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Creativity Education for Early Adolescents Aged 12–15: A Systematic Review, Meta-Analysis, and Component–Context Synthesis of Educational Interventions

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ABSTRACT

Purpose: This study aimed to systematically evaluate the effectiveness of educational interventions for enhancing creativity among adolescents aged 12–15 years and to identify the instructional components, implementation conditions, and contextual features associated with favorable outcomes.

Methods and Materials: A systematic review with conditional random-effects meta-analysis and complementary component–context synthesis was conducted according to PRISMA 2020 and PRISMA-S recommendations. Scopus, Web of Science Core Collection, APA PsycINFO, ERIC, Education Source, and PubMed/MEDLINE were searched from inception to August 23, 2026. Thirty-eight study groups met the eligibility criteria, of which 18 contributed to quantitative performance syntheses. Hedges' g was calculated for comparable outcomes, and random-effects models using restricted maximum likelihood and modified Hartung–Knapp confidence intervals were applied. Risk of bias was evaluated using RoB 2 and ROBINS-I.

Findings: The pooled effect for divergent thinking was significant and large (k=9, g=1.53, 95% CI [0.45, 2.62]); after excluding one influential study, the effect remained significant (k=8, g=1.11, 95% CI [0.51, 1.71]). Scientific creativity showed a positive but nonsignificant inclusive effect (k=6, g=1.04, 95% CI [−0.08, 2.16]); exclusion of one reporting-sensitive study yielded a significant moderate effect (k=5, g=0.62, 95% CI [0.14, 1.09]). Mathematical creativity showed a large but nonsignificant exploratory effect (k=3, g=1.22, 95% CI [−0.63, 3.08]). Heterogeneity was substantial across all outcome families.

Conclusion: Creativity among early adolescents appears responsive to structured educational intervention, particularly for divergent thinking. Effective programs repeatedly incorporated structured ideation, open or authentic problem engagement, externalization and iterative refinement, and feedback or metacognitive reflection; however, substantial heterogeneity and methodological limitations preclude endorsement of a single universal intervention model.

Keywords: *early adolescence; creativity education; divergent thinking; scientific creativity; mathematical creativity; systematic review; meta-analysis*

1. Introduction

Creativity has become an increasingly important educational outcome in contemporary societies because learners are expected not only to acquire established knowledge but also to generate, evaluate, adapt, and communicate novel ideas in response to complex and changing problems. Rather than being regarded as a rare talent possessed by a small group of exceptional individuals, creativity is now commonly conceptualized as a developable capacity that can emerge through interactions among cognitive processes, domain knowledge, motivation, personal dispositions, and environmental conditions. Contemporary theoretical perspectives generally define creativity in terms of producing ideas, solutions, or products that combine originality with appropriateness or usefulness, while recognizing that creative performance varies across tasks and domains (Kaufman & Sternberg, 2019). From an educational perspective, this multidimensional conception is especially consequential because creativity cannot be reduced to unrestricted idea generation alone. It encompasses divergent processes such as fluency, flexibility, and originality, but also convergent evaluation, problem identification, selection, elaboration, revision, and the transformation of emerging ideas into meaningful products or solutions (Eon Duval et al., 2023). Accordingly, creativity education requires instructional environments in which students are encouraged to explore alternatives while also learning how to evaluate and progressively improve what they produce.

The developmental period of early adolescence is particularly significant for creativity education. Between approximately 12 and 15 years of age, young people experience substantial changes in cognition, identity development, autonomy, motivation, peer orientation, and relationships with teachers and school structures. Creativity during this period does not develop according to a simple linear trajectory. Developmental research has identified considerable individual variation, including periods of growth, temporary decline, recovery, and relative stability (Barbot et al., 2016). School transition may also coincide with reductions in creative performance, particularly when educational transition is accompanied by stress or is experienced negatively by students (He & Wong, 2015). More recent longitudinal evidence further demonstrates that divergent-thinking originality follows several distinct developmental trajectories across early adolescence rather than a universal pattern of decline. While many adolescents may show reductions across successive school grades, others maintain or increase originality, with more favorable trajectories associated with potentially malleable personal and environmental factors (Anderson, 2024). Thus, early adolescence should not simply be viewed as a period characterized by an inevitable “creativity slump”; rather, it represents a developmentally sensitive window during which educational experiences may either constrain or strengthen creative functioning.

The proposition that creativity is educationally malleable has generated a substantial intervention literature spanning several decades. Early work demonstrated that systematic creativity instruction could influence creative problem solving and divergent-thinking abilities among middle-school students. Creative problem-solving curricula produced favorable outcomes across students with different levels of ability (Schack, 1993), while structured problem-identification techniques improved classroom fluency and flexibility (Kurtzberg & Reale, 1999). SCAMPER-based activities were also investigated among intellectually gifted students, providing early evidence that deliberate manipulation and restructuring of ideas could influence creative thinking (Mijares-Colmenares et al., 1988). Longitudinal research further suggested that some benefits of creativity training could persist beyond the immediate post-intervention period (Baer, 1988). At the same time, evidence that divergent-thinking training may produce stronger gains on closely related trained tasks than on dissimilar tasks introduced an enduring concern regarding the generalizability and transfer of creativity training (Baer, 1996). These early studies established two questions that remain central today: whether creativity can be systematically fostered through education and whether improvements extend beyond the specific activities through which they were acquired.

Subsequent intervention research broadened considerably in both instructional strategy and disciplinary context. Explicit thinking-skills and creative-problem-solving programs continued to demonstrate the potential of structured instruction. Secondary-school interventions targeting general thinking skills have reported improvements in creativity-related abilities alongside broader cognitive outcomes (Sanz de Acedo Lizarraga et al., 2010), while specific creativity-development programs have shown substantial immediate gains and evidence of maintenance at delayed assessment (Larraz Rábanos & Allueva Torres, 2012). Future Problem Solving has likewise been applied to adolescent creativity education, with

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favorable development of several creative skills reported following structured participation (Azevedo et al., 2017). Heuristic approaches to inventive problem solving have demonstrated that students can be taught systematic strategies for generating innovative solutions (Barak, 2011), and creative reversal procedures incorporated into science instruction have been associated with improved creativity among middle-school learners (Karaca & Koray, 2017). More recently, systematic approaches integrating inventive problem-solving strategies within authentic science problems have reinforced the educational value of guiding students through structured exploration rather than limiting instruction to predetermined answers (Demirci Saygı & Şahin, 2023). SCAMPER remains relevant in contemporary classrooms, with recent evidence indicating favorable effects of SCAMPER-based science activities on students' creative thinking and related learning outcomes (Yüzüak & Recepkethüda, 2025).

Creativity education has also increasingly become embedded within particular curriculum areas. Mathematics provides a prominent example because open-ended tasks permit multiple strategies, representations, and defensible solutions. Open-ended mathematical instruction has been shown to cultivate divergent thinking, particularly fluency and flexibility (Kwon et al., 2006). Cooperative instructional structures have also been associated with improvements in mathematical creative-thinking ability (Lince, 2016), while dedicated mathematics learning-management models have been developed specifically to promote creative thinking through instructional sequences designed around active mathematical exploration (Sriwongchai et al., 2015). In language education, the Six Thinking Hats strategy has been used to support both writing performance and creativity by encouraging learners to approach a problem or writing task through differentiated cognitive perspectives (Phuntsho & Wangdi, 2020). Geography instruction has similarly incorporated creative mapping and mnemonic representation, with evidence that visual and associative strategies can contribute to verbal and figural creativity (Liao et al., 2019). Brainstorming embedded in science-related learning has also enhanced students' creative-thinking skills by intentionally creating opportunities for multiple responses and alternative ideas (Hidayanti et al., 2018). Collectively, these findings indicate that creativity can be cultivated within disciplinary learning rather than being restricted to stand-alone creativity courses.

The rapid expansion of STEM and STEAM education has further transformed the creativity-intervention literature. STEM-based learning frequently incorporates inquiry, design, engineering challenges, experimentation, and the construction of products, all of which may create opportunities for creative cognition when creativity is explicitly incorporated into instructional goals. Research among middle-school students has documented favorable effects of STEM activities on scientific creativity (Doğan & Kahraman, 2021), while STEM-supported research-inquiry learning has produced substantial improvements in scientific-creativity outcomes (Kırıcı & Bakırcı, 2021). STEM applications implemented within regular science units have likewise been associated with improvements in scientific creativity (Çalışıcı & Benzer, 2021). Robotics provides another context in which students must generate ideas, construct or program solutions, identify failures, and iteratively modify their designs; STEM-based robotic applications have consequently demonstrated positive effects on student creativity (Tiryaki & Adıgüzel, 2021). Computational-thinking activities also appear capable of supporting creative-thinking outcomes when learners engage with problems requiring decomposition, representation, algorithmic reasoning, and alternative solutions (Şener Koruk & Benzer, 2025). Importantly, evidence from repeated creativity practice indicates that strengthening creative capacities may also relate to improvements in computational thinking, suggesting potentially meaningful intersections between creative and computational processes (Israel-Fishelson & Hershkovitz, 2024).

STEAM and design-oriented approaches extend these opportunities by integrating artistic, representational, and design processes with scientific and technological learning. STEAM-based courses have been associated with gains in junior-high students' scientific creativity (Tran et al., 2021), and STEAM design processes have demonstrated potential for enhancing creativity through cycles of problem exploration, design, construction, and revision (Ozkan & Umdu Topsakal, 2021). Design thinking-based STEAM project-based learning has yielded particularly favorable creativity outcomes while simultaneously supporting computational-thinking development (Chang et al., 2023). Maker education has also become an important environment for creativity because students externalize ideas into artifacts and refine those artifacts through iterative activity. Makerspace participation has been linked with scientific creativity in middle-school students (Caballero-García & Grau Fernández, 2018), while contemporary evidence suggests that incorporating design thinking into maker

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education can outperform conventional maker instruction in fostering junior-high students' creativity (Chen et al., 2025). Similarly, integrating STEM and design thinking through authentic projects such as water-filtration design has been associated with improvements in creative disposition and creative products (Ain et al., 2025). Recent meta-analytic evidence reinforces this broader pattern by indicating that design thinking can enhance creativity outcomes in STEM education, although effects differ according to instructional methodology, assessment procedures, duration, disciplinary context, and other implementation features (Muneer et al., 2026).

Digital and representational environments provide another expanding avenue for creativity education. Technology may facilitate experimentation, visualization, collaboration, storytelling, and rapid revision, although its educational effectiveness depends on how it structures learners' cognitive activity rather than on the mere availability of digital devices. Early research on computer-game development combined with appreciative learning suggested that technology-supported production could enhance students' perceptions of their creative capacities (Eow et al., 2010). Tablet-based interactive classrooms have subsequently been used to foster creative performance through collaborative visual-thinking activities (Kim et al., 2016). Digital storytelling provides an especially relevant example because it integrates narrative construction, visual representation, technological production, and iterative organization of ideas; recent evidence indicates that digital storytelling can significantly foster creative-thinking skills among adolescents (Wan Mohd Nasir et al., 2024). These findings converge with a wider instructional principle: technology appears most educationally meaningful when learners use it to generate, represent, manipulate, test, and communicate ideas rather than simply consume information.

Other intervention lines have emphasized psychological and metacognitive processes associated with creativity. Creative-thinking counseling programs have improved creativity, creative tendency, and self-concept among Grade 7 students, illustrating that creativity education can involve both demonstrated performance and creativity-related beliefs (Huang et al., 2021). Daily creativity planning has likewise been shown to promote creative behavior and related motivational or self-belief outcomes by encouraging learners to translate intentions into concrete creative activities (Liu et al., 2023). Instruction combining critical and creative thinking has demonstrated that divergent generation and critical evaluation need not be viewed as competing processes; instead, integrating them may strengthen originality by helping students generate possibilities and subsequently examine their quality (Chang et al., 2015). Scientific-creativity programs provide similar evidence. The Learn to Think intervention produced improvements in scientific creativity and indicated that gains can be maintained over time (Hu et al., 2013), while the more recent Scientific Creativity in Practice program emphasizes the importance of how instructional procedures are enacted in real classrooms (Haim et al., 2024). Such findings support a conception of creativity education in which ideation, evaluation, reflection, self-regulation, and implementation operate as interconnected elements.

Despite the generally favorable intervention literature, several systematic reviews and meta-analyses demonstrate why strong conclusions require caution. A systematic review of creative-thinking models in secondary education reported broadly positive findings across approaches such as creative problem solving, SCAMPER, and Future Problem Solving, but also highlighted the limited size and methodological diversity of the available evidence (Saeed & Ramdane, 2022). A much larger meta-analysis spanning approximately five decades of creativity-training research found an overall positive effect on creative performance, yet effect estimates were reduced when potential publication bias was considered and persistent methodological weaknesses limited confidence in the magnitude of the effect (Sio & Lortie-Forgues, 2024). Domain-specific synthesis similarly indicates that scientific creativity can benefit from problem-, project-, inquiry-, and STEM-related approaches, while simultaneously demonstrating meaningful heterogeneity among intervention models (Pinar et al., 2025). These patterns suggest that the question is no longer adequately framed as whether creativity training "works." More informative questions concern which creativity outcomes respond to intervention, which instructional processes are shared across effective programs, how implementation influences outcomes, and whether observed improvements are durable and transferable.

A further challenge is the heterogeneity of what researchers call creativity. Divergent-thinking tests, scientific-creativity measures, mathematical creativity, inventive problem solving, expert-rated products, creative behavior, creative self-efficacy, creative disposition, and perceived creativity are related but non-equivalent constructs. Treating them as interchangeable risks obscuring theoretically and educationally important distinctions. Performance-based change may not correspond directly to

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changes in self-beliefs, and success on a domain-specific task may not demonstrate generalized creativity. This problem becomes particularly important when studies vary substantially in intervention content, measurement modality, comparison conditions, duration, classroom organization, and follow-up periods. Consequently, systematic synthesis should avoid simply counting statistically significant results when quantitative pooling is inappropriate and should instead organize evidence according to conceptually defensible outcome and intervention groupings (Campbell et al., 2020). Equally, methodological credibility should be evaluated independently from effect magnitude. Randomized trials require systematic appraisal of bias arising from randomization, deviations from intervention, missing data, outcome measurement, and selective reporting (Sterne et al., 2019), while non-randomized intervention studies require careful consideration of confounding, participant selection, intervention classification, deviations, missingness, measurement, and selective reporting (Sterne et al., 2016).

The diversity of intervention labels also creates a practical limitation for translating research into educational design. Programs described as creative problem solving, SCAMPER, design thinking, maker education, STEM, STEAM, robotics, brainstorming, creative counseling, or inquiry learning may differ substantially in surface form while sharing underlying instructional processes. Conversely, two programs carrying the same label may be implemented very differently. Clear characterization of intervention content, provider, mode of delivery, dose, setting, adaptation, and fidelity is therefore essential if evidence is to guide replication and educational application (Hoffmann et al., 2014). Across the intervention literature, several potentially transferable processes appear repeatedly: generation of multiple alternatives, problem finding and engagement with open or authentic problems, external representation of emerging ideas, iterative testing and revision, collaboration, evaluative feedback, and metacognitive reflection. The persistence of such processes across explicitly taught creativity programs, disciplinary interventions, and technology-supported learning suggests that an instructional architecture organized around functional components may provide greater explanatory value than reliance on branded intervention categories alone.

Accordingly, the present study aimed to systematically review educational interventions designed to enhance creativity among adolescents aged 12–15 years, quantitatively synthesize sufficiently comparable creativity outcomes, and identify the instructional components, implementation conditions, and contextual features associated with favorable, durable, and potentially transferable effects.

2. Methods and Materials

2.1. Review Design and Eligibility

This study was conducted as a systematic review with conditional meta-analysis and a complementary component–context synthesis of educational interventions designed to enhance creativity among early adolescents aged 12–15 years. The review was structured in accordance with PRISMA 2020, while the reporting of information sources and search procedures followed PRISMA-S recommendations (Page et al., 2021; Rethlefsen et al., 2021). Intervention characteristics were examined with reference to the TIDieR framework, particularly the content of the intervention, provider, mode of delivery, dose, setting, adaptation, and implementation fidelity (Hoffmann et al., 2014).

Eligibility was defined using a prespecified PICOS framework. Studies were eligible when participants were aged 12–15 years or were enrolled in an equivalent lower-secondary or middle-school stage. Mixed-age samples were included only when the target-age subgroup could be extracted separately or when at least 80% of the analyzed sample could reasonably be shown to fall within the target range; such cases were flagged for sensitivity analysis. When chronological age was unavailable, grade-based eligibility was accepted only where the educational level clearly corresponded to lower-secondary schooling and did not include an upper-secondary cohort.

Eligible interventions had to explicitly aim to foster creativity or a defined creativity-related capacity and to assess at least one quantitative creativity outcome. Accordingly, approaches such as creative problem solving, divergent-thinking training, SCAMPER, brainstorming, design thinking, maker education, robotics, computational thinking, arts-based instruction, and STEM/STEAM were included only when creativity was an explicit intervention target. For the primary effectiveness synthesis, studies were required to use a randomized, cluster-randomized, or controlled prospective quasi-experimental design. Single-group studies were excluded from causal pooling but could contribute to the component–context synthesis when they offered distinctive information on intervention design or implementation. Only peer-reviewed journal articles were eligible as primary reports; companion reports were used solely to supplement missing methodological or numerical information.

2.2. Search and Study Selection

The search framework covered Scopus, Web of Science Core Collection, APA PsycINFO, ERIC, Education Source, and PubMed/MEDLINE, from database inception to August 23, 2026. The final search strategy (version 1.3) combined three concept blocks: population, creativity, and educational intervention. Population terms included adolescent, middle school, junior high, lower secondary, and Grades 6–9; creativity terms included creativity, divergent and convergent thinking, creative problem solving, scientific and mathematical creativity, originality, ideation, and creative performance; intervention terms included training, curriculum, instruction, brainstorming, SCAMPER, design thinking, maker activities, robotics, computational thinking, STEM/STEAM, and problem-, project-, or inquiry-based learning. No mandatory study-design filter was applied to the primary search in order to preserve sensitivity to educational studies described using heterogeneous quasi-experimental terminology. Full database-specific strategies were retained for reproducibility in accordance with PRISMA-S (Rethlefsen et al., 2021).

Backward and forward citation searching of included studies and recent high-relevance reviews was used as a supplementary identification method. Records identified through citation searching were subjected to the same eligibility criteria as database-derived records. Screening distinguished records, reports, and underlying studies, consistent with PRISMA terminology, so that multiple publications from the same intervention cohort were not treated as independent evidence (Page et al., 2021).

Two reviewers applied the eligibility criteria, with disagreements resolved through consensus. Particular attention was given to four recurring sources of misclassification: age eligibility, whether creativity was an explicit intervention target, the presence of an appropriate comparator, and the distinction between performance-based creativity and related self-report constructs. When several reports described the same cohort, the most complete peer-reviewed article was designated as the primary report and companion publications were linked to it before synthesis.

Study selection was conducted according to the prespecified eligibility criteria and PRISMA 2020 framework. Following identification, deduplication, screening, full-text eligibility assessment, and study-level linkage of companion reports, 38 study groups were retained in the systematic review. Of these, 18 study groups contributed to at least one quantitative performance synthesis: nine to divergent thinking, six to scientific creativity, and three to mathematical creativity (Figure 1).

2.3. Data Extraction and Outcome Classification

Data extraction covered participant characteristics, study design, allocation, comparator, intervention duration and frequency, facilitator, delivery format, materials, instructional components, implementation fidelity, creativity construct, measurement instrument, assessment time point, attrition, and numerical data required for effect-size calculation. TIDieR informed the extraction of implementation characteristics because intervention effects may depend not only on program labels but also on who delivered an intervention, how much was delivered, where it occurred, and whether it was implemented as intended (Hoffmann et al., 2014).

Creativity outcomes were classified by both construct domain and measurement modality. The primary domains were divergent production, convergent/evaluative creative thinking, creative problem solving, creative product or performance, domain-specific creativity such as scientific or mathematical creativity, and validated composite measures. Creative self-efficacy, disposition, identity, attitudes, and perceived creativity were treated as secondary outcomes and were not pooled with performance measures. Measurement modalities were classified as standardized performance tests, expert/product ratings, behavioral measures, self-report measures, informant reports, or mixed methods.

For the explanatory synthesis, interventions were additionally coded along the sequence Intervention → Component → Mechanism → Delivery → Context → Outcome → Transferability. Candidate components included structured ideation, problem finding, analogy and association, perspective shifting, prototyping, iterative revision, feedback, collaboration, metacognitive reflection, learner autonomy, and authentic problem contexts. Follow-up outcomes were categorized as immediate (≤1 month), short-term (>1–3 months), medium-term (>3–6 months), or long-term (>6 months).

2.4. Risk of Bias

Randomized studies were assessed using the revised RoB 2 framework, including the appropriate variants for cluster-

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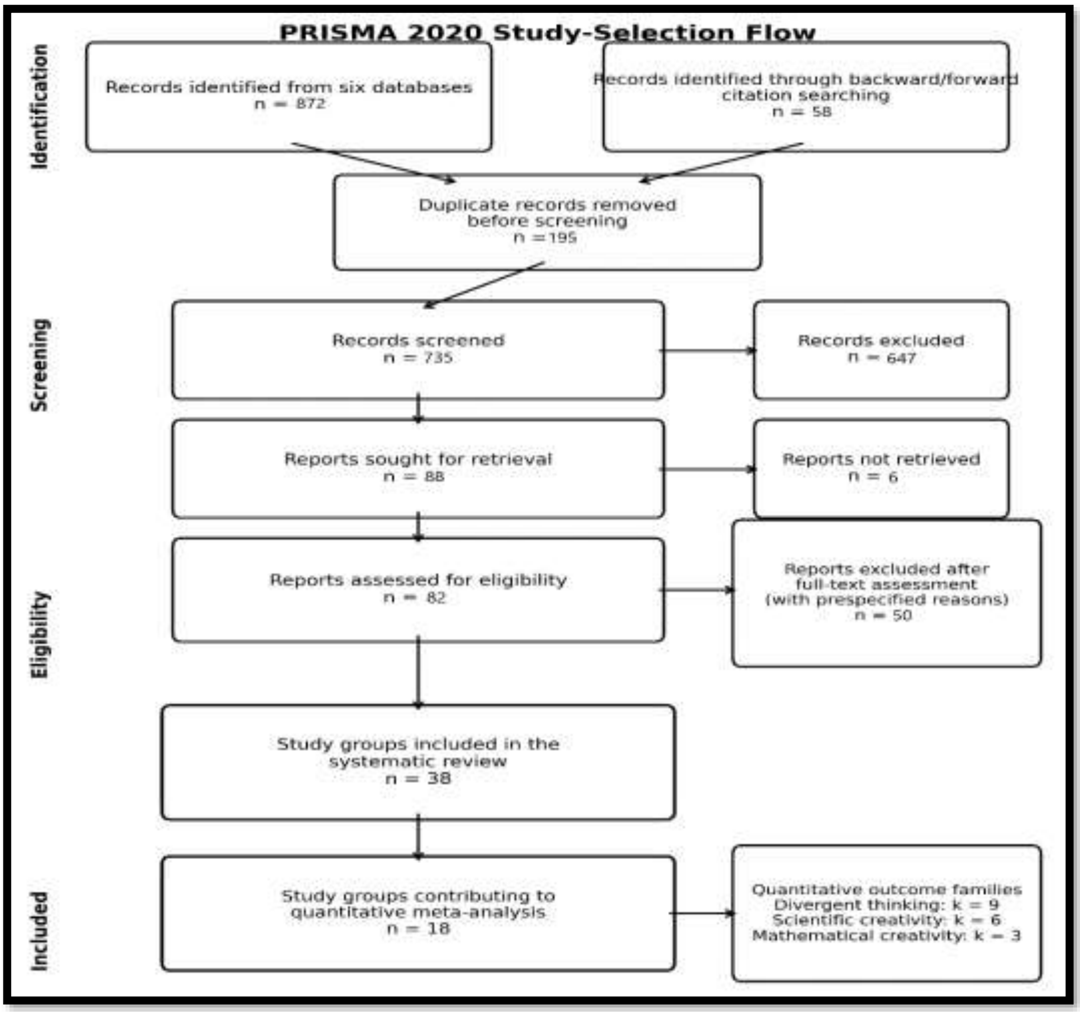
randomized designs where necessary. RoB 2 evaluates bias arising from randomization, deviations from intended interventions, missing outcome data, outcome measurement, and selection of reported results (Sterne et al., 2019).

Controlled non-randomized studies were evaluated using ROBINS-I, covering confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, outcome measurement, and selective reporting (Sterne et al., 2016). Risk-of-bias judgments informed interpretation and sensitivity analysis rather than functioning as an automatic exclusion criterion. Consequently, unusually large but source-verified effects were retained and examined through influence analyses rather than removed solely on the basis of magnitude.

Figure 1

PRISMA 2020 flow diagram of study identification, screening, eligibility assessment, and inclusion.



2.5. Quantitative and Component–Context Synthesis

Continuous creativity outcomes measured on different scales were standardized as Hedges' g, using the pooled within-study standard deviation and the small-sample correction. This is the standardized mean difference convention recommended in the Cochrane Handbook when continuous outcomes represent the same underlying construct but are measured using different scales (Higgins et al., 2024; Higgins et al., 2003). All effects were oriented so that positive values represented better creativity outcomes in the intervention group.

Post-intervention means and standard deviations were preferred when baseline comparability was adequate; standardized change scores were used when appropriate change-score data were reported. Adjusted multilevel or cluster-corrected standardized effects accompanied by

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standard errors or confidence intervals were retained using generic inverse-variance methods rather than reconstructed from unadjusted data. Comparisons between two active creativity interventions were synthesized separately from intervention-versus-usual-practice comparisons.

To avoid unit-of-analysis errors, an available validated total creativity score was preferred over multiple correlated subscales. Where no defensible total score existed, parallel subdomains were combined into a study-level composite, using a prespecified within-study correlation of ρ=.50, with sensitivity analyses from 0 to .90. Repeated follow-up assessments, multi-arm studies, cluster designs, and counterbalanced designs were handled according to their underlying dependency structure. Cochrane guidance specifically cautions that failure to account for clustering, repeated observations, or multiple outcomes can distort study precision and weighting (Higgins et al., 2024).

Meta-analysis was undertaken only when studies were sufficiently comparable in creativity construct, measurement modality, population, comparator, and design. Random-effects models were estimated using restricted maximum likelihood (REML) because genuine variation among interventions and educational contexts was anticipated. REML has favorable performance among estimators of between-study variance and is now the default heterogeneity estimator in current Cochrane random-effects implementation (Deeks et al., 2024; Langan et al., 2019).

Because several outcome families contained relatively few studies, inference was supplemented with a modified Hartung–Knapp procedure, which provides more conservative uncertainty estimates when study numbers and precisions are limited (Röver et al., 2015). Heterogeneity was summarized using τ^2, τ, Cochran's Q, and I^2, and prediction intervals were reported when the number and configuration of studies made them interpretable (Deeks et al., 2024; Higgins et al., 2003). Robustness was examined through leave-one-study-out analysis, risk-of-bias sensitivity analyses, alternative within-study correlations, and explicit examination of influential effects.

When quantitative pooling was inappropriate, studies were synthesized in accordance with SWiM principles rather than by counting statistically significant findings. Studies were grouped by creativity domain, intervention characteristics, measurement approach, and design, and findings were then interpreted alongside their methodological credibility (Campbell et al., 2020). The complementary component–context synthesis examined which instructional components, delivery features, implementation conditions, and proposed mechanisms repeatedly accompanied favorable or unfavorable outcomes. Potentially transferable design principles were subsequently categorized as core, adaptable, or context-dependent, providing a structured bridge between intervention effectiveness and the design of developmentally appropriate creativity education.

3. Findings and Results

Following screening, eligibility assessment, and study-level linkage of companion reports, the current analysis-locked evidence set comprised 38 study groups addressing educational interventions intended to foster creativity among adolescents within the prespecified 12–15-year developmental range. Most studies involved Grade 7–9 students or equivalent lower-secondary cohorts. Controlled quasi-experimental classroom studies predominated, whereas individually randomized trials were uncommon. Intact classes were frequently assigned to intervention and comparison conditions, making class-level differences and residual confounding recurrent features of the evidence base.

The studies were also pedagogically diverse. Four broad instructional architectures could nevertheless be distinguished. First, several interventions taught creativity or creative problem solving explicitly through approaches such as CPS, SCAMPER, CREACT, brainstorming, Future Problem Solving, Six Thinking Hats, and related structured thinking strategies. Second, creativity was embedded within STEM/STEAM, design thinking, maker education, robotics, and computational-thinking activities. A third group emphasized representational or digital processes, including digital storytelling, visual mapping, mnemonic strategies, and collaborative drawing. The fourth integrated creative processes into disciplinary learning, particularly open-ended mathematics, science, writing, and cooperative problem solving.

Measurement was similarly heterogeneous. Performance-based assessments constituted the principal evidence base, with Torrance-type divergent-thinking measures being especially common. Other studies assessed scientific creativity, mathematical creativity, creative products, inventive problem solving, writing creativity, or domain-specific performance. Creative disposition, self-efficacy, perceived creativity, and related self-report constructs were retained as conceptually distinct secondary outcomes rather than treated as interchangeable with demonstrated creative performance.

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Table 1

Condensed characteristics and systematic-review findings of the 38 study groups

Study	Sample/design	Intervention	Creativity outcome	Principal finding
Baer (1988)	Grade 8; ages 12–13; N=48; matched controlled	Osborn–Parnes CPS	Creative problem solving	Large intervention advantage remained evident at 6-month follow-up.
Schack (1993)	Grades 6–8; N=267; controlled six-school study	45-lesson CPS curriculum	Fluency, flexibility, originality, criteria use	Favorable CPS gains were reported across ability levels.
Baer (1996)	Grade 7; N=157; controlled classrooms	Divergent-thinking/creative-writing training	Expert-rated creative products	Stronger improvement occurred on the trained writing task; transfer was weaker.
Kurtzberg & Reale (1999)	Grade 8; ages 13–14; N=43; two-class controlled study	Problem-identification/FPS training	Problem finding, fluency, flexibility	Post-intervention performance favored the trained class across problem-finding outcomes.
Eow et al. (2010a)	Ages 13–14; N=69; randomized controlled	Appreciative learning in game development	Creative perception	Self-reported creative perception favored intervention; kept outside performance pooling.
Hu et al. (2013)	Grade 7; N=107; longitudinal controlled	Learn to Think; 2 years	Scientific creativity	Positive immediate effect and maintenance at 6 months.
Azevedo et al. (2017)	Ages 12–15; N=131; controlled pre–post	Future Problem Solving Program International	Figural creativity/CPS	Favorable changes occurred across several creative skills; companion reports counted once.
Israel-Fishelson & Hershkovitz (2024)	Grade 9; N=132; controlled field study	Repeated online AUT practice	Divergent/computational creativity	Originality and computational-creativity outcomes improved, with selection-bias caution.
Chen, Wang & Ma (2025)	Grade 7; N=60; controlled quasi-experiment	Design thinking in maker education	Creative thinking/tendency; design performance	Design-thinking maker instruction outperformed conventional maker teaching.
Yüzüak & Recepkethüda (2025)	Grade 7; N=43; controlled mixed-method study	SCAMPER science activities	Creative thinking/tendency	Intervention students demonstrated greater creativity-related gains.
Mijares-Colmenares et al. (1988)	Gifted junior-high students; N=27	SCAMPER	TTCT figural creativity	The clearest intervention improvement was reported for flexibility.
Demirci Saygı & Şahin (2023)	Grade 7; N=78; quasi-experimental	SIPS/TRIZ/ASIT, CoRT, SCAMPER, brainstorming	Inventive problem solving	Intervention students generated a larger proportion of inventive solutions.
Tran et al. (2021)	Junior high; mean age 14.2; N=62; counterbalanced	STEAM curriculum	Scientific creativity	Creativity increased during STEAM exposure; ordinary final-post SMD was inappropriate.
Huang et al. (2021)	Grade 7; N=133; nonequivalent controlled	Creative-thinking counseling; 8 weeks	Figural divergent thinking	Moderate positive study-level divergent effect, (g≈0.622).
Liu et al. (2023)	Ages 14–15; final N=77; controlled	Daily creativity planning; 2 weeks	Creative behavior, motivation, self-efficacy	Creative behavior and related beliefs improved; retained as secondary evidence.
Karaca & Koray (2017)	Grade 7; N=39; quasi-experimental	CREACT science instruction	TTCT-Figural	Large positive divergent-thinking effect, (g≈1.223).
Sanz de Acedo et al. (2010)	Ages 13–15; N=110; controlled	TAAC thinking-skills program	Creativity within broader thinking skills	Favorable creativity-related changes accompanied broader thinking-skill gains.
Kwon, Park & Park (2006)	Grade 7; N=398; controlled school study	Open-ended mathematics	Mathematical creativity	Fluency and flexibility improved; composite (g≈0.496).
Hidayanti et al. (2018)	Grade 7; N=50; quasi-experimental	Brainstorming in nutrition learning	Verbal divergent thinking	Fluency, flexibility, and originality gains favored intervention.
Doğan & Kahraman (2021)	Grade 8; N=98; controlled pre–post	STEM activities; 6 weeks	Scientific creativity	Large positive scientific-creativity effect, (g≈1.273).
Sriwongchai et al. (2015)	Grade 9 implementation sample; N=62	Integrated mathematics creativity model	Mathematical creative thinking	Large post-intervention advantage, (g≈1.992).
'Ain et al. (2025)	Grade 9; N=52; controlled quasi-experiment	STEM–Design Thinking project	Creative disposition and product	Moderate disposition improvement and substantially better creative products.

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Chang et al. (2015)	Grade 9; N=265; three-arm quasi-experiment	Creative vs critical+creative instruction	Creative thinking/originality	Both intervention conditions outperformed control; combined instruction showed stronger originality.
Barak (2011)	Middle/junior high; approximately N=224; controlled	Heuristic inventive-problem-solving course	Inventive problem solving	Intervention increased production of innovative solutions; companion reports linked.
Wan Mohd Nasir et al. (2024)	Grade 8; N=63; quasi-experimental	Digital storytelling; 6 weeks	Associative, visual, divergent creativity	Divergent thinking showed a clear positive effect, (g≈0.950).
Liao, Kung & Chen (2019)	Grade 9; N=79; quasi-experimental	Creative-map mnemonic strategy	Verbal and figural creativity	Moderate positive study-level divergent effect, (g≈0.723).
Phuntsho & Wangdi (2020)	Grade 7; N=65; quasi-experimental	Six Thinking Hats; 7 weeks	Writing creativity	Writing-related fluency, flexibility, and originality improved.
Lince (2016)	Grade 8; N=130; stratified quasi-experiment	Numbered Heads Together mathematics	Mathematical creative thinking	Both school strata favored cooperative instruction; combined (g≈1.299).
Chang et al. (2023)	Grade 7; initial N=54; controlled classes	Design-thinking STEAM-PBL	TTCT verbal and figural	Very large source-verified creativity effect, composite (g≈2.287).
Ozkan & Umdu Topsakal (2021)	Grade 7; sample reported inconsistently	STEAM design activities; 11 weeks	TTCT verbal and figural	Large adjusted gains were reported, but inconsistent sample reporting precluded pooling.
Haim, Aschauer & Weber (2024)	Grades 7–8; N=793; multilevel controlled	Scientific Creativity in Practice	Scientific creativity	Small-to-moderate adjusted effects; adherence predicted outcomes more consistently than dosage.
Şener Koruk & Benzer (2025)	Grade 7; analyzed N=39; controlled classes	Computational-thinking activities	TTCT Verbal	Moderate positive total-creativity effect, (g≈0.916), with attrition caution.
Larraz & Allueva (2012)	Ages 13–14; N=48; quasi-experimental	Explicit creativity program; 9 sessions	TTCT; PIC-J follow-up	Exceptionally large immediate effect and positive 3-month maintenance.
Kırıcı & Bakırcı (2021)	Grade 7; analyzed E=29/C=35	STEM-supported inquiry activities	Scientific Creativity Test	Very large effect, (g≈3.201); reporting inconsistency required sensitivity analysis.
Çalışıcı & Benzer (2021)	Grade 8; N=44; quasi-experimental	STEM Organisms & Energy unit	Scientific creativity	Modest positive effect, (g≈0.563), with imprecise CI.
Caballero-García & Grau Fernández (2018)	Ages 13–15; N=200; quasi-experimental	Maker-centred project; 8 weeks	Scientific creativity	Maker instruction produced a moderate positive effect, (g≈0.491).
Tiryaki & Adıgüzel (2021)	Grade 7; N=60; controlled study	STEM-based robotics	TTCT performance	Large positive divergent-thinking effect, (g≈2.192).
Kim et al. (2016)	Ages 13–14; N=262; controlled school study	Tablet-based collaborative visual thinking	TTCT-Figural	Small but positive overall figural-creativity effect, (g≈0.303).

Across these studies, favorable findings were not confined to a particular branded program. Explicit creativity training, STEM/STEAM environments, design- and maker-based learning, robotics, digital representation, cooperative learning, and subject-specific open-ended instruction all produced favorable outcomes in at least some settings. At the same time, effects were clearly non-uniform, and several studies could not enter conventional pooling because of counterbalanced designs, active-comparator structures, self-report outcomes, categorical measures, dependency issues, or unresolved numerical reporting. Their exclusion from a meta-analytic pool was therefore methodological rather than evidence of absence of effect.

Intervention duration ranged from brief programs of only several weeks to semester- and year-long curricula and a two-year Learn to Think intervention. No consistent pattern suggested that longer programs invariably produced stronger outcomes. Instead, the qualitative evidence pointed more strongly toward differences in instructional structure and implementation. Particularly informative was Haim et al. (2024), in which adherence to the intended SCIP procedures was more consistently related to scientific-creativity outcomes than the simple quantity of activities completed.

Evidence for maintenance and transfer was much more limited than evidence for immediate post-intervention change. Hu et al. (2013) reported persistence of scientific-creativity improvement at six months, while Larraz and Allueva (2012) reported a positive three-month follow-up. In contrast, Baer (1996) found that improvement transferred less clearly from a trained creative-writing task to a different writing task. These findings suggest that persistence is possible, whereas generalized transfer should not be assumed.

Methodological appraisal reinforced the need to interpret the systematic-review findings independently from effect magnitude. Among the 38 study groups in the integrated

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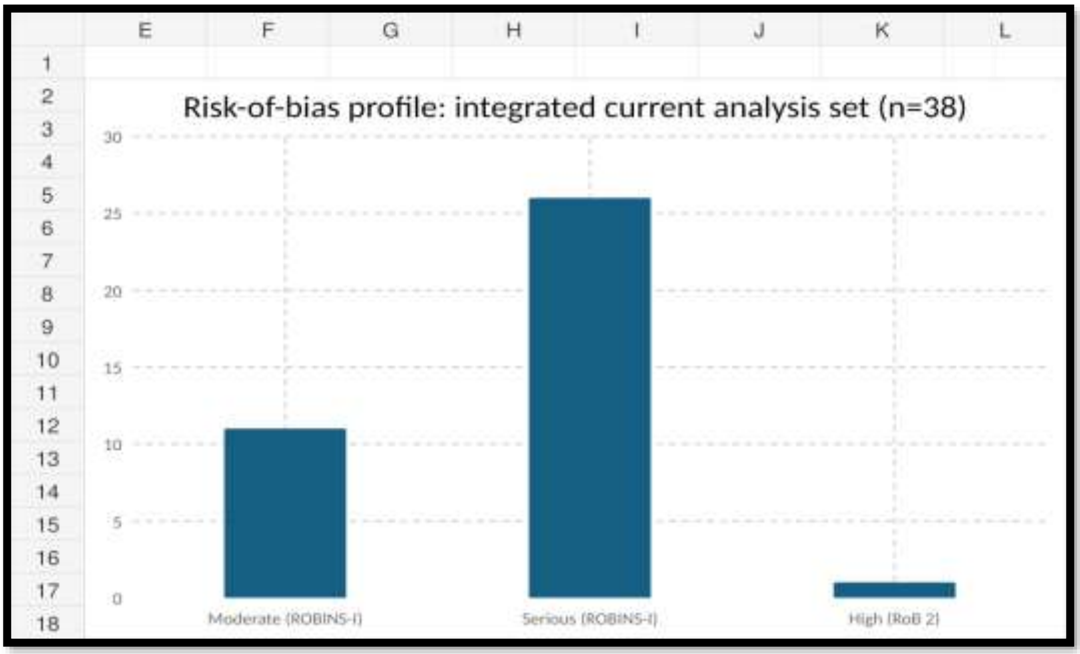
evidence set, 11 (28.9%) were rated Moderate under ROBINS-I, 26 (68.4%) were rated Serious under ROBINS-I, and one randomized study (2.6%) was rated High under RoB 2. Recurrent concerns included non-random assignment of intact classes, residual confounding, attrition or reductions in analyzed samples, and occasional inconsistencies in outcome or sample reporting.

Figure 2

Risk-of-bias profile of the included study groups.



Taken together, the systematic review therefore identified a substantial and diverse intervention literature, but one in which methodological credibility varied considerably. This distinction was retained in the quantitative synthesis: large source-verified effects were not automatically discarded, but neither were they interpreted as intrinsically more credible than smaller effects.

Three sufficiently compatible performance-outcome families were available for quantitative synthesis: domain-general divergent thinking, scientific creativity, and mathematical creativity. Because interventions, educational settings, and measurement procedures varied substantially, principal models used random-effects estimation with REML and modified Hartung–Knapp confidence intervals.

Nine independent study-level effects entered the inclusive divergent-thinking model. The pooled effect was large and favored intervention:

$$Hedges' \ (g = 1.53), modified\ HK\ 95\%\ CI\ [0.45, 2.62] \quad (1)$$

Between-study heterogeneity was very high:

$$(Q(8) = 125.06, p < .001;\ \tau^2 = 1.79;\ \tau = 1.34;\ I^2 = 93.6\%) \quad (2)$$

Larraz and Allueva (2012) produced an exceptionally large but source-verified change-score effect. Rather than removing this observation on the basis of magnitude, its influence was evaluated explicitly. Excluding it reduced the pooled effect but did not remove the positive intervention signal:

$$(g = 1.11, 95\%, CI[0.51, 1.71];\ Q(7) = 59.00, p < .001;\ \tau^2 = 0.44;\ I^2 = 88.1\%) \quad (3)$$

Leave-one-study-out analyses of the remaining eight studies produced pooled effects of approximately (g=0.94–1.24). Removing Chang et al. (2023) yielded approximately (g=0.94), while removal of Tiryaki and Adıgüzel (2021) yielded approximately (g=0.96). The positive pooled effect was therefore not attributable to either of these large individual estimates.

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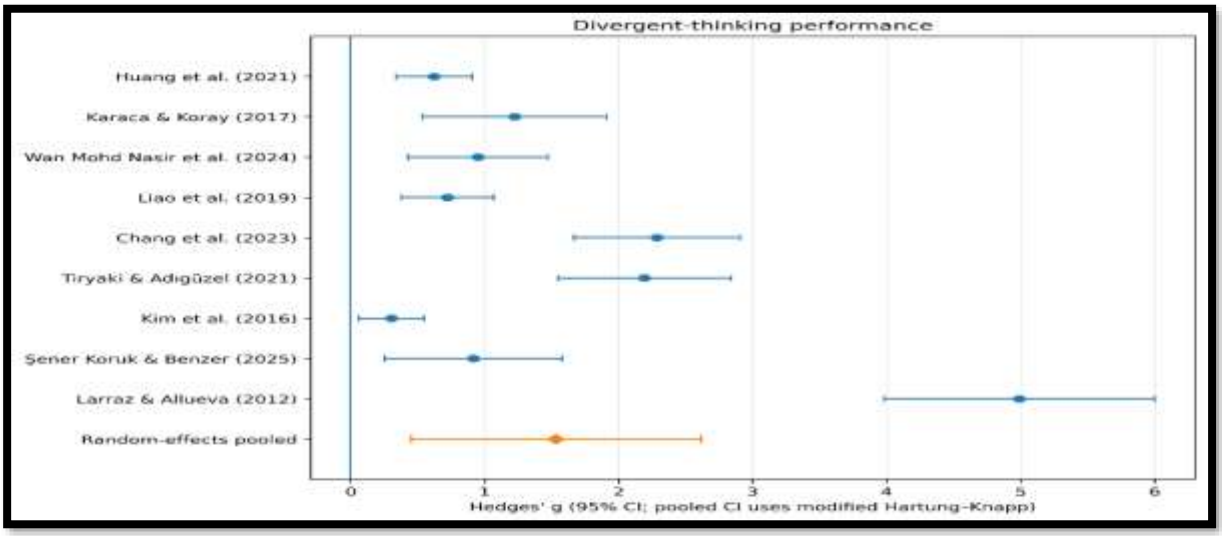
Figure 3

Forest plot of divergent-thinking effects



Six study groups contributed to the inclusive scientific-creativity model. The pooled point estimate was positive:

$$(g = 1.04), modified\ HK\ 95\%\ CI\ [-0.08, 2.16] \quad (4)$$

Heterogeneity was again substantial:

$$(Q(5) = 69.57, p < .001;\ \tau^2 = 1.03;\ \tau = 1.01;\ I^2 = 92.8\%) \quad (5)$$

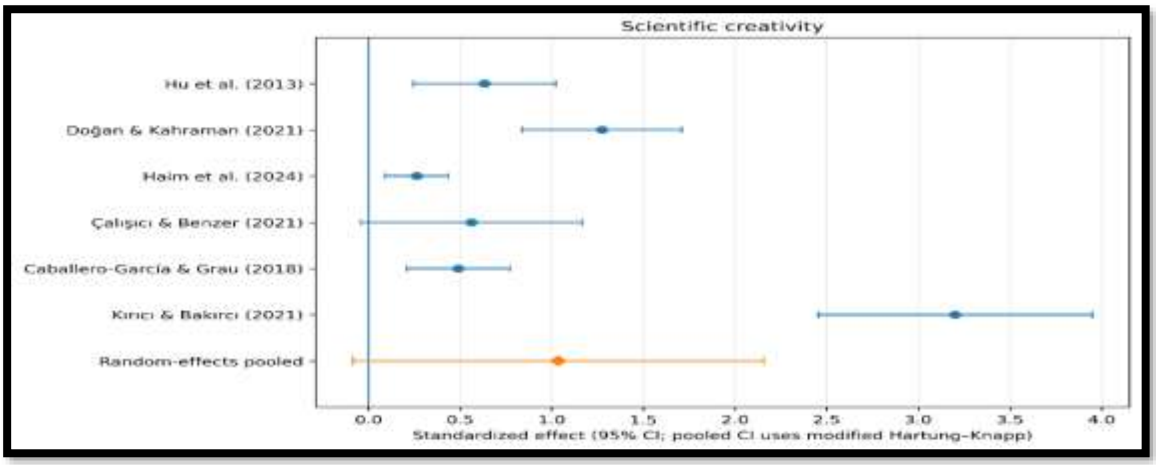
Kırıcı and Bakırcı (2021) generated an exceptionally large estimate and contained an internal reversal of experimental and control sample-size labels between narrative reporting and the repeated outcome tables. The effect was retained using the analyzed group sizes consistently reported in those tables, but a reporting-quality sensitivity analysis was prespecified. Excluding the study reduced the pooled estimate to:

$$(g = 0.62), modified\ HK\ 95\%\ CI\ [0.14, 1.09];\ (Q(4) = 19.24, p < .001;\ \tau^2 = 0.11;\ I^2 = 79.2\%) \quad (6)$$

The remaining estimates ranged from a small adjusted SCIP effect to a large STEM intervention effect, indicating a generally favorable but clearly non-uniform response of scientific creativity to educational intervention.

Figure 4

Forest plot of scientific-creativity effects



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Three independent study groups were sufficiently compatible for an exploratory mathematical-creativity synthesis. The pooled estimate was:

$$(g = 1.22), modified\ HK\ 95\%\ CI\ [-0.63, 3.08] \quad (7)$$

Heterogeneity was high:

$$(Q(2) = 31.59, p < .001;\ \tau^2 = 0.51;\ \tau = 0.71;\ I^2 = 93.7\%) \quad (8)$$

The large point estimate, wide confidence interval, and very small number of contributing studies preclude a precise estimate of effectiveness. Mathematical-creativity findings should therefore be regarded as promising but exploratory.

Table 2

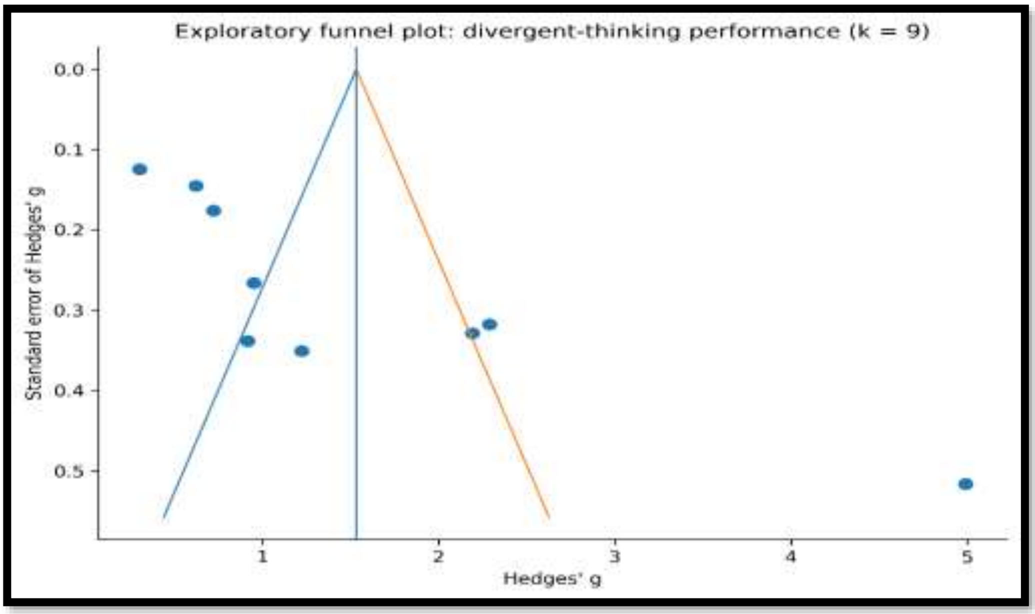
Summary of meta-analytic results

Outcome/specification	k	Pooled g	Modified HK 95% CI	Q (df)	τ²	I²
Divergent thinking – inclusive	9	1.53	0.45 to 2.62	125.06 (8)	1.79	93.6%
Divergent thinking – excluding C064	8	1.11	0.51 to 1.71	59.00 (7)	0.44	88.1%
Scientific creativity – inclusive	6	1.04	−0.08 to 2.16	69.57 (5)	1.03	92.8%
Scientific creativity – excluding C065	5	0.62	0.14 to 1.09	19.24 (4)	0.11	79.2%
Mathematical creativity – exploratory	3	1.22	−0.63 to 3.08	31.59 (2)	0.51	93.7%

An exploratory funnel plot of Hedges' (g) against its standard error was examined for divergent thinking, the largest quantitative synthesis.

Figure 5

Exploratory funnel plot of Hedges' g by standard error



The plot was interpreted descriptively only. The divergent-thinking model contained nine studies, while the scientific- and mathematical-creativity syntheses contained six and three studies, respectively. These numbers are insufficient for reliable formal inference from funnel-plot asymmetry. Egger regression, Begg–Mazumdar testing, and trim-and-fill estimates were therefore not used to support claims for or against publication bias. The appropriate conclusion is that the available number of studies was insufficient for a reliable formal assessment of small-study effects or publication bias.

Integrating the systematic-review evidence with the quantitative findings showed that favorable creativity outcomes were not tied to one intervention label. Instead, several instructional processes recurred across otherwise different programs.

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The most consistent feature was structured generation of multiple alternatives, evident in explicit creativity training, CPS and SCAMPER approaches, CREACT, Learn to Think, open-ended mathematics, SCIP, and robotics-based instruction. Because these processes were normally embedded in multicomponent programs, they cannot be regarded as experimentally isolated active ingredients. Their recurrence nevertheless identifies structured ideation as a candidate core component. A second recurrent feature was problem finding and engagement with open-ended or authentic problems. STEM/STEAM, maker, robotics, design-thinking, and creative problem-solving interventions frequently required learners to define, reinterpret, or explore a problem rather than merely identify a predetermined correct solution. A third pattern involved progression from idea generation to externalization, iteration, and refinement. Favorable design-, maker-, robotics-, visual-, and project-based interventions commonly required learners to transform ideas into products or representations and subsequently test, discuss, revise, or improve them. Creative learning therefore appeared to involve not only expansion of possible ideas but also their evaluation and refinement.

Feedback and metacognitive reflection formed a related recurrent feature. Learn to Think, SCIP, design-thinking approaches, and integrated disciplinary programs provided opportunities to compare alternatives, justify choices, monitor thinking, or reflect on the adequacy of proposed solutions.

Implementation evidence added an important qualification. Positive outcomes occurred after both comparatively short and substantially longer interventions, and no simple dose–response relationship was evident. The clearest implementation evidence came from Haim et al. (2024), where adherence to the intended instructional procedures was more consistently related to outcomes than the simple number of activities completed. Implementation coherence may therefore be more consequential than exposure quantity alone.

On the basis of these convergent patterns, intervention characteristics were classified into candidate core, adaptable, and context-dependent elements.

Table 3

Evidence-informed classification of instructional principles

Classification	Principle	Evidence pattern	Design implication
Candidate core	Structured generation of alternatives	Recurrent across explicit training, CPS/SCAMPER, LTT, mathematics, SCIP, robotics	Make repeated ideation an intentional instructional process
Candidate core	Problem finding/open-authentic problems	STEM/STEAM, design, maker, robotics, CPS	Use problems permitting multiple formulations and solution pathways
Candidate core	Externalization, iteration, refinement	Design, maker, STEAM-PBL, robotics, representational activities	Require ideas to be represented, tested, and revised
Candidate core	Feedback/metacognitive reflection	LTT, SCIP, design-thinking and integrated programs	Include evaluation, justification, selection, and improvement
Cross-cutting condition	Implementation adherence	Strongest direct evidence from SCIP	Preserve the intended process architecture rather than maximizing session count
Adaptable	Collaboration	Cooperative mathematics, SCIP, robotics, maker, visual activities	Adapt group format to task and classroom conditions
Adaptable	Representation/delivery medium	Verbal, visual, digital, physical and disciplinary formats	Avoid dependence on one technology or material medium
Adaptable	Duration/scheduling	Brief interventions through multi-year programs	Provide sufficient practice and iteration; longer is not automatically better
Adaptable	Curricular domain	Science, mathematics, writing, design, computing, STEM/STEAM	Preserve processes while adapting disciplinary content
Context-dependent	Outcome/assessment modality	Performance, product, scientific/math and self-report measures	Align assessment with the intended creativity construct
Context-dependent	Transfer	Sparse and non-uniform evidence	Teach and assess generalization explicitly
Context-dependent/evidence-limited	Maintenance	Positive but sparse delayed assessments	Include delayed assessment and test maintenance strategies

Figure 6 brings together the main strands of our evidence—the systematic review, meta-analyses, and component–context synthesis—into a coherent instructional framework. The core of this framework consists of four recurring processes, arranged not as a linear sequence but as a recursive cycle: starting with problem finding and open-

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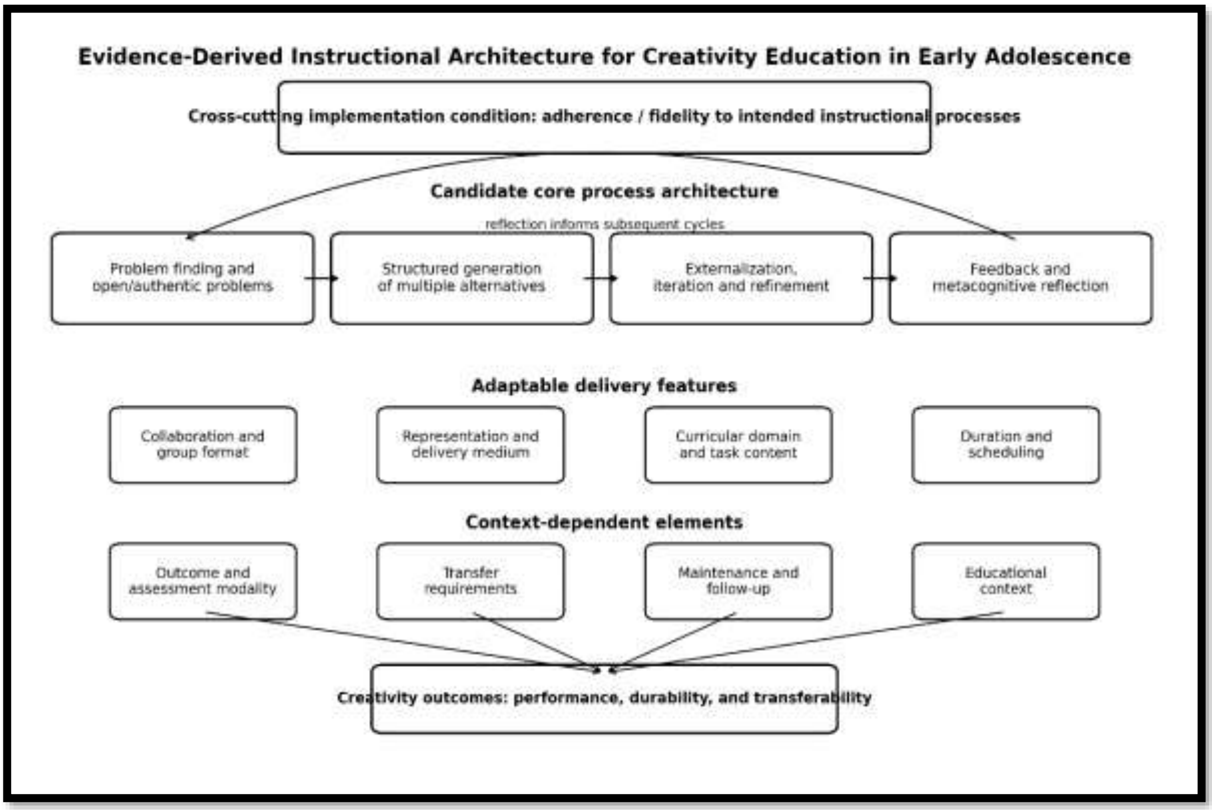
ended exploration, moving through structured ideation and externalization, then to iterative refinement, and finally feeding back via metacognitive reflection into earlier stages. In other words, the cycle deliberately shifts between divergent generation and convergent evaluation, with each reflective loop potentially redefining the problem itself.

What makes this architecture more than a checklist is the cross-cutting role of implementation fidelity. As findings such as those from Haim et al. (2024) suggest, how faithfully these processes are enacted matters more than how many sessions are delivered. Surrounding this core are features that can be adapted to local circumstances—group arrangements, media and materials, subject content, and timeframes—without losing the underlying logic. The outer layer, by contrast, includes aspects that are not part of the intervention itself but shape what can be measured, sustained, or transferred across settings.

Importantly, this model is not a causal model of discrete components; rather, it is a guiding framework based on repeated empirical patterns. This framework can be considered a principled starting point for designing, localizing, and evaluating a creativity intervention tailored to early adolescents in Iran, while keeping the underlying processes intact.

Figure 6

Evidence-derived instructional architecture for creativity education in early adolescence.



The combined findings therefore support an intervention signal that is positive but heterogeneous. The evidence does not identify a universally superior program or a single expected effect magnitude. More defensibly, it indicates that creativity performance in early adolescence is responsive to structured educational intervention and that outcomes vary according to the creativity construct being targeted, the architecture of instruction, implementation quality, assessment method, and educational context.

4. Discussion and Conclusion

The present systematic review, conditional meta-analysis, and component–context synthesis examined educational interventions designed to enhance creativity among adolescents aged 12–15 years. The findings indicate that creativity during early adolescence is responsive to structured educational intervention, but that the magnitude and consistency of effects vary substantially according to the creativity domain, instructional architecture, implementation characteristics, and methodological quality of the studies. The clearest quantitative evidence emerged for divergent thinking. Across nine independent study-level effects, the pooled intervention effect was large (g=1.53, 95% CI [0.45, 2.62]), although between-study heterogeneity was very high. Importantly, after excluding the exceptionally large but source-verified effect reported in one study, the pooled effect remained positive and substantial (g=1.11, 95% CI [0.51, 1.71]). Leave-one-study-out analyses similarly showed that the positive effect was not dependent on any single remaining study. Scientific creativity also showed a favorable pattern, with an inclusive pooled effect of g=1.04, although the confidence interval crossed zero. After excluding one study with reporting inconsistencies, the pooled estimate was reduced to a moderate but statistically supported effect of g=0.62. Mathematical creativity yielded a large pooled point estimate of g=1.22, but the wide confidence interval and the inclusion of only three studies make this finding exploratory rather than conclusive. Taken together, these results suggest that educational intervention can improve creativity performance during early adolescence, but the evidence supports a positive and heterogeneous intervention signal rather than a single universal effect size.

The strong divergent-thinking findings are consistent with a substantial body of intervention research showing that fluency, flexibility, originality, and related forms of idea generation can be deliberately strengthened through instruction. Early creativity programs already demonstrated that structured creative problem-solving curricula could improve performance among middle-school students across different ability levels (Schack, 1993). Problem-identification training likewise increased fluency and flexibility by requiring students to generate and reformulate possible problems rather than immediately search for one predetermined answer (Kurtzberg & Reale, 1999). SCAMPER-based instruction among gifted adolescents also provided early support for deliberately teaching transformations such as substitution, combination, adaptation, modification, and rearrangement as a means of stimulating creative thinking (Mijares-Colmenares et al., 1988). More recent research has reported similarly favorable outcomes for creative-thinking counseling (Huang et al., 2021), creative-reversal instruction in science (Karaca & Koray, 2017), brainstorming (Hidayanti et al., 2018), and SCAMPER activities integrated into science education (Yüzüak & Recepkethüda, 2025). The present meta-analytic findings therefore reinforce the broader conclusion that divergent-thinking processes are particularly amenable to structured educational practice.

The magnitude of the divergent-thinking effect should nevertheless be interpreted cautiously. The observed estimate is larger than the average effects found in broader creativity-training research. In a comprehensive meta-analysis spanning approximately five decades, Sio and Lortie-Forgues found an overall positive effect of creativity training, but effect estimates became smaller after adjustment for potential publication bias and methodological limitations (Sio & Lortie-Forgues, 2024). The larger effect found in the present review may partly reflect the narrower developmental focus on early adolescence, the separation of creativity domains rather than indiscriminate pooling of heterogeneous constructs, and the inclusion of classroom-based quasi-experimental studies that sometimes yielded unusually large intervention effects. Some individual studies within the current evidence base have indeed reported very large creativity gains following interventions such as design-thinking STEAM project-based learning (Chang et al., 2023), STEM-based robotics (Tiryaki & Adıgüzel, 2021), and intensive explicit creativity programs (Larraz Rábanos & Allueva Torres, 2012). At the same time, the high heterogeneity observed in the present analysis indicates that these effects should not be interpreted as a typical expected gain for all school-based creativity programs.

The scientific-creativity findings provide a similar but more qualified picture. The inclusive analysis produced a large positive point estimate, but substantial heterogeneity and the influence of one unusually large study reduced the precision of the pooled effect. When that reporting-sensitive study was removed, the resulting moderate effect remained positive and statistically supported. This pattern aligns with previous studies showing that scientific creativity can be enhanced through STEM, inquiry, design, and problem-solving approaches. STEM activities have produced substantial improvements in scientific creativity among middle-school learners (Doğan & Kahraman, 2021), while STEM-supported research-inquiry instruction has also yielded strong favorable effects (Kırıcı & Bakırcı, 2021). Other work has reported positive scientific-creativity outcomes from STEM applications embedded within science instruction (Çalışıcı & Benzer, 2021), STEAM-based courses (Tran et al., 2021), and makerspace-based learning (Caballero-García & Grau Fernández, 2018). The Learn to Think program further demonstrated that scientific creativity can be enhanced through structured cognitive instruction and that some gains can be maintained beyond immediate post-testing (Hu et al., 2013). These findings are also consistent with recent meta-analytic evidence indicating that scientific creativity benefits from problem-based, project-based, inquiry-oriented, and STEM-related instruction, although intervention effects vary considerably across instructional approaches and contexts (Pinar et al., 2025).

One interpretation of the scientific-creativity findings is that domain-specific creativity requires more than general divergent-thinking practice. Scientific creativity depends on the ability to generate novel ideas within the constraints of disciplinary knowledge, causal reasoning, evidence, and scientific problem solving. Consequently, programs may be more effective when creativity is embedded in authentic scientific activity rather than added superficially to conventional instruction. This interpretation is supported by studies in which learners were required to solve real-life inventive problems (Demirci Saygı & Şahin, 2023), design and construct products within STEM contexts (Ain et al., 2025), or engage in scientific creativity through a deliberately structured instructional program (Haim et al., 2024). The findings therefore suggest that the label "STEM" itself is insufficient to explain effectiveness. What appears to matter more is whether students are required to identify problems, generate alternatives, produce representations or products, test ideas, revise solutions, and reflect on the adequacy of their reasoning.

The mathematical-creativity findings should be interpreted even more conservatively because only three study groups were sufficiently comparable for meta-analysis. Nevertheless, the positive direction is consistent with existing classroom evidence. Open-ended mathematics instruction has been shown to enhance fluency and flexibility by allowing learners to produce multiple solution paths and representations (Kwon et al., 2006). Cooperative mathematical learning has also been associated with improved creative-thinking performance (Lince, 2016), and dedicated mathematics-learning models have been designed to promote creativity through structured exploration and problem solving (Sriwongchai et al., 2015). These studies support the plausibility of a genuine effect, but the current evidence base is too small to determine a precise pooled magnitude. Mathematical creativity should therefore be regarded as a promising domain for intervention rather than one for which effectiveness has already been firmly established.

A particularly important finding of the component–context synthesis was that favorable outcomes were not confined to one branded intervention. Positive results were observed across creative problem solving, SCAMPER, Future Problem Solving, brainstorming, design thinking, maker education, robotics, digital storytelling, open-ended mathematics, cooperative learning, STEM/STEAM, and related approaches. This pattern is consistent with evidence from systematic and meta-analytic reviews showing that several different instructional models can foster creativity (Muneer et al., 2026; Saeed & Ramdane, 2022). The implication is that the effectiveness of creativity education may depend less on the formal name of the program than on the functional processes embedded within it. This is especially important for intervention development because the same label can describe quite different forms of classroom implementation, whereas different labels may contain highly similar cognitive and instructional mechanisms.

Across the included studies, four processes appeared repeatedly in favorable interventions: structured generation of alternatives; engagement with open, authentic, or partially defined problems; externalization followed by iterative refinement; and feedback or metacognitive reflection. The first of these, structured ideation, was evident in creative problem solving, SCAMPER, brainstorming, open-ended mathematical activities, and explicit creativity-training programs. These approaches intentionally increase the range of possible responses before requiring students to settle on a particular solution. This logic is compatible with research demonstrating positive effects from Future Problem Solving (Azevedo et al., 2017), structured thinking-skills instruction (Sanz de Acedo Lizarraga et al., 2010), and creative-thinking programs emphasizing systematic generation and evaluation of alternatives. It is also consistent with the broader conceptual distinction between divergent and convergent processes, both of which contribute to creative performance across development (Eon Duval et al., 2023).

Problem finding and engagement with authentic or open-ended problems represented a second recurring feature. In design thinking, STEM/STEAM, maker education, and inventive problem solving, students typically encounter tasks that permit more than one interpretation or solution. Rather than merely reproducing a known procedure, learners must frame the problem, identify constraints, explore alternatives, and justify choices. Design-thinking approaches in maker education have been shown to improve creativity relative to more conventional maker instruction

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(Chen et al., 2025), while design-thinking-based STEAM project-based learning has similarly produced substantial gains (Chang et al., 2023). Recent meta-analytic evidence further suggests that design thinking is positively associated with creativity outcomes across STEM education, although effects vary according to teaching methodology, assessment, course duration, and implementation context (Muneer et al., 2026). These findings support the present conclusion that authentic problem engagement may be more consequential than the disciplinary label attached to an intervention.

The third recurring process involved externalization, iteration, and refinement. Creative ideas become educationally meaningful when students transform them into visible, communicable, or testable representations and then modify them in response to evidence or feedback. This process is especially apparent in design, maker, robotics, digital, and project-based environments. Water-filtration projects integrating STEM and design thinking, for example, require learners to translate conceptual ideas into products that can be evaluated and revised (Ain et al., 2025). Robotics similarly requires repeated cycles of construction, testing, failure detection, and modification (Tiryaki & Adıgüzel, 2021). Digital storytelling combines idea generation with narrative organization, visual representation, revision, and production, and has been shown to foster creative-thinking skills (Wan Mohd Nasir et al., 2024). Tablet-based visual collaboration also provides opportunities to externalize and manipulate emerging ideas (Kim et al., 2016). These approaches suggest that creativity education should not stop at ideation; students need opportunities to elaborate, test, revise, and communicate what they generate.

Feedback and metacognitive reflection constituted a fourth recurring process. Creativity involves not only producing many possibilities but also evaluating their relevance, novelty, feasibility, and quality. Programs integrating critical and creative thinking illustrate how divergent generation and evaluative reasoning may operate synergistically rather than competitively (Chang et al., 2015). Similarly, daily creativity planning encourages students to regulate creative behavior intentionally and connect goals with action (Liu et al., 2023). Such findings support an instructional architecture in which students are asked to monitor their thinking, compare alternatives, explain their choices, evaluate emerging products, and revise their ideas in response to feedback. This interpretation is also consistent with multidimensional accounts of creativity that view creative achievement as emerging through interactions among cognitive resources, motivation, domain knowledge, and environmental support (Kaufman & Sternberg, 2019).

Implementation quality emerged as another central explanatory factor. The reviewed interventions ranged from brief programs to long-term curricula, yet longer duration did not consistently correspond to larger effects. The Scientific Creativity in Practice study was particularly informative because adherence to the intended instructional procedures appeared more consistently related to outcomes than simple exposure or activity quantity (Haim et al., 2024). This finding has important implications for interpreting heterogeneity. A theoretically strong intervention may produce limited effects if its core processes are implemented inconsistently, whereas a relatively brief program may generate meaningful outcomes when its instructional architecture is enacted coherently. Detailed reporting of provider, delivery mode, dose, setting, adaptation, and fidelity is therefore essential for interpreting intervention effects and reproducing successful programs (Hoffmann et al., 2014).

The findings regarding maintenance and transfer were considerably less certain. Some studies reported persistence of gains beyond immediate post-testing, including long-term effects of creativity training among middle-school students (Baer, 1988) and maintained improvements following explicit creativity programs (Larraz Rábanos & Allueva Torres, 2012). Scientific-creativity gains have also been reported at delayed follow-up (Hu et al., 2013). However, evidence of transfer across tasks and domains was less convincing. Task-specific divergent-thinking training has shown stronger gains for the trained task than for different creative tasks (Baer, 1996). This distinction is theoretically important because improvements on a particular creativity measure cannot automatically be interpreted as generalized creative capacity. Developmental evidence also indicates that creativity trajectories vary substantially across early adolescence (Anderson, 2024; Barbot et al., 2016), and school experiences may either facilitate or inhibit creative expression (He & Wong, 2015). Therefore, maintenance and transfer should be considered explicit intervention objectives and should be assessed directly rather than assumed from immediate post-intervention gains.

Finally, the methodological profile of the evidence base requires a cautious interpretation of the favorable results. Most included studies used controlled quasi-experimental classroom designs rather than individually randomized trials, and serious risk of bias was common. Non-random assignment of intact classes, confounding, attrition,

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inconsistent reporting, and selective outcome presentation can influence estimated intervention effects. The use of ROBINS-I for non-randomized intervention studies (Sterne et al., 2016) and RoB 2 for randomized trials (Sterne et al., 2019) therefore provided an important distinction between magnitude of effect and credibility of evidence. Likewise, when quantitative synthesis was inappropriate, narrative synthesis needed to be structured around outcome domains and methodological characteristics rather than counts of significant findings, consistent with SWiM recommendations (Campbell et al., 2020). The present findings are consequently best interpreted as evidence that creativity in early adolescence is educationally malleable and that several recurring instructional processes are promising, while recognizing that more rigorous trials are needed before precise causal effects can be assigned to individual components.

Several limitations should be considered when interpreting the findings of this review. First, the evidence base was dominated by controlled quasi-experimental classroom studies, and many studies had serious risk-of-bias concerns related to non-random allocation, residual confounding, attrition, and incomplete reporting. Second, relatively few studies were available for each quantitative outcome family, particularly mathematical creativity, which limited precision, moderator analysis, and assessment of small-study effects or publication bias. Third, substantial heterogeneity remained across divergent-thinking, scientific-creativity, and mathematical-creativity syntheses because studies differed in participant characteristics, interventions, comparators, duration, instructional settings, and measurement procedures. Fourth, creativity was operationalized through diverse performance, product, domain-specific, and self-report measures, limiting direct comparability. Fifth, most interventions consisted of multiple instructional components, making it impossible to determine which particular component was causally responsible for improvement. Finally, evidence concerning long-term maintenance, transfer across tasks or domains, and applicability across different educational and cultural contexts remained limited.

Future research should prioritize adequately powered randomized and cluster-randomized school-based trials with transparent allocation procedures, preregistered outcomes, standardized reporting, and careful management of attrition. Studies should clearly distinguish performance-based creativity from self-reported creativity, creative disposition, and related psychological constructs. Factorial, dismantling, and sequential experimental designs would be particularly valuable for determining whether structured ideation, problem finding, iterative refinement, feedback, collaboration, and metacognitive reflection make independent or interactive contributions to creativity development. Researchers should include delayed follow-up assessments and direct measures of transfer to untrained tasks and domains. Greater attention should also be given to intervention fidelity, teacher adherence, implementation quality, contextual moderators, and the relationship between intervention dose and actual engagement with core instructional processes. Additional high-quality studies of mathematical creativity and other underrepresented creativity domains are especially needed.

Educational programs for adolescents aged 12–15 years should be designed around a coherent set of creativity-supporting processes rather than simply adopting a branded intervention. Teachers and curriculum developers should provide repeated opportunities for students to generate multiple alternatives, identify and reframe problems, work with authentic and open-ended tasks, represent their ideas in visible or testable forms, revise those ideas iteratively, and evaluate them through feedback and reflection. These processes can be adapted to different subjects, technologies, classroom arrangements, and time schedules while preserving their instructional function. Schools should also prioritize quality and consistency of implementation rather than assuming that longer programs are necessarily more effective. Creativity assessment should include performance-based measures aligned with the intended learning outcomes and, where possible, tasks that evaluate whether skills transfer beyond the immediately practiced activity. For locally developed programs, including those intended for Iranian early adolescents, cultural relevance, curriculum compatibility, teacher feasibility, available resources, and fidelity monitoring should be incorporated from the earliest stages of intervention design.

Authors' Contributions

Authors equally contributed to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

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Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

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