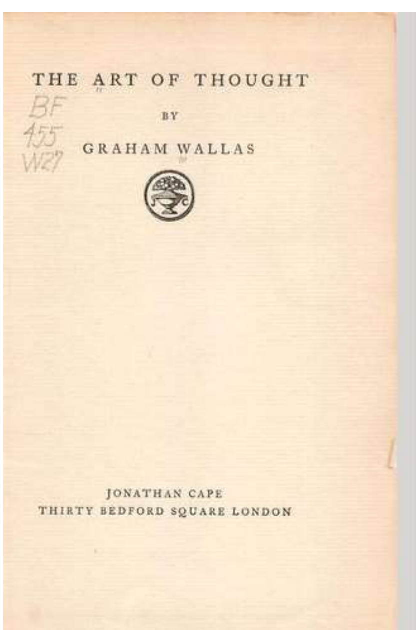

Figure 2. Cover of 'the art of thought' by graham wallas (1926)

Over time, as human knowledge and needs have increased, various versions of the creative thinking process have emerged. Referring to Wallas's creative thinking process, Sadler-Smith (2015) added another stage, bringing the five stages back together, integrating the stages of creative thinking: the intimacy stage. Intimacy occurs between incubation and illumination. Intimacy is described as a "series of associations" at the level of consciousness that overlaps the conscious and subconscious levels.

Cropley & Cropley (2012) believe that Wallas' four stages are indeed appropriate for generating effective new ideas (inventions). However, this innovation goes far beyond invention and includes implementation, so several new stages need to be added to support its emergence. They added activation and generation between the preparation and illumination stages, and added communication and validation after the verification stage. The activation stage involves data collection and the development of problem awareness. The generation stage relates to the development of a range of candidate solutions. The communication stage involves revealing the product to knowledgeable others. Meanwhile, the validation stage concerns the product's launch in the marketplace.

Wallas's stages of creative thinking remain the most frequently referenced model of the creative process in the literature, despite the emergence of other models. For example, Corcuera (2024) explicitly states that the book "The Art of Thought" is the most popular model of the creative process, alongside later models. This statement reveals the influence of Wallas's model's dominance in the discourse on creativity: its stages of preparation, incubation, illumination, and verification have become the standard conceptual framework that continues to be used. Many articles on mathematics education explicitly refer to Wallas, making this model the most conceptually fundamental.

Similarly, Thoring et al. (2021) noted the broadest definition of creativity as a process,

Table 2. Stages of the creative thinking process according to experts

Conceptual Expert	Year of Emergence	Process Stages
Wallas	1926	1. Preparation 2. Incubation 3. Illumination 4. Verification
David H. Cropley dan Arthur Cropley	2012	1. Preparation 2. Activation 3. Generation 4. Illumination 5. Verification 6. Communication 7. Validation
Eugene Sadler-Smith	2015	1. Preparation 2. Incubation 3. Intimation 4. Illumination 5. Verification

stating, "*The most widely accepted definition of creativity as a process is still the one developed by Wallas*." In other words, Wallas is still considered the most widely accepted in explaining the creative process. This quote shows that despite the development of various new theories, the literature (including contextual ones in the educational realm) explicitly and implicitly uses Wallas' stages within its creative thinking framework (Batdal-Karaduman, 2025), while other models (Sadler-Smith and Cropley's stages of creative thinking) only appear in brief discussions as variations. Thus, implicit evidence suggests that Wallas' stages are most frequently used, while Sadler-Smith and Cropley's are less frequently used as the primary conceptual framework.

This finding is supported by a literature search in the Scopus (Elsevier) database using keywords combining the names of prominent figures with the term "creativity." The search results revealed a significant difference in the number of publications referencing each figure. 47 publications referenced Wallas's stage model of creativity, indicating its strong dominance in the study of the creative process. This number is higher than that of Cropley (39 articles) and Sadler-Smith (only 4 publications). This difference indicates that Wallas's model remains the primary reference for understanding creativity as a process in contemporary literature.

The process approach to creative thinking implies that creativity can be learned and enhanced by facilitating the appropriate stages

Table 3. Article search results by figure in the scopus database

Expert	Number of Publications	Interpretation Literature Dominance
Wallas	47	Very dominant as the primary reference for the stages of the creative process
Cropley & Cropley	39	Fairly widely used as a developmental process model
Sadler-Smith	4	Limited use as a conceptual variation

of the process. If teachers understand these stages, they can support students at each stage: for example, by allowing time for incubation (a pause to process information/ideas), encouraging reflective discussion after the illumination phase (the emergence of new solutions), and providing feedback during the verification phase (testing and evaluating emerging solutions).

Creative thinking should not focus solely on assessing creativity by the final product, without considering the process and context. The process view emphasizes the importance of the thinking journey students undertake, not just the final product, allowing teachers to value students' unique ideas, even if they may not yet be fully realized. By understanding creativity as a dynamic process, teachers can design learning experiences that allow for exploration, brainstorming, temporary failure, and unexpected insights, all of which are part of mathematical creativity.

Understanding creativity as a dynamic process enables teachers to design learning experiences that encourage exploration, discovery, and deep reflection. Recent literature (2020–2024) shows that open-ended tasks and problem-posing (e.g., "what-if?" tasks) significantly enhance students' mathematical creativity (fluency, flexibility, originality) (Zioga & Desli, 2025). Teachers need to create a learning environment that allows students to experiment and fail: initial mistakes are considered "early clay" to be re-sculpted (Luzano, 2024). In online/blended contexts, the use of digital tools (such as GeoGebra, collaborative platforms) and generative AI (ChatGPT, Wolfram Alpha, etc.) can enhance exploration. For example, flipped or blended learning has been shown to enhance students' mathematical creativity compared to conventional methods (Tabieh & Hamzeh, 2022). Concrete strategies include contextual project assignments, brainstorming discussions, collaborative learning, and the use of AI to pose idea-provoking questions. Creativity assessment is conducted by combining products (original work and mathematical models) and processes (portfolios, problem-solving journals, and creativity rubrics). Common barriers include gaps in access to technology and teachers' skills, as well as difficulties in measuring creativity. Addressing this requires intensive teacher training in creative pedagogy and digital literacy, as well as curriculum policies that prioritize creative thinking skills (including the development of formative assessment-based rubrics and projects).

Creative Thinking as a Cognitive Ability

The view of creative thinking as an ability stems from several different definitions. Creative thinking is defined as students' ability to engage productively in the development, evaluation, and refinement of ideas that can lead to original and effective solutions, advances in knowledge, and impactful expressions of imagination (Burakgazi & Reiss, 2025). Creative thinking also entails the ability to detect previously unidentified relationships and generate novel experiences as patterns (Yang & Zhao, 2021). In psychological studies, creative thinking is defined as an important high-level cognitive ability closely related to brain functions such as executive function, emotional regulation, and associative processing (Peng et al., 2025).

In mathematics, creative thinking is defined as a person's ability to discover new solutions to mathematical problems (Rahayuningsih et al., 2021) and to generate original and imaginative ideas through technology (Hidajat, 2024). Furthermore, mathematical creative thinking can be defined as the ability to formulate mathematical problems, solve them creatively, and have self-efficacy in mathematical creativity (Hu & Wang, 2024). Mathematical creative thinking is assessed by evaluating students' ability to generate, modify, and innovate hypotheses and to achieve original results in mathematics (Bicer et al., 2024).

Creative thinking as an ability stems from a concept proposed by Guilford. Guilford (1967) stated that creative thinking ability (divergent condition) has its own characteristics, including fluency, flexibility, elaboration, and originality. Fluency refers to the capacity to generate multiple ideas (Suherman & Vidákovich, 2022) or correct solutions to a given task. It is measured by counting the total number of correct mathematical responses to a given task (Ron-Ezra & Levenson, 2025). Flexibility refers to switching between different approaches (Meier et al., 2021) and to generating ideas from different perspectives or categories (Van Hooijdonk et al., 2023). Elaboration refers to the development and enrichment of initial ideas with detail and complexity (Yurt, 2025), the refinement and expansion of ideas (Zioga & Desli, 2025), and the detailing of ideas, making them more comprehensive and actionable (Ji & Wong, 2025). These aspects of creative thinking ability (fluency, flexibility, elaboration, and originality) are often referred to as indicators, aspects, or components. However, these three terms refer to the same understanding, namely the characteristics or signs of someone having creative thinking ability, as stated by Sriraman (2004) and Leikin (2009), that, as an ability, creative thinking can be operationalized through indicators such as fluency, flexibility, originality, and elaboration.

Creativity as a cognitive ability is often measured by four main indicators: fluency (ideas), flexibility (thinking), originality (ideas), and elaboration (ideas). Although popular in creative assessments, recent literature (2020–2024) highlights significant limitations of this approach. For example, high fluency (a large number of ideas) does not always result in high-quality creative solutions. Instead, factors such as mastery of mathematical concepts (accuracy) are found to be more predictive of original outcomes (Bahar, Can, & Maker, 2024). Furthermore, flexibility of thinking often overlaps with fluency (Alabbasi, Paek, Kim, & Cramond, 2022), and originality depends on the task context and is therefore difficult to standardize. A recent review also highlighted that many studies focus solely on product scores (fluency, flexibility, originality) without examining students' thought processes (Sipahi & Bahar, 2025).

This critical perspective has important implications for mathematics assessment and learning. Teachers should not simply enumerate ideas but also facilitate the creative process holistically. Recommended strategies include providing challenging, open-ended tasks, encouraging exploration of diverse approaches, and creating a safe learning environment for experimentation and temporary failure. For example, in online learning, teachers can use discussion forums or collaborative tools (e.g., digital whiteboards) for brainstorming and leverage AI (such as ChatGPT) as a partner to generate ideas while still guiding students critically. Research emphasizes the need for teachers to allow sufficient time, allow for mistakes as part of learning, and encourage students to take academic risks (Turan, Sengil-Akar, & Saygý, 2025). This approach, which emphasizes thinking processes (reasoning, reflection) over output, aligns with contemporary literature and can more meaningfully develop mathematical creativity.

One of the assessment instruments frequently used to measure creative thinking ability is the instrument developed by Torrance (Yu et al., 2023), known as the TTCT (Torrance Tests of Creative Thinking) measuring tool, which includes aspects of fluency, originality, abstractness of titles, elaboration, and resistance to premature closure (Torrance, 2018). Several recent studies that still use the TTCT as an instrument to measure students' creative thinking ability included those by Rubenstein et al. (2022), Sbaih (2023), Tang et al. (2025), and Xu et al. (2025). Specifically in mathematics or mathematics education, instruments for measuring mathematical creative thinking tend to be designed directly by researchers (using indicators of fluency, flexibility, originality, and elaboration) and adapted to the scope of the mathematical material being studied.

Researchers often develop domain-specific mathematics instruments to ensure alignment with syllabi and authentic tasks (e.g., problem posing or open-ended problem solving) (Bal-Sezerel & Sak, 2022; Ikhsana, Anwar, & Sisworo, 2025). The main reasons for creating new instruments include: (1) Curriculum Context Fit – questions are structured around specific mathematical content; (2) Task Authenticity – for example, contextual problems or projects that reflect real-world applications of mathematics; (3) Scoring Focused on Mathematical Quality – rubrics assess the quality of solutions (mathematical rigor, validity) rather than simply the number of ideas; (4) Process vs. Product – emphasizes the process of creative thinking (through observation, think-aloud protocols, or step-by-step artifacts) rather than just the result; (5) Classroom Feasibility – questions and instruments are easily integrated into learning activities (including online) without requiring special training; (6) Language/Culture Issues – adaptation to the local language and cultural context so that questions are relevant (TTCT often needs to be translated and adapted (Ikhsana et al., 2025).

Mathematical creative thinking is a skill that offers several advantages. First, it enables the identification of creative or talented students in mathematics through formal assessment, which is helpful for enrichment or special programs. Second, with quantitative measurement, the effectiveness of a learning intervention or the use of learning media in improving mathematical creative thinking can be evaluated. For example, the use of virtual STEAM Tasks with Artificial Intelligence Mathematical Dance (Cahyono et al., 2025), problem-based learning interventions (Maskur et al., 2020), project-based learning interventions (Ndiung & Menggo, 2024), blended project-based learning model interventions (Mursid et al., 2024), STEM-based learning interventions (Tunceli et al., 2025), or through interventions using GeoGebra (Wahyuni et al., 2025).

This perspective suggests that creativity (as a skill) can be enhanced and its progress tracked. Third, the skills perspective encourages the development of more objective and standardized assessments, for example, for cross-country comparative research or curriculum evaluation. In fact, international assessment frameworks such as the OECD PISA 2021 have also included a creative thinking component that encompasses the mathematics domain, highlighting the importance of measuring creative thinking skills globally.

However, there are also challenges related to creative thinking according to this view. Some critics argue that creativity tests tend to measure simple divergent thinking and fail to capture other dimensions of creativity, such as imagination, emotion, or motivation. A high fluency score does not necessarily guarantee that an idea is valuable or appropriate to the context. Amabile (1982) cautioned that creativity assessments should consider the product within the context of the process and the environment. This means that although creativity is measured as an ability, its interpretation must be careful not to reduce it to mere numbers without understanding the creative process behind it. This encourages the need for integration with the process approach, as discussed in the implications section below (Sipahi & Bahar, 2025).

A Critical Exploration of the Literature Related to Wallas' Stages of the Creative Thinking Process and Guilford's Creative Thinking Ability Indicators

Recent literature demonstrates fundamental criticism of the linear creative process model and the use of Guilford's creativity indicators in problem-solving. Several studies highlight that Wallas's linear model does not reflect the nature of creativity in the field. In contrast, creativity assessments that rely solely on fluency, flexibility, and originality tend to ignore students' thinking processes. These findings reinforce the urgency of developing a nonlinear integrative model that connects the process and product components of creativity.

Some researchers have criticized the assumptions of Wallas's traditional linear model. Sawyer (2021) points out that traditional views of the creative process are often assumed to be linear, when in reality, they are not. He writes that "the creative process has often been conceived as a linear process," but the practices of creative practitioners actually teach a process that is "nonlinear, iterative, and improvisational." In other words, Wallas's four-stage model oversimplifies reality: inspiration or insight can strike at any time, and creators often return to earlier stages or explore ideas at random. Some art/design studio studies even detail eight key characteristics of the creative process, such as iteration, ambiguity, exploration, ideation, failure, reflection, and constraints, emphasizing the cyclical and nonlinear nature of creativity. This gap between linear models and practice is also relevant in the context of mathematical problem-solving, where students typically experiment with strategies, revise ideas, and think along multiple paths simultaneously.

The second criticism concerns Guilford's creativity indicators (fluency, flexibility, originality), which are often used in assessments. Sipahi & Bahar (2025) highlight that most studies prefer product-based scoring, such as counting the number of ideas (fluency) or the uniqueness of ideas (originality), while neglecting to track students' thought processes. They write that overall, "the field prioritizes product-based scoring (e.g., fluency, flexibility, originality) over evidence about students' solution processes." In other words, studies of mathematical creativity tend to assess the final product (number/diversity of solutions) without recording the thinking behind those solutions.

Consistent with this, Forthmann (2026) observes that while fluency and originality can be measured objectively, flexibility "is often subjectively rated, hence influenced by interindividual variations in the perception of semantic similarities." This means that flexibility assessments are highly dependent on the assessor's perception and can vary from one individual to another. Furthermore, Acar et al. (2021) highlight weaknesses in the measurement of originality. In the Torrance Test of Creative Thinking (TTCT), originality is measured using a standardized list of Zero Originality Lists, but "the applicability of those ZOLs to diverse groups has not been examined." This raises doubts about validity: the standardized list may not accommodate cultural variations or the specific context of complex mathematics. Overall, this literature indicates that traditional creativity indicators focus too much on specific outcomes and are prone to bias.

The implications of these critical findings are important for mathematics assessment and learning. If assessments measure only creative output (e.g., the number of correct solutions or the originality of answers), many aspects of the creative process are overlooked. However, complex mathematical tasks often involve nuanced thinking: students try different strategies, evaluate ideas, and may fail before finding a solution. Therefore, Suherman & Vidákovich (2022) recommend more transparent reporting of empirical evidence in mathematical creativity assessment tools, particularly their validity and reliability. They write that "the validity and reliability of the evidence of the MCT assessment tool should be collected and reported in further research." In other words, the design of mathematical creativity assessment instruments should include rigorous validation studies. Several studies also suggest using open-ended assessment tools (e.g., essay questions, think-aloud interviews, qualitative rubrics) to evaluate thinking processes rather than just the final results. In the context of learning, this means that teachers need to encourage students to practice iterative and reflective thinking: for example, by providing opportunities to explore a range of strategies, discussing problem-solving processes, and recognizing the importance of failure as part of the creative learning process (Sawyer, 2021).

These critical findings support the development of a non-linear integrative model, as proposed in the author's flowchart. This integrative model illustrates how the components of creativity influence each other dynamically and cyclically. For example, fluency and flexibility are causally related; generating many ideas (fluency) can trigger new, different ideas (increasing flexibility), and vice versa. Deep idea elaboration (elaboration) can also foster the emergence of further original ideas. By incorporating feedback loops between these stages, this model reflects the complex nature of the creative process as suggested by the literature.

Integrative Justification and Implications for Mathematics Learning

Approaching creativity as both a process and an ability makes significant contributions to the practice of mathematics education. Both approaches complement our understanding of how to stimulate and assess student creativity. Below, we outline the key implications of each perspective and how its integration can be implemented in learning and assessment.

These critical findings call for a more holistic approach to assessment and learning. For example, teachers and researchers are advised to use rubrics that assess the problem-solving process rather than just the final solution. This aligns with Turan et al. (2025) recommendation that teachers allow more time, allow students to make mistakes, and encourage risk-taking. As cited by Turan et al. (2025), Dogan (2020), and Sternberg (2007), mistakes should be viewed as learning opportunities. In practice, teachers can design open-ended tasks (e.g., problems with no single standard answer) that require students to explore multiple approaches. In online classes, this can be realized through group discussions on an online whiteboard, exploratory quizzes, or collaborative projects. Teachers can also leverage artificial intelligence (AI) tools as creative partners for example, having students submit creative questions to ChatGPT or a similar brainstorming tool, then having the teacher critique and develop them together.

The following diagram shows a map of the creative thinking process in mathematical problem solving. Fluency and flexibility emerge during the idea generation stage (the "Idea" diagram). Fluency represents the number of ideas, while flexibility reflects the variety of strategies. The next stage is idea development, where elaboration involves exploring the details of these ideas. Solution selection then occurs; this is where originality comes into play, namely, choosing the most novel or unusual solution. The result is a valid creative solution. A good assessment of the creative process should capture the activities at each stage, not just the final output.

The flowchart on Figures 3 demonstrates that creative thinking in solving mathematical problems is not a linear process but rather a dynamic, iterative one, with interplay among its components. The process begins with the "facing mathematical problems" stage, which involves a deeper understanding of the problem, leading to idea generation and the exploration of possible solutions. At this stage, two key components of creativity emerge: fluency (the ability to generate many ideas) and flexibility (the ability to generate diverse strategies). These two components do not operate in isolation but influence each other causally: a large number of ideas increases the likelihood of diverse strategies, and, conversely, a diversity of strategies can trigger the emergence of new ideas. This flow demonstrates that creativity develops through the continuous interaction between the quantity and variety of ideas, rather than through a single, rigid pathway.

Next, the generated ideas are developed through the idea development and elaboration stages, which emphasize refining, deepening, and enriching them. This process then leads to solution selection, an evaluation to select the best solution, which results in originality as an indicator of the uniqueness of the idea. This flowchart explicitly demonstrates feedback loops, in which failing to select a solution can return an individual to a previous stage, even to the idea-generation stage. Furthermore, in-depth elaboration can also trigger the emergence of new ideas, thus repeating the process. This relationship emphasizes that originality does not emerge immediately but rather results from a complex interaction among fluency, flexibility, and elaboration. Thus, the final creative product is not simply the result of a single stage, but rather the accumulation of a cyclical, reflective, and adaptive process. A good assessment of the creative process must capture the activities at each of these stages, rather than simply calculating the final output, with numerous implications.

First, attention is needed to develop learning strategies that can foster creative thinking. If creative thinking is viewed as a process, teachers need to design learning activities that accommodate all stages of the process. Mathematics learning should not consist solely of routine exercises with a single correct answer, but also include open-ended problems and assignments that require multiple correct answers. Teachers act as facilitators, encouraging students to explore various approaches, appreciating unexpected questions such as "what if" from students, and not providing immediate answers, thereby allowing students to experience the incubation process and gain their own insights.

Furthermore, teachers need to organize the classroom environment to support creative thinking. The theory of creativity as a process suggests the need for an incubation period. Research by Shaw et al. (2022) found that taking a short break during the incubation stage when working on complex problems proved beneficial, improving students' ability to generate new strategies and think more creatively. Therefore, teachers can schedule breaks or assign long-term projects that allow ideas to emerge and develop over time. Teachers can also foster a classroom climate that minimizes failure by encouraging students to generate unique ideas without fear of making mistakes, since mistakes are seen as part of the creative process.

Second, teachers need to implement learning activities that develop students' creative thinking skills through structured practice. From the perspective of creative thinking as a skill, a significant impact is that creativity can be enhanced through structured practice and intervention. The mathematics curriculum can be interspersed with specific activities to train fluency, flexibility, and originality. For example, providing problems by inserting the question "Name as many ways as possible to..." within a particular mathematical concept as a lesson opener. Enrichment programs should be provided to students with mathematical talent by including modules with problems or projects that assess indicators of creative mathematical thinking. If necessary, statements that indicate mathematical creative thinking skills can even be included in the school curriculum's learning objectives. An example of such a learning objective is "Students can generate various original strategies for solving mathematical problems related to the material...".

Third, teachers, who are also classroom assessors, need to develop creative-thinking assessment instruments that include both process and ability assessments. Each perspective (creative thinking as a process stage and as a cognitive ability) highlights different aspects to

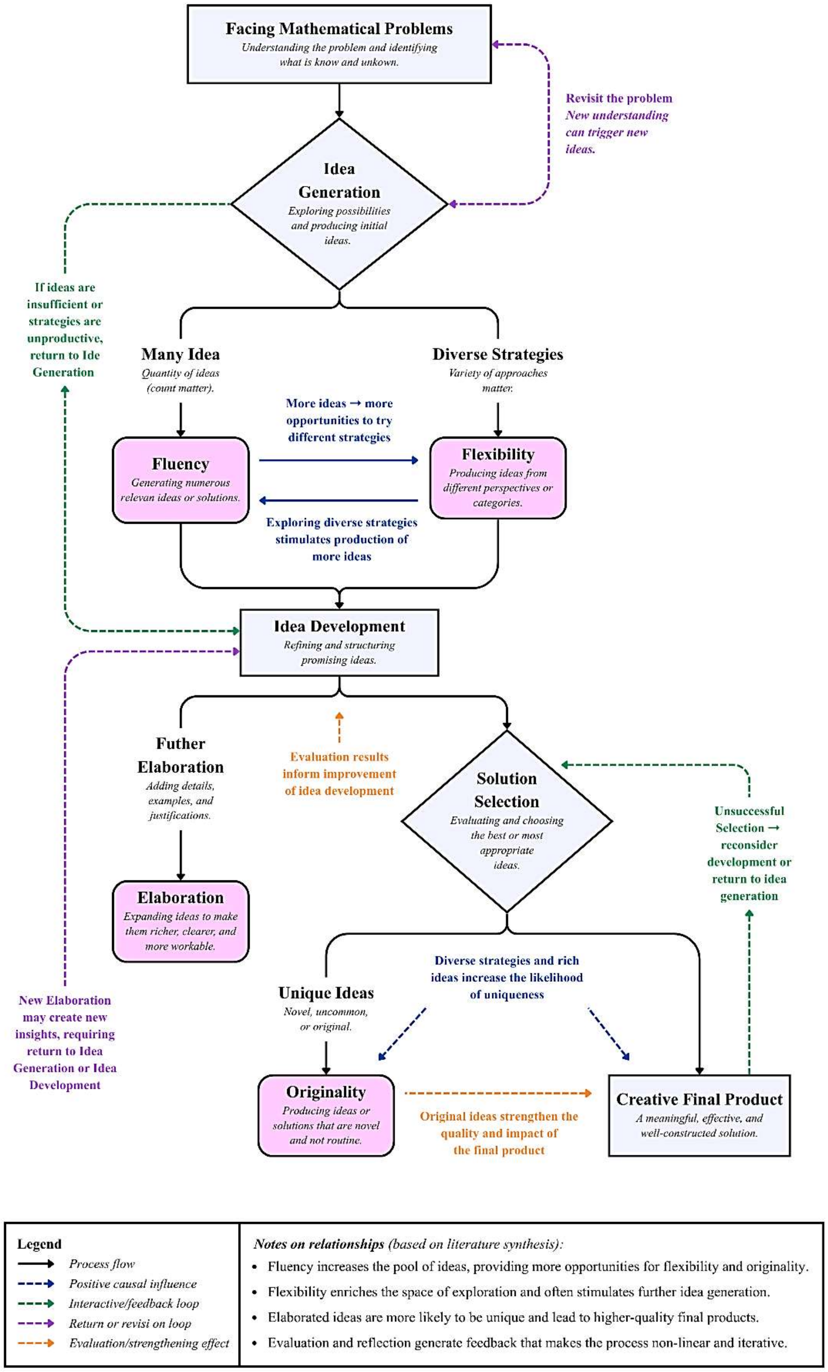

Figure 3. Creative process flowchart and indicators

measure. Relying on only one perspective can lead to an incomplete evaluation. Therefore, efforts are needed to develop comprehensive creative thinking assessment instruments that include assessments of both the final product and the process stage. For example, when students work on open-ended assignments, teachers should not only collect final answers to assess their uniqueness and quantity, but also use process rubrics or creative logs in which students are asked to write down their thoughts, ideas they abandoned, and so on. In this way, teachers not only act as assessors but also see traces of the creative thinking process behind the final product.

Fourth, professional development for teachers related to understanding mathematical creative thinking is necessary. This is in line with the findings of a research study conducted by Shodiq et al. (2025), which revealed that many teachers find it difficult to integrate creativity due to a lack of understanding or classroom experience, underscoring the need for professional development. This implies that mathematics teachers need a deep understanding of the nature of creative thinking to identify students' creative potential and guide their creative processes. This training can include modules on creativity theory (both processes and abilities), designing open-ended assignments, facilitating creative discussions, and assessing creative thinking.

Teacher professional development activities are expected to provide teachers with the means and resources to help students integrate creativity into daily learning activities without sacrificing curriculum content. This is consistent with research by Vale & Barbosa (2024), which found that it is important for teachers to create appropriate learning opportunities that allow students' creativity to flourish and help them develop their mathematical potential. This is particularly true regarding the use of content-rich and challenging tasks that can encourage fluency, flexibility, and originality, three important dimensions of creative thinking.

CONCLUSION

Creativity in mathematics is complex and can be understood from two complementary perspectives: as a process and as a cognitive ability. As a process, creativity is seen as a gradual mental journey that can be facilitated by a conducive learning environment, open-ended problem-solving, and an appreciation of students' unique thinking processes. As a cognitive ability, creativity is considered part of an individual's cognitive profile and can be measured, trained, and improved like other mathematical abilities. Viewing creative thinking as both a process and an ability is equally important: the creative thinking process describes how students think creatively, while the creative thinking ability describes how well students generate creative ideas. The two complement each other in providing a comprehensive understanding of mathematical creativity.

By integrating the process and ability perspectives, mathematics education can simultaneously foster and more comprehensively measure student creativity. Students are trained through experiences that push them through the stages of the creative thinking process (thus honing their creative abilities), and teachers are provided with comprehensive information to assess and nurture that creativity. Ultimately, these two integrated perspectives will produce graduates who are not only able to solve problems correctly but also possess flexible, original, and skilled creative thinking in solving new problems. This integration constructs a conceptual framework that positions mathematical creativity as both a cognitive process and a measurable ability. Unlike previous studies that tended to separate these two perspectives, this review demonstrates that process and ability are two complementary analytical lenses in explaining the dynamics and manifestations of mathematical creativity. This integration is not only conceptual but also has methodological implications for developing more comprehensive learning and assessment designs.

However, this study also uncovers several significant knowledge gaps. First, there is limited empirical research that simultaneously examines the relationships between the stages of the creative thinking process and ability indicators within a single, integrated analytical framework. Second, there is a lack of valid and reliable assessment instruments capable of simultaneously capturing the interaction between the process and product of creativity. Third, there is a lack of longitudinal studies that explore the development of mathematical creativity as a non-linear phenomenon influenced by the learning context, individual characteristics, and pedagogical interventions.

Based on these gaps, several new research questions can be formulated, including: (1) To what extent does the idea generation stage (operationalized through fluency and flexibility) predict the emergence of originality in the solution selection stage in solving mathematical problems? (2) What is the causal relationship between fluency (number of ideas) and flexibility (strategy variation) in improving the quality of students' idea development and elaboration? (3) To what extent does the quality of idea development and elaboration contribute significantly to the formation of an effective and meaningful creative final product?

DECLARATION OF GENERATIVE AI USAGE IN THE WRITING PROCESS

In preparing this manuscript, the author made limited use of artificial intelligence (AI)-based tools to support technical aspects of the writing, such as improving grammar, clarity, editing, and sentence structure. The use of AI did not cover the main conceptual processes, including the formulation of research ideas, literature analysis, interpretation of results, or concluding. All scientific substance, theoretical arguments, and synthesis presented in this article are solely the result of the author's thinking and responsibility. The author has also thoroughly verified all content produced to ensure accuracy, academic integrity, and compliance with ethical standards for scientific publication.

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