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Secondary school students' creativity in STEM education: A systematic literature review ☆

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ABSTRACT

Creativity is increasingly recognized as a crucial 21st-century skill, and STEM education has emerged as a key strategy for fostering it in students. However, creativity in STEM is defined and measured in varied ways, and pedagogical practices differ widely. The present study seeks to identify which fields of creativity are explored in the literature, how these are measured, and what characteristics define the instructional practices commonly implemented in STEM programs. To address these questions, a systematic review was conducted, analyzing studies from the Web of Science and Scopus databases. Following PRISMA guidelines, 22 studies were included after applying a methodological quality appraisal using the Mixed Methods Appraisal Tool (MMAT). The most significant findings indicate that the majority of the research uses quantitative methods and concentrates on students' creative abilities. Creativity is typically defined in several categories, with scientific creativity most often assessed using domain-specific tools. The definitions of creativity provided in the studies generally align with the aspects being assessed. Design-based methodologies are frequently employed in the implementation of STEM projects. The review offers recommendations for educators and researchers, emphasizing the adoption of design-based methodologies and the enhancement of measurement techniques to assess creativity in secondary education, with a particular focus on STEM programs.

1. Introduction

In recent decades, the importance of creativity as a fundamental skill for the 21st century has been increasingly emphasized (OECD, 2024; Scott, 2017), underscoring the imperative to cultivate creative thinking, adaptability, and problem-solving capacities to equip students for a rapidly evolving society (Kalogeratos et al., 2023). Indeed, creative thinking was identified as one of the core skills in 2025 (World Economic Forum, 2025), and it is expected to increase in importance in the future.

Recent research identifies creativity as a key developmental asset during secondary education for several reasons. Firstly, creativity has been shown to predict resilience, with social skills acting as a mediating factor (González Moreno & Molero Jurado, 2024). Furthermore, creativity has been shown to correlate positively with self-esteem (González Moreno & Molero Jurado, 2023), and plays a critical role in identity construction by enhancing cognitive processes involved in self-definition, promoting adaptive self-expression, and reinforcing self-esteem (Barbot & Heuser, 2017). Therefore, balancing autonomy and supervision fosters student confidence,

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openness, and agency, which in turn support creativity and adolescent well-being (Barbot & Golab, 2025; van der Zanden et al., 2020).

To develop effective strategies for promoting creativity in education, the term "creativity" must first be defined. However, the conceptualization of creativity has historically proven to be a persistent challenge. Numerous definitions can be found in the extant literature. For reference, Runco and Jaeger (2012) proposed a standard definition of creativity, encompassing two fundamental characteristics: originality and effectiveness. These are related to people's capacity to generate ideas, along with fluency, flexibility, and elaboration (Torrance, 1962) as well as novelty, resolution, and synthesis (Besemer & Treffinger, 1981). In this regard, several theoretical models have been proposed, including the 4Ps model (Rhodes, 1961), the 5As model (Glăveanu, 2013), and the 7Cs model (Lubart, 2017). Equally, many aspects of creativity can be investigated, such as creative potential (cognitive abilities, personality traits, and expertise), creative behavior, and creative achievements (Benedek, 2024). More recently, scholars have argued for a clearer distinction between creativity-as-product and creativity-as-process, highlighting the need to explicitly conceptualize and assess creative processes in educational research (Green et al., 2024).

1.1. Measuring creativity in education

Measuring creativity remains challenging due to its complexity. Beghetto and van Geffen (2024) propose various tools that have been tailored to align with the aims and approaches of teachers and researchers. Systematic reviews show that creativity is still mainly assessed through divergent thinking tests, self-reports, and product-based subjective methods, with psychological and educational researchers differing in their approaches (Long et al., 2022). The authors found that the assessment of creativity in education is approached differently by psychological and educational researchers, and it is still mainly conducted using divergent thinking or creativity tests, self-report questionnaires, and subjective techniques based on products. Suherman and Vidákovich (2022) indicate that mathematical creative thinking is mainly assessed in secondary schools, primarily through open-ended questions, with little attention to the assessment of the thinking process itself. Burns et al. (2025) report significant variation in definitions and measures of creativity in early childhood education. Li et al. (2024) examine self-assessment in design education, while Zetian et al. (2023) focus on creativity assessment within the design field. However, it is important to note that the participants in the studies analyzed in the latter reviews were exclusively from higher education institutions or professional fields.

1.2. Creativity & STEM education

Creativity often varies by disciplinary context (Baer, 2015). While it is a universal human potential (Guilford, 1950), its expression is shaped by domain-specific tools and conventions (Baer, 2015). Accordingly, Van Broekhoven et al. (2020) argue that education should foster both general and domain-specific creativity, particularly in STEM fields.

Similarly, interdisciplinary approaches have been shown to foster both domain-specific and transferable creative skills (Harris & De Bruin, 2018). Project-based learning and the removal of rigid disciplinary boundaries have been demonstrated to promote divergent thinking and interdisciplinary problem-solving. As an interdisciplinary field, STEM education has been shown to enhance key competencies and adaptability for applying creativity in complex, real-world contexts (Breiner et al., 2012).

Numerous studies highlight the role of STEM education in fostering creativity and 21st-century skills. Wan et al. (2023) show that STEM projects have a positive impact on students' fluency and flexibility in STEM creativity. Methods such as design thinking (He et al., 2023) and engineering design-based learning (Zhang et al., 2024) support the development of design competencies (Rusmann & Ejsing-Duun, 2022). Additionally, Timotheou and Ioannou (2021) find that maker activities promote collective creativity through a co-creation culture and interdisciplinary understanding. However, a recent report prepared for the Joint Research Centre (JRC; Pokropek, 2024) indicates that more experimental studies are needed to determine whether STEM education develops students' creativity. While some studies have focused on primary and even preschool settings (e.g., Yalçın & Erden, 2021), there is a noted need for further research in secondary education (Kanematsu & Barry, 2016; Khushk et al., 2023).

Furthermore, despite the numerous studies that demonstrate the considerable impact of STEM education on cultivating creativity and creative thinking (Aguilera & Ortiz-Revilla, 2021), the concept of creativity is not consistently addressed in STEM-related literature. A significant number of studies have focused on the impact of STEM education on students' creativity, while others have referred to creative thinking (Sumarni & Kadarwati, 2020), problem-solving skills (Akcay Malcok & Ceylan, 2022), divergent and convergent thinking (Bicer et al., 2019), higher-order thinking (Baharin et al., 2018), and scientific creativity (Erkan & Duran, 2023). This raises a critical question: Do these terms refer to the same construct, or do they represent distinct but related cognitive and affective abilities? Clarifying these distinctions is essential for understanding what exactly is being measured and developed through STEM education.

STEM pedagogical practices and their impact on students' creativity warrant further attention. Although not specific to STEM, Cremin and Chappell (2019) identified seven features of creative pedagogy: idea generation, autonomy, playfulness, problem-solving, risk-taking, collaboration, and teacher creativity. Many of these characteristics align with practices in STEM education (Breiner et al., 2012).

Recent reviews highlight the diverse approaches to fostering creativity in STEM education. Soomro et al. (2023) examined makerspaces across educational levels, identifying key creativity-enhancing factors such as student-centered project-based learning, interdisciplinary collaboration, and digital fabrication tools. Similarly, Giang et al. (2024) found that research on problem-solving in STEM mainly uses qualitative and experimental methods, highlighting the need for more quantitative and mixed-methods studies to enrich the field. Meanwhile, Aguilera and Ortiz-Revilla (2021) revealed significant theoretical and practical variability through a decade-long analysis of STEM and STEAM interventions, thereby underscoring the lack of standardized models for applying creativity-focused educational strategies. Accordingly, the JRC notes a lack of consensus on best practices for implementing integrated

STEM education (Pokropek, 2024), emphasizing the need to examine concrete practices that promote problem-solving and creativity.

1.3. The present study

Overall, some aspects of creativity research in secondary STEM education remain underexplored, despite recent studies addressing the topic. Building on the aforementioned theoretical background, the following research questions (RQs) were formulated:

- RQ1. What aspects or types of creativity are being measured in studies of creativity within secondary STEM education?
- RQ2. What instruments are used to measure or assess creativity in secondary STEM students?
- RQ3. What are the features of the practices undertaken in STEM programs to enhance creativity?

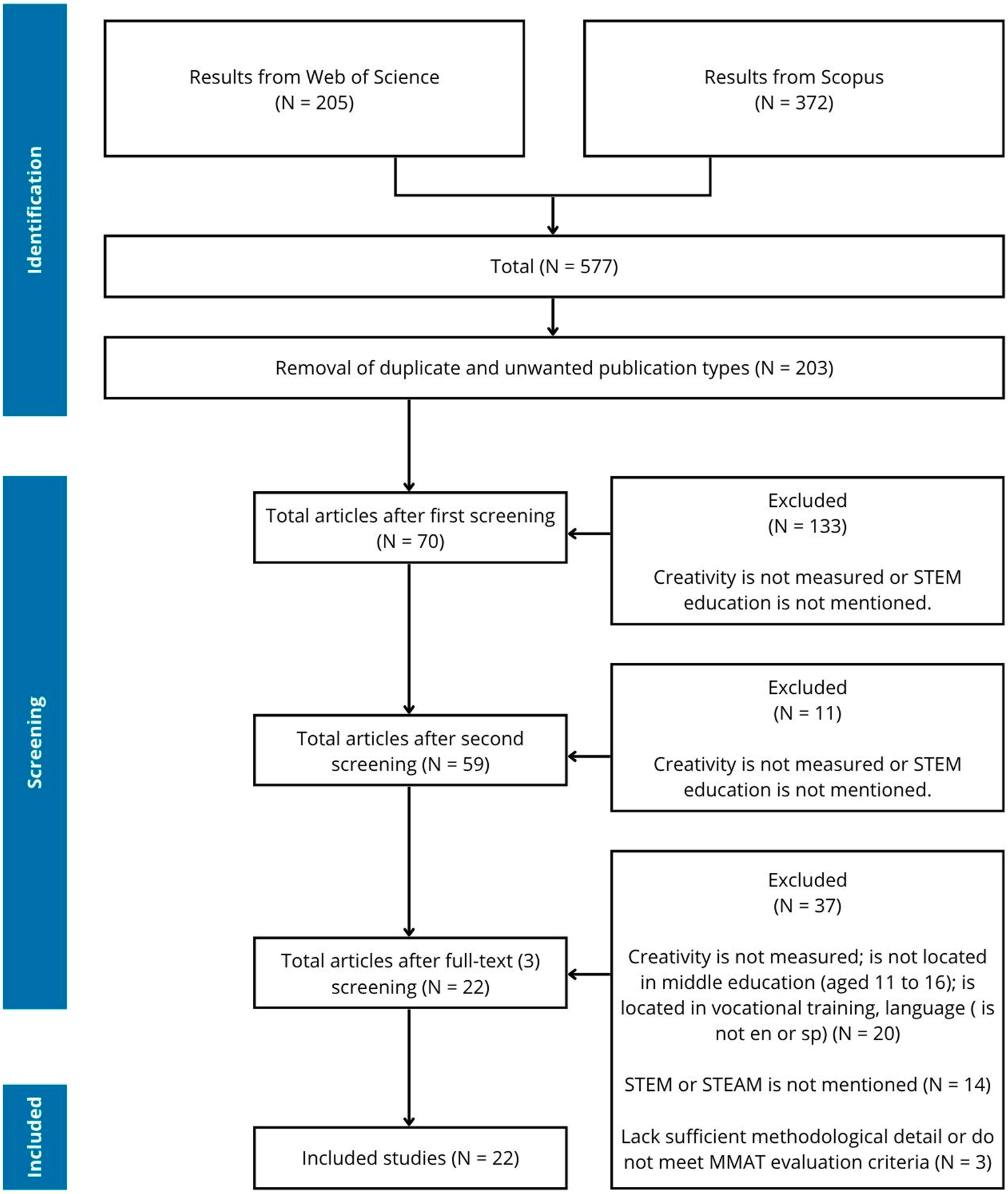

Fig. 1. PRISMA flow diagram for the systematic review.

2. Methods

2.1. Search strategy and data sources

The PRISMA method was used to guide the systematic literature review, ensuring process transparency through detailed documentation. The Parsifal tool (https://parsif.al) facilitated the process. The scope and research questions of the review shaped study selection, data extraction, and analysis, requiring the careful use of PICOC elements (Population, Intervention, Comparison, Outcome, Context). Keywords were extracted from PICOC components, with synonyms identified to build the search string. The initial search strategy was based on six key concepts: educational level, students, creativity, assessment, STEM, and education. The objective was to identify studies in which student creativity was assessed within the context of STEM education at the secondary level. A detailed explanation of the search string construction can be found in the Supplementary Material (Appendix A1). The search string was collaboratively formulated among all authors to ensure comprehensive inclusion of relevant terms. This review focuses on STEM studies conducted in secondary schools that measure student creativity. The resulting search string is as follows:

("secondary school" OR "secondary educat*" OR "middle school" OR "middle educat*" OR "high school") AND ("student*" OR "pupil*") AND (("creativ*" AND "problem" AND "solving") OR ("creativ*" OR "divergent*" OR "creative thinking*")) AND ("assess*" OR "test*" OR "measure*" OR "effect*" OR "impact*" OR "foster*") AND ("STEM" OR "STEAM" OR "STE(A)M" OR "technology classroom" OR "engineering design" OR "design process*" OR "design thinking") AND ("educat*")

The literature search was conducted across two scientific databases: Web of Science (https://www.webofscience.com/) and Scopus (https://www.scopus.com/). The search included articles published up to the end of 2024, and the search was conducted on January 4, 2025.

2.2. Eligibility criteria

The following inclusion criteria were applied and agreed upon by all authors:

- Creativity focus: Studies were required to explicitly examine students' creativity. While different study designs and methodologies were accepted, the primary aim had to be the analysis of students' creativity.
- Study design: Only empirical studies were included. Eligible studies had to report original data (qualitative, quantitative, or mixed methods) on students' creativity. Theoretical, conceptual, and review papers were excluded.
- Intervention context: Studies had to investigate students' creativity within the context of STEM education. Given the lack of consensus regarding the definition of STEM education (Pokropek, 2024), terms related to engineering, design, or technology education were also included in the search string.
- Population: Studies had to be conducted in secondary education settings and focus on students.
- Language: Only articles published in English and Spanish were included.
- Type of publication: Only peer-reviewed journal articles were considered. Other publication types, such as book chapters, conference papers, reviews, errata, and retracted articles, were excluded.

2.3. Study selection

After conducting searches in Web of Science ($N = 205$) and Scopus ($N = 372$), the results were exported to spreadsheet software, and duplicate records and studies that did not meet the language and publication type eligibility criteria were removed by the first author, leaving 203 articles.

Subsequently, study selection was performed in three stages (title, abstract, and full-text screening) by the first and second authors. Disagreements were resolved in consultation with the third author (see Fig. 1).

2.4. Data extraction

Data were extracted into a custom-designed data extraction form in spreadsheet software. The extraction framework was developed to systematically capture key characteristics of the included studies and was refined during the initial stages of the review process.

The first and second authors conducted the data extraction in a structured manner, and the research team reviewed and validated it to ensure methodological rigor. Discrepancies identified during the data extraction process were addressed through team discussion.

The following information was extracted from each study: publication details (authors, year of publication, paper title, source title, DOI, and abstract); study aim; study characteristics (study design and approach, data collection tools or methods, participants, age, and country); creativity-related aspects (definition of creativity and specific dimensions or constructs analyzed); and a detailed description of the intervention (program duration, instructional methodology, implemented technology, and intervention details).

This process enabled a structured comparison of studies and supported the subsequent analysis of how creativity was conceptualized and assessed across STEM education contexts.

2.5. Quality appraisal

The methodological quality of the included studies was assessed using the Mixed Methods Appraisal Tool (MMAT), because it enables the evaluation of qualitative, quantitative, and mixed-methods studies within a single review framework.

Following the procedure proposed by Hong et al. (2018), the appraisal was conducted in several steps. First, two screening questions were applied to ensure that all included studies were empirical. Second, each study was classified according to its methodological design (qualitative, randomized controlled, non-randomized, quantitative descriptive, or mixed-methods), and the corresponding MMAT criteria were applied, with each item rated as “yes,” “no,” and “can’t tell.”

The appraisal was conducted by the first author and subsequently reviewed by the research team to ensure consistency and reliability. Any uncertainties or disagreements were resolved through discussion.

Based on the MMAT assessment, studies that did not achieve a minimum level of methodological quality were excluded from the final synthesis. Specifically, three studies were omitted due to limitations (Fernández-Morante et al., 2022; Gök & Sürmeli, 2022; Wang & Li, 2024), such as the absence of a control group or the lack of validated measurement instruments. Consequently, 22 studies were selected for the final analysis.

The detailed appraisal criteria and the full results of the quality assessment are provided in the Supplementary Material (Appendix A2 and A3).

2.6. Data analysis

The extracted data were analyzed through a descriptive and framework-guided approach. First, a descriptive analysis was conducted to summarize the main characteristics of the included studies, such as the country in which the study was conducted, the students’ age range, the study design and aims, and the additional dimensions explored alongside creativity.

Subsequently, studies were examined to identify how creativity was conceptualized and assessed. For this purpose, a classification framework integrating three established models of creativity was applied: the 4Ps model (Rhodes, 1961), the 5As model (Glăveanu, 2013), and the 7Cs model (Lubart, 2017). This framework enabled the identification of seven analytical dimensions: the individual, the process, the outputs, the social reception, the context, the collaboration, and the curriculum.

In addition, particular attention was given to the instruments used to measure students’ creativity and to the characteristics of the STEM interventions implemented to foster creativity. This allowed for a more detailed understanding of how creativity was operationalized and supported across studies.

Rather than applying a formal coding scheme, studies were categorized according to the aspects of creativity explicitly addressed in their aims, methods, and reported findings. Each study could be associated with one or more dimensions, reflecting the multidimensional nature of creativity.

The classification was conducted by the first author and discussed with the research team to ensure consistency and alignment with the theoretical framework. The results were then synthesized to identify patterns in how creativity was conceptualized and assessed within the context of STEM education research.

3. Results

3.1. General characteristics and objectives of included studies

Most studies were conducted in Asia, with only two exceptions (see Table 1). Sample sizes ranged from 24 to nearly 900 students. All studies were conducted in secondary schools, with most targeting one or two grades, though some covered ages 11–16 across the full secondary school period (see Fig. 2).

Seventy-three percent of the studies used a quantitative design; 17% used a mixed-methods approach (Baran et al., 2021; Chen & Lo, 2019; Kim et al., 2023; Ladachart et al., 2024), and only two studies employed qualitative methods (Bozkurt Altan & Tan, 2021; Weng et al., 2023).

Most studies examined the impact of specific STEM projects on students’ creativity, often focusing on particular practices implemented within those projects. For example, Jalaludin et al. (2024) evaluated the EYE program using Zoom; Kim et al. (2023) studied an intercultural STEAM program; and Weng et al. (2023) explored Scratch-based programming. Many focused on active methodologies such as human-centered design (Chen & Lo, 2019), STEM-EDELCY (Herianto et al., 2024), design-based learning (Ladachart et al., 2024), STEAM design processes (Ozkan & Umdu Topsakal, 2021), and 5E-based STEM (Shahbazloo & Abdullah Mirzaie, 2023). Some studies compared different methodologies (Herianto et al., 2024; Maskur et al., 2022; Zhan et al., 2023). Furthermore, creativity was not always the sole variable measured (see Table 2).

3.2. Creativity aspects measured in included studies

The reviewed studies were categorized according to the aspects of creativity they assessed. This categorization (see Table 3) was informed by an integrative framework combining three widely recognized models of creativity: the 4Ps model (Rhodes, 1961), the 5As model (Glăveanu, 2013), and the 7Cs model (Lubart, 2017). Overall, the analysis indicates that while a substantial number of studies focused on a single aspect of creativity, others adopted a more comprehensive approach by combining multiple creativity dimensions (e.g., Bozkurt Altan & Tan, 2021; Herianto et al., 2024; Hsiao et al., 2022; Jalaludin et al., 2024; Kim et al., 2023; Saleh et al., 2020; Tran et al., 2021; Tubb et al., 2020; Weng et al., 2023; Zhan et al., 2023).

Across all included studies, creativity was primarily examined at the individual level, conceptualized as a perception, trait, or ability. Consequently, the individual dimension is the most consistently assessed aspect of creativity in the reviewed literature. As

Table 1
Summary of Included Studies and Quantitative Tools Used.
Note. Authors' own work.

Study reference	Country	Tool name(s)	Tool author(s)	Tool reliability	Tool validity	Measured/analised dimensions
(Baran et al., 2021)	Turkey	a) 21st-century Skills Usage Scale b) Environmental Awareness Scale	a) Orhan Göksün (2016) b) Çetin and Yalçınkaya, 2018	a) Original scale's construct reliability. Cronbach's alpha. b) Original scale's construct reliability. Cronbach's alpha.	a) Original scale's construct validity b) Original scale's construct validity	a) Cognitive skills, Autonomous skills, Cooperation and flexibility skills, Innovation skills b) Environmental Sensitiveness sub-dimension
(Borg Preca et al., 2023)	Malta	a) Alternate Uses Test (AUT) b) Biographical Inventory of Creative Behaviours (BICB)	a) Guilford et al. (1960) b) Adapted from Batey (2007)	a) Explicitly calculated Pearson's bivariate correlation (having resolved divergences between the raters). b) Not reported	a) Explicitly established PCA b) Not reported, just a theoretical justification	a) Divergent thinking b) Participation in creative activities
(Bozkurt Altan & Tan, 2021)	Turkey	(No quantitative tool used)				a) Fluency, flexibility, originality, and elaboration of the idea generation processes b) Contextual factors influencing creativity c) Students' own perception of creativity during DBL
(Chang et al., 2023)	Taiwan	a) Torrance Test of Creative Thinking (TTCT), verbal and figural b) Bebras Computing Challenge	a) Chinese version: (Wu et al., 1998) b) https://www.bebraschallenge.org/	a) Not reported b) Not reported	a) Not reported, just a mention of the prior validation by Wu et al. (1998) b) Not reported	a) Fluency, Flexibility, Originality, Elaboration b) Computational Thinking
(Chen & Lo, 2019)	Hong Kong	A modified version of The Runco Ideational Behavior Scale (RIBS)	Runco et al. (2001)	Explicitly calculated Cronbach's alpha.	Not reported, just a theoretical justification.	Factor 1: divergent thinking, idea fluency, originality Factor 2: cognitive side-effects of ideation (e.g., distraction)
(Cho et al., 2018)	Korea	Development of life skills: communication, problem-solving, and self-directed learning	Korean Educational Development Institute (KEDI) (2003)	Explicitly calculated Cronbach's alpha	Explicitly established construct validity by EFA.	Problem recognition, Information collection, Analytical ability, Divergent thinking, Decision making, Planning ability, Action and risk-taking, Assessment, Feedback
(Eroğlu & Bektaş, 2022)	Turkey	a) Atomic System and Periodic Table Academic Achievement Test (ASPTAT) b) Scientific creativity test (SCT) c) Views of Nature of Science Questionnaire (VNOS-C)	a) Authors developed instrument b) Hu and Adey's (2002) Turkish version: (Deniş Çeliker & Balım, 2012) c) Lederman et al.'s (2002)Turkish version: (Ayvaci, 2007)	Explicitly calculated Cronbach's alpha in all of them.	a) Author-developed; explicit empirical validity b) Adapted; theoretical validity only c) Standardised; inherited validity	a) Students' academic achievement in the topic of the atomic system and the periodic table. b) Fluency, Flexibility, Originality c) Students' views, beliefs, and understanding of the Nature of Science

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Table 1 (*continued*)

Study reference	Country	Tool name(s)	Tool author(s)	Tool reliability	Tool validity	Measured/analised dimensions
(Herianto et al., 2024)	Indonesia	(Ad-hoc tool)		Reliability established through internal consistency (composite reliability) and indicator reliability (outer loadings)	Explicitly established content validity (Aiken's V) and construct validity (CFA/PLS-SEM)	Critical thinking, Creative thinking, Written communication skills, Collaboration
(Hsiao et al., 2022)	Taiwan	a) STEAM Knowledge Examination Paper (STEAM KEP) b) Creative Product Analysis Matrix (CPAM) c) Creativity Assessment Packet (CAP)	a) Authors developed instrument b) (Besemer & Treffinger, 1981) c) Chinese version: (Lin & Wang, 1994)	a) Not reported b) Explicitly calculated Cohen's Kappa c) Inherited reliability	a) Expert-based revision b) Inherited validity c) Inherited validity	a) STEM content knowledge b) Novelty, Resolution, Elaboration and synthesis, Risk-taking, Curiosity, Imagination, Complexity
(Jalaludin et al., 2024)	Malaysia	(Adapted from previous related studies)	(Not reported)	Not reported	Not reported	21st-century skills, Scientific process skills, Scientific creativity
(Kim et al., 2023)	Korea (and Australia)	Revised Science Classroom Creativity Questionnaire (R-SCCQ)	SCCQ original (Hong et al., 2022) was modified in this study: R-SCCQ	Explicitly calculated Cronbach's alpha	Expert-based revision and inherited validity	Students' characteristics, participation in science class, science teacher support, science classroom environment, and creative behavior
(Kim & Lee, 2022)	Korea	a) Creative Problem-Solving Profile Inventory (CPSPI) b) Attitudes Toward Convergence (ATC)	a) (Lee et al., 2014) b) (Shin et al., 2014)	Original scale's construct reliability in both tools. Cronbach's alpha.	Inherited validity in both tools.	a) Problem-finding and analysis, Generating ideas, Execution plan, Execution, Persuade and communicate b) Knowledge, Personal relevance, Social relevance, Interest, Self-efficacy
(Kırıcı & Bakırcı, 2021)	Turkey	Scientific creativity test (SCT)	(Hu & Adey, 2002)	Explicitly calculated Cronbach's alpha	Expert-based revision and item-based validity	Fluency, Flexibility, Originality
(Ladachart et al., 2024)	Thailand	(No name)	(Ladachart et al., 2022): Based on (Dosi et al., 2018)	Explicitly calculated Cronbach's alpha	Not reported, just a theoretical justification	Creative confidence
(Maskur et al., 2022)	Indonesia	(Ad-hoc tool)	Created from the Indonesian curriculum (Kementerian Pendidikan dan Kebudayaan Republik Indonesia, 2014)	Explicitly calculated Cronbach's alpha	Not reported, just a theoretical justification: curriculum alignment	Creative thinking, Critical thinking
(Ozkan & Umdu Topsakal, 2021)	Turkey	Torrance Test of Creative Thinking (TTCT) verbal and figural	Torrance's (1966) Turkish version: (Aslan, 2001)	Explicitly calculated Cronbach's alpha	Inherited validity	Fluency, Flexibility, Originality, Abstractness, Elaboration, Resistance
(Saleh et al., 2020)	Malaysia	a) Newtonian Conceptual Understanding Test (NCUT) b) Inventive Thinking Skills Test (ITST)	a) Adapted from Force Concept Inventory (Hestenes et al., 1992) and Physics SPM questions (developed by the Malaysian Examination Board) b) Developed based on Kuratko and Hodgetts (1992); NCREL and Metiri Group (2003), and Ali (2014)	a) Explicitly calculated KR-20 b) Explicitly calculated Cronbach's alpha	a) Inherited validity b) Expert-based and theoretical validity	a) Core physics concepts such as force, motion, and laws of motion b) Management and adaptation to complexity, Self-regulation, Curiosity, Creativity, Risk-readiness, High-order thinking skills, and sound reasoning

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Table 1 (*continued*)

Study reference	Country	Tool name(s)	Tool author(s)	Tool reliability	Tool validity	Measured/analised dimensions
(Shahbazloo & Abdullah Mirzaie, 2023)	Iran	a) Torrance Creativity Test, Visual Form B b) Teacher-prepared Science and Mathematics Exams	a) (No reference to the study) b) Created from the National curriculum of Iran	a) Explicitly calculated Cronbach's alpha b) Not reported	a) Inherited validity b) Not reported	a) Fluency, Flexibility, Originality, Elaboration b) Science and mathematics academic achievement
(Tran et al., 2021)	Taiwan	Scientific creativity test (SCT)	(Hu & Adey, 2002)	Explicitly calculated Cronbach's alpha	Inherited validity	Fluency, Flexibility, Originality
(Tubb et al., 2020)	Australia	Mathematical creativity assessed with CAT (Amabile, 1982)	Based on (Baer, 1991)	Inter-rater reliability calculated	Not reported, just a theoretical justification	Mathematical creativity
(Weng et al., 2023)	China	(No quantitative tool used)				a) Students' creative decision-making while solving problems b) The qualities of their digital artifacts c) How the learning environment fosters or constrains creativity d) Students' reflections on their creative processes.
(Zhan et al., 2023)	China	a) Creative thinking test (CTT) -> assessed by CAT (Baer & McKool, n. d.) b) Williams' Creativity Aptitude Test (WCAT) c) Basic Empathy Scale d) Creative Idea Evaluation Form	a) (Zheng & Xiao, 1983) b) (Williams, 1993) c) (Jolliffe & Farrington, 2006) d) Authors developed instrument	Not reported for either tool	Validity inherited from previously validated tools	a) Fluency, Flexibility, Uniqueness b) Imagination, Risk-taking, Curiosity, Challenge c) Cognitive and affective empathy d) Fluency, Flexibility, Uniqueness, Precision, Sensitivity

shown in Table 3, the specific individual-level dimensions varied across studies, encompassing creative skills, perceptions, beliefs, and dispositional traits. Five studies focused exclusively on the problem-solving dimension. For instance, Cho et al. (2018) delineated problem-solving ability through components such as problem recognition, information collection, analytical ability, divergent thinking, decision-making, planning ability, action, risk-taking, assessment, and feedback. Kim and Lee (2022) described creativity as problem-solving, although the authors referred to mathematical and scientific problems. Furthermore, creative convergence was identified in the definition as a factor directing actions such as connection, decision-making, or refinement. As Weng et al. (2023) have noted, creativity "enables the production of new and valuable things and the capability to propose different solutions to a problem" (p. 307). In addition, problem-solving ability was identified as a component of the creativity construct assessed in numerous studies (Bozkurt Altan & Tan, 2021; Chen & Lo, 2019; Ozkan & Umdu Topsakal, 2021; Tran et al., 2021).

Another skill identified in the studies was idea generation. Borg Preca et al. (2023) mention divergent thinking as the capacity to produce novel, original, or unique, as well as useful, appropriate, or contextually relevant ideas. Chang et al. (2023) align with the aforementioned concept, yet they emphasize the role of empathy in the context of divergent thinking activities. Maskur et al. (2022) and Zhan et al. (2023) both incorporate imagination into the definition of this aspect. However, the latter added further characteristics, including risk-taking, curiosity, and challenge. Furthermore, idea generation was identified as a component of the creativity construct assessed in several studies (Bozkurt Altan & Tan, 2021; Chen & Lo, 2019; Hsiao et al., 2022; Ozkan & Umdu Topsakal, 2021; Tran et al., 2021).

Inventive thinking skills were an additional aspect recognized. Although they were identified only once (Saleh et al., 2020), it is noteworthy that they integrate creative and critical thinking and incorporate specific elements from the NCREL and Metiri group (2003, as cited in Saleh et al., 2020) framework: management and adaptation to complexity, self-regulation, curiosity, creativity, risk-readiness, higher-order thinking skills, and sound reasoning.

The final general aspect within this category treats creativity as an integral component of 21st-century skills. Two studies examined how interventions explored the impact on students' 21st-century skills (Baran et al., 2021; Herianto et al., 2024). The descriptions of the aspects analyzed indicate characteristics such as critical thinking, problem-solving, collaboration, effective use of technology,

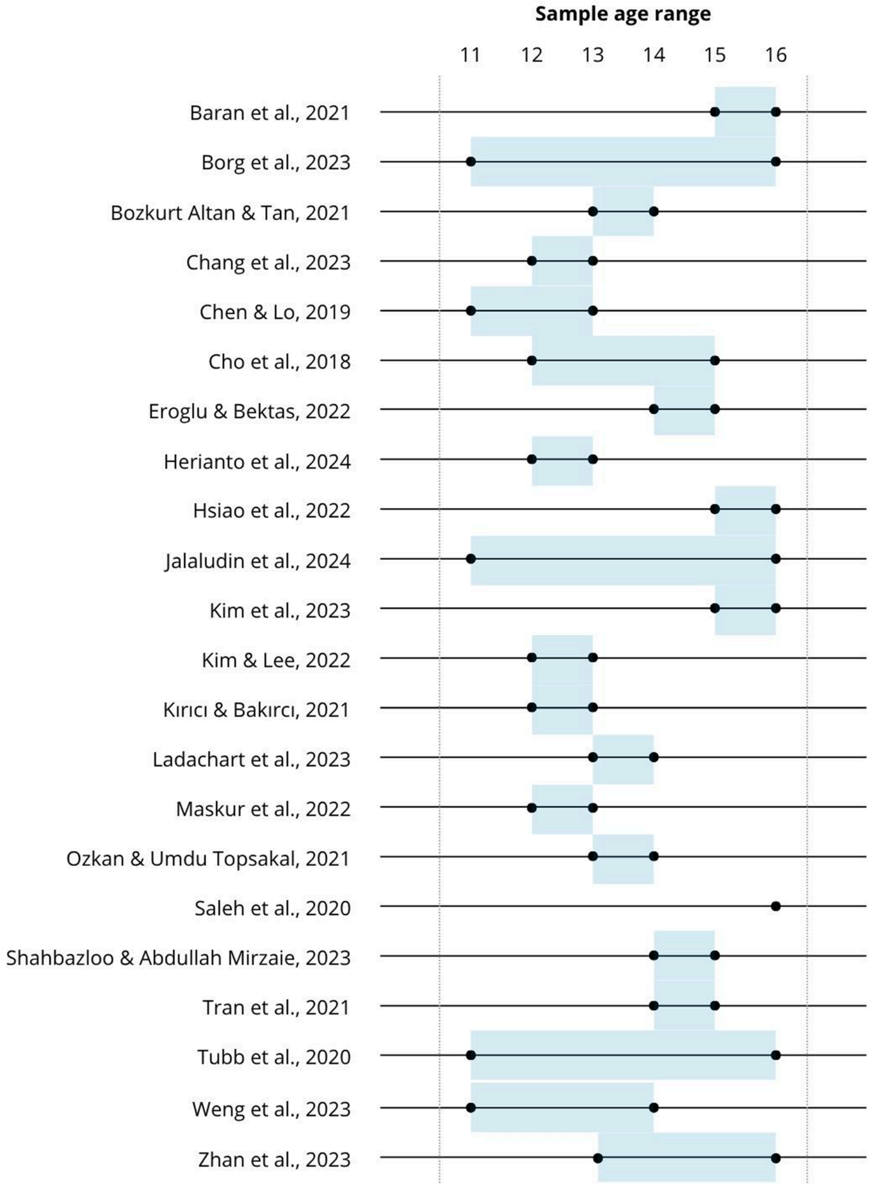

Fig. 2. Sample Age Range by Study.

Table 2
Dimensions measured in addition to creativity.
Note. Authors' own work.

Studies	Dimensions
(Baran et al., 2021; Herianto et al., 2024)	21st-century skills.
(Chang et al., 2023)	Computational Thinking.
(Cho et al., 2018)	Problem solving.
(Jalaludin et al., 2024)	21st-century skills, scientific creativity, and scientific process skills.
(Hsiao et al., 2022)	STEAM knowledge, creativity, and hands-on performance.
(Maskur et al., 2022)	Critical Thinking.
(Saleh et al., 2020)	Inventive Thinking skills.
(Shahbazloo & Abdullah Mirzaie, 2023; Tubb et al., 2020)	Learning performance or knowledge.
(Zhan et al., 2023)	Students' creative thinking, aptitude, empathy, and design scheme.

Table 3
Creativity categorization
Note. Authors' own work.

	The individual Who creates: traits, abilities, identity…	The process How creativity unfolds over time	The outputs What is produced	The social reception How creativity is judged and used	The context Where creativity happens	The collaboration Creativity as a collective activity	The curriculum How creativity is taught
4Ps (Rhodes, 1961)	Person	Process	Product	(Implicit in press)	Press	(Implicit)	(Implicit in press)
5As (Glăveanu, 2013)	Actor	Action	Artifact	Audience	Affordances	(Distributed across actor-audience)	(Implicit in affordance)
7Cs (Lubart, 2017)	Creator	Creating	Creation	Consumption	Context	Collaboration	Curriculum
(Baran et al., 2021)	X				Described		As an intervention
(Borg Preca et al., 2023)	X						
(Bozkurt Altan & Tan, 2021)	X	X			X	X	As an intervention
(Chang et al., 2023)	X**				Described		
(Chen & Lo, 2019)	X				Described		As an intervention
(Cho et al., 2018)	X				Described		Descriptive only
((Eroğlu and Bektaş, 2022)	X*				Described		National curriculum
(Herianto et al., 2024)	X				Described	X	As an intervention
(Hsiao et al., 2022)	X**		X		Described		As a intervention
(Jalaludin et al., 2024)	X*				X		
(Kim et al., 2023)	X*	X			X	X	
(Kim & Lee, 2022)	X				Described		Alignment with national standards
(Kırıcı & Bakırcı, 2021)	X*				Contextualised		National science curriculum
(Ladachart et al., 2024)	X				Described		As an intervention
(Maskur et al., 2022)	X				Described		As an intervention
(Ozkan & Umdu Topsakal, 2021)	X				Described		National science curriculum
(Saleh et al., 2020)	X**		X		Described		National physics curriculum
(Shahbazloo & Abdullah Mirzaie, 2023)	X**				Described		National science curriculum
(Tran et al., 2021)	X*		X		Described		As an independent variable (comparison of two interventions)
(Tubb et al., 2020)	X*		X		Described		As an intervention
(Weng et al., 2023)	X	X	X		X		As an intervention
(Zhan et al., 2023)	X		X		X		As an intervention

X: Creativity was assessed.
X*: Creativity of the individual or creator was measured, specifically, scientific creativity or mathematical creativity.
X**: Creativity of the individual or creator was measured, combined with quantitative measures from other disciplines.

interdisciplinary work, effective communication, and creativity.

Nevertheless, it is noteworthy that several studies focused on domain-based creativity among students, indicating an interest in discipline-specific conceptualizations of creativity rather than general creative ability. Specifically, mathematical and scientific creativity were identified. For instance, Eroğlu and Bektaş (2022); Kırıcı and Bakırcı (2021), and Tran et al. (2021) used a unidimensional definition of scientific creativity. Nevertheless, scientific creativity was identified in numerous studies as a component of the broader creativity construct assessed (Jalaludin et al., 2024; Kim et al., 2023). In addition, the study conducted by Tubb et al. (2020) focused exclusively on mathematical creativity, which is defined as the ability to engage in divergent production within mathematical situations. Furthermore, several studies adopted a multidimensional assessment approach by combining creativity measures with additional quantitative indicators from other domains. Specifically, Chang et al. (2023) assessed computational thinking; Hsiao et al. (2022) measured students' STEM content knowledge; Saleh et al. (2020), Newtonian conceptual understanding; and Shahbazloo and Abdullah Mirzaie (2023), science and mathematics achievement.

The second most frequently assessed aspect of creativity concerned creative output. Studies adopting this focus (Hsiao et al., 2022; Saleh et al., 2020; Tran et al., 2021; Tubb et al., 2020; Weng et al., 2023; Zhan et al., 2023) evaluated the artifacts produced by students during the pedagogical interventions, with the creative outcomes typically being assessed by researchers, teachers, or expert raters.

Process-related dimensions are theoretically central to creativity research but remain empirically underrepresented as research outcomes, with only three of the 22 studies explicitly examining them. Although many studies described the instructional processes implemented during the interventions, often framing these processes as inherently creativity-related, the creative process itself was rarely positioned as a primary research objective. Notably, in the three studies that did assess process-related dimensions, the creative process was examined exclusively through qualitative methods, including interviews, field notes, and behavioral coding.

Contextual and sociocultural dimensions of creativity are often treated implicitly rather than being directly measured. In most studies, context is described as part of the intervention setting but is rarely operationalized as a dependent variable. Only a limited number of studies explicitly assessed contextual factors related to creativity. For example, Bozkurt Altan and Tan (2021) examined creativity within a design-based learning process situated in a natural environment. Jalaludin et al. (2024) explored students' skills in a virtual learning context, comparing outcomes between rural and urban students. Similarly, Kim et al. (2023) examined creativity within the science classroom by analyzing five interrelated dimensions that combined internal and external components, including students' characteristics, participation in science classes, teacher support, classroom environment, and creative behavior. In Weng et al. (2023), creativity was examined within a virtual environment, with particular attention to how the learning environment afforded or constrained creative expression. Finally, Zhan et al. (2023) conducted their study during the COVID-19 pandemic, aligning the intervention with real-life user needs; the use of explicit design constraints and interview data highlighted how authentic contextual factors influenced creative outcomes.

The dimension of social reception was implicitly present in some studies in which creative outputs were evaluated by experts; however, the perception of creativity by third parties was not explicitly treated as a research objective in any of the reviewed studies. Although creativity as a collective and socially situated activity was discussed in several articles, it was rarely operationalized as a distinct assessed dimension.

Regarding Lubart's (2017) curriculum dimension, all studies were situated within secondary education contexts and involved pedagogical interventions aimed at fostering creativity, assessing specific curricular competencies, or analyzing creativity in relation to a particular instructional approach. Nevertheless, the level of curricular detail varied considerably across studies. While some articles provided only limited descriptions of the implemented interventions, Tran et al. (2021) compared multiple instructional designs, differing in implementation order to examine their relative effects.

3.3. Instruments for measuring students' creativity

A wide array of tools was identified in the analyzed studies. In 20 of these studies, data were collected using a quantitative tool. Most studies relied on previously validated instruments, such as the Torrance Test of Creative Thinking (TTCT), Williams's Creativity Aptitude Test (WCAT), and the Runco Ideational Behavior Scale (RIBS), although the most widely used instrument was the scientific creativity questionnaire developed by Hu and Adey (2002), utilized in three studies (Eroğlu & Bektaş, 2022; Kırıcı & Bakırcı, 2021; Tran et al., 2021). The remaining studies employed a variety of quantitative instruments (see Table 1), and several studies used multiple tools.

Across the reviewed studies, the quality of quantitative measurement varied considerably in terms of reported reliability and validity. To address this, information regarding reliability and validity for each measurement tool was systematically extracted and reported (see Table 1). Studies that relied on validity evidence established in previous studies rather than re-establishing it empirically within the current samples. When tools were adapted or translated, the appropriateness of these adaptations was examined based on reported procedures such as expert review, pilot testing, and recalculation of reliability coefficients. Internal consistency reliability, most commonly assessed using Cronbach's alpha, was explicitly calculated in a substantial proportion of studies, particularly when adapted versions of existing tools were employed. In contrast, several studies using standardized instruments did not report reliability coefficients, assuming adequacy based on prior use. A smaller subset of studies demonstrated stronger methodological rigor by explicitly establishing construct validity through exploratory factor analysis, confirmatory factor analysis, or principal component analysis.

Three of these studies documented the development of a novel instrument (Herianto et al., 2024; Jalaludin et al., 2024; Maskur et al., 2022). These cases demonstrated the greatest variability in measurement quality: while some studies conducted expert-based content validation or applied indices such as Aiken's V, others reported neither reliability nor validity evidence (Jalaludin et al., 2024).

Overall, the findings indicate a predominant reliance on previously established validity evidence from standardized tools, with reliability more frequently reported than validity. This highlights the need for clearer and more consistent psychometric reporting in creativity research within the STEM education field.

3.4. Characteristics of STEM programs developed to enhance creativity

Two studies failed to provide detailed descriptions of their STEM interventions. The underlying reasons for this absence of detail vary. Borg Preca et al. (2023) used an existing dataset; although the study met the empirical inclusion criteria, no pedagogical details about the intervention were available. Tubb et al. (2020) used a cohort-sequential design with data from 2016 to 2018, meaning that no single intervention could be directly associated with the reported results.

The remaining studies provided a more comprehensive overview of the intervention implementations. Further details on the duration, instructional methodology, implemented technologies, and program descriptions are provided in the Supplementary Material (Appendix A4). Program content varied, but most involved design-based challenges requiring students to develop solutions.

A considerable number of studies (Chang et al., 2023; Chen & Lo, 2019; Cho et al., 2018; Kim et al., 2023; Kim & Lee, 2022; Saleh et al., 2020; Shahbazloo & Abdullah Mirzaie, 2023) noted the use of digital gadgets and technologies, including 3D printers, Micro:bit, Makey, Padlet, and Scratch. However, it is noteworthy that six studies were developed during the COVID-19 pandemic (Jalaludin et al., 2024; Kim et al., 2023; Kim & Lee, 2022; Shahbazloo & Abdullah Mirzaie, 2023; Weng et al., 2023; Zhan et al., 2023). Consequently, the use of digital technologies became essential in the development of these projects, even though not all programs were conducted remotely.

Most STEM programs employed a specific methodology, although some combined multiple approaches. Five programs implemented project-based learning (PBL) (e.g., Baran et al., 2021). One combined PBL with design thinking (Chang et al., 2023). Two used the engineering design process or engineering design learning cycle (EDELCY) (Herianto et al., 2024; Ozkan & Umdu Topsakal, 2021). Others applied design-based learning (Bozkurt Altan & Tan, 2021), design thinking (Chen & Lo, 2019), the 5E model (Kim et al., 2023), or problem-based learning (Jalaludin et al., 2024). Additional models include human-centered design (Chen & Lo, 2019), cognitive-affective interaction (Hsiao et al., 2022), SMICE (Kim & Lee, 2022), research inquiry–based learning (Kırıcı & Bakırcı, 2021), and SSCS (Maskur et al., 2022). Zhan et al. (2023) described a four-stage process without explicitly identifying it as a named model.

4. Discussion

This systematic review analyzed 22 studies in which creativity was explored in the context of STEM education in secondary schools. The publication dates of the studies indicate that the present review contributes to addressing a gap in the literature. Indeed, nine of the studies were published in 2023 and 2024, the final two years included in the search, with the oldest published in 2018. The fields of STEM education and creativity research are evolving rapidly, thereby requiring novel approaches to address current challenges. Moreover, the need for STEM education research in the European context, as identified by Pokropek (2024), was further highlighted by the findings of the present review, given that 20 of the 22 included studies were conducted in Asia.

This systematic review indicates a strong predominance of studies conceptualizing creativity as an individual characteristic, ability, or skill, most commonly operationalized through self-report measures, questionnaires, or standardized creativity tests. As shown in Table 3, all included studies assessed creativity at the individual level, suggesting that this remains the primary analytical lens in STEM creativity research. A smaller subset of studies complemented this perspective by assessing students' creative outputs, typically through expert or researcher evaluation of artifacts produced during the intervention. In contrast, creativity as a process was markedly underrepresented as an explicit object of analysis, with only a few studies qualitatively examining how creativity unfolded over time through observations, interviews, or behavioral coding. Other theoretically salient dimensions, such as social reception, collaboration, curriculum, and broader contextual influences, were largely implicit rather than empirically assessed, despite their prominence in contemporary creativity frameworks (Rhodes, 1961; Glăveanu, 2013; Lubart, 2017).

Across the reviewed studies, three main categories of creativity definitions emerged, with the most common of which focused on idea generation, problem-solving, and 21st-century skills. When compared with the classification of creativity assessments proposed by Beghetto and van Geffen (2024), the present review identified an additional category that appears to be specific to STEM education contexts. This divergence likely reflects the applied and discipline-oriented nature of STEM learning environments, where creativity is often embedded in problem-solving and innovation-related competencies. Nevertheless, despite calls to foster creativity both as a general capacity and within specific disciplinary domains (Van Broekhoven et al., 2020), relatively few studies explicitly conceptualized or measured domain-specific creativity. Among those that did, scientific creativity was by far the most frequently assessed form, suggesting a limited exploration of creativity across other STEM disciplines. Taken together, these findings reveal a persistent imbalance between theoretically multidimensional conceptions of creativity and the narrow empirical focus adopted in much of the STEM education literature, underscoring the need for more comprehensive, process-oriented, and context-sensitive approaches in future research.

When addressing the second research question, a consensus was found on the use of quantitative measurement tools, consistent with the findings of Aguilera and Ortiz-Revilla (2021). Although scientific creativity was not the most prevalent aspect in the definition of creativity, the most frequently used instrument was the one designed by Hu and Adey (2002), following the findings of Wiyanto et al. (2020). Regarding methodological approaches, the findings indicate that six of the 22 studies used mixed or qualitative methodologies, whereas the remaining studies relied exclusively on quantitative approaches. Therefore, a gap was identified in the use of mixed or qualitative methods, such as observations and interviews, echoing the concerns raised by the findings of Cremin and Chappell (2019) and Giang et al. (2024). In addition, the review revealed that many studies relied on previously validated instruments without re-establishing validity or reporting comprehensive reliability information, which may limit the interpretability of findings across contexts and highlight the need for more rigorous and transparent psychometric reporting. This further emphasizes the scarcity of measures and research approaches for different creativity types. Researchers should consider this gap when designing future studies.

Many studies focused on methodologies within STEM education intended to foster creativity. Design-based approaches were among the most frequently implemented methodologies, particularly in problem-solving projects where students created products to address design challenges. However, despite the widespread use of these methodologies, few studies explicitly examined the creative process itself, even though these methodologies were positioned as the primary innovation for fostering creativity. Instead, most studies assessed creativity as an individual ability, disposition, or outcome through self-report questionnaires, standardized creativity tests, or evaluations of final products. This reveals a methodological misalignment between the process-oriented nature of design-based pedagogies and the predominantly outcome-oriented approaches used to assess creativity.

This emphasis on outcomes rather than processes contrasts with established creativity frameworks that conceptualize creativity as a dynamic process and situated practice (e.g., the 4Ps model; Rhodes, 1961; the 5As model; Glăveanu, 2013; the 7Cs model; Lubart, 2017), as well as with recent calls to conceptualize creativity explicitly as a process and to incorporate process-focused assessments in empirical research (Green et al., 2024). As Green et al. (2024, p. 548) argue, "You can teach the 'how' of a process, but you cannot teach the 'how' of a product." This distinction highlights a methodological inconsistency across the reviewed studies: although the instructional approaches aimed to teach students how to engage in design and creative problem-solving processes, the assessment procedures focused primarily on the final outcomes rather than on the processes through which creativity emerged.

Moreover, design methodologies were shown to enhance students' design competencies (Rusmann & Ejsing-Duun, 2022), which are primarily associated with process phases such as problem setting, ideation, modeling, and process management. Nevertheless, although problem-solving processes were central to the definition of STEM practices, none of the analyzed studies required students to formulate or define a problem.

These findings suggest that, if methodological approaches are to effectively foster student creativity, future research should prioritize the systematic exploration of the creative process rather than focusing predominantly on creative products. Therefore, STEM educators and researchers may benefit from incorporating methodologies such as observations, think-aloud protocols, behavioral coding, or longitudinal process analyses to better understand how creativity develops during STEM learning activities.

5. Limitations and further research

It is important to acknowledge the limitations of this review. First, the database search was limited to Scopus and Web of Science, which may have excluded potentially eligible studies indexed elsewhere. Second, only publications in English and Spanish were included, potentially omitting valuable contributions published in other languages. In addition, the exclusion of gray literature (e.g., book chapters, dissertations, and conference proceedings) may have introduced publication bias by favoring peer-reviewed sources.

Furthermore, the study selection and screening process was conducted collaboratively by the first and second authors and discussed with the research team until consensus was reached, rather than being carried out independently by multiple reviewers. As a result, no formal inter-rater reliability statistic (e.g., Cohen's kappa) was calculated. Although consensus-based discussions were used to enhance consistency, the absence of independent screening may limit the reproducibility of the review process. Future reviews should incorporate independent dual screening and formal agreement measures to strengthen methodological rigor.

A further consideration is that, although a methodological quality appraisal was conducted using the MMAT, certain limitations remain. While clear inclusion and exclusion criteria were applied, the methodological rigor of the primary studies varied in terms of research design, sample size, measurement instruments, and reporting of validity and reliability, despite all included studies having met the minimum quality threshold. Moreover, the MMAT provides a structured but relatively broad assessment, which may limit the extent to which the strength of evidence can be weighed across studies. Therefore, the findings should be interpreted with caution.

Publication bias also represents a general limitation. Studies reporting positive or statistically significant effects of STEM interventions on creativity are more likely to be published, whereas studies with null or negative findings may remain underrepresented. As a result, the overall effectiveness of STEM-based approaches for fostering creativity may be overestimated in the available literature.

These findings suggest several directions for future research. Beyond continuing to investigate design-based methodologies, which have been shown to enhance creativity (Chen & Lo, 2019; Chang et al., 2023), 21st-century skills (Herianto and Purwastuti, 2024), and creative confidence (Ladachart et al., 2024), future studies should place greater emphasis on examining creative processes rather than focusing predominantly on outcomes (Green et al., 2024). This gap is particularly significant given ongoing calls to better understand how creativity unfolds during learning activities (Suherman & Vidákovich, 2022), especially in secondary education, a critical period for cognitive and identity development during adolescence (Barbot & Golab, 2025).

From a methodological perspective, future systematic reviews would benefit from incorporating more explicit analyses of publication bias, independent dual screening procedures, and more detailed approaches to quality appraisal. Additionally, further empirical work should explore creativity from a domain-specific perspective during adolescence, combining rigorous methodological designs with multidimensional creativity frameworks.

6. Conclusion

The current study aimed to identify which aspects of creativity are conceptualized within STEM education research, how these are assessed, and what characteristics define the instructional practices commonly implemented in STEM programs. Findings reveal that creativity research has explored only a limited range of creativity aspects (Glăveanu, 2013; Lubart, 2017; Rhodes, 1961). Similarly, research methods show a notable inclination toward quantitative approaches. As Giang et al. (2024) suggested, mixed-methods research approaches would contribute to a more holistic perspective. As Cremin and Chappell (2019) argued, reporting how creativity is defined and measured could be pivotal in advancing research on pedagogical approaches designed to foster students' creativity. The majority of studies, however, conceptualized creativity primarily as a general individual characteristic, thereby limiting the examination of how engagement with specific disciplines (Van Broekhoven et al., 2020) may influence the development of domain-specific creativity.

Given ongoing questions about how STEM education is implemented in practice (Pokropek, 2024), this review provides preliminary insights. The analysis identified several characteristics that align with those defined by previous authors (Breiner et al., 2012; Cremin & Chappell, 2019), including the implementation of real-world problem-solving activities and the promotion of student autonomy and agency. Most notably, design-based methodologies emerged as one of the most prevalent practices.

In summary, the adoption of design-based methodologies, the shift toward more varied research approaches in creativity studies, and the development of better measurement techniques for assessing creativity in secondary education all present opportunities for future research and teaching practice.

CRediT authorship contribution statement

Amaia Guridi-Bikuña: Writing – original draft, Conceptualization. **Ainara Bilbao-Eraña:** Writing – review & editing, Conceptualization. **Paula Álvarez-Huerta:** Writing – review & editing.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tsc.2026.102264.

Data availability

No data was used for the research described in the article.

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