Scientific creativity in secondary STEM education: a PRISMA-based systematic review of psychological, instructional, and assessment dimensions

Wan Nur Hafizah Wan Hussain, Hidayah Mohd Fadzil, Edy Hafizan Mohd Shahali
Department of Mathematics and Science Education, Faculty of Education, Universiti Malaya, Kuala Lumpur, Malaysia

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ABSTRACT

Grounded in creativity theory and cognitive psychology, this preferred reporting items for systematic reviews and meta-analyses (PRISMA)-based systematic review synthesizes evidence from 28 peer-reviewed studies (2021-2025) indexed in Scopus and Web of Science examining scientific creativity in secondary science, technology, engineering, and mathematics (STEM) education. The review analyses the roles of teacher psychological traits, instructional interventions, and assessment approaches in fostering students' scientific creativity. The findings indicate that creativity-supportive classroom environments, shaped by teacher beliefs and motivation, enhance scientific creativity when aligned with inquiry-based and design-oriented pedagogies. However, assessment practices remain fragmented and insufficiently integrated with instructional design. The review highlights the need for coherent frameworks that connect psychological, pedagogical, and evaluative dimensions of scientific creativity. Implications are discussed for teacher preparation, instructional design, and future research in STEM education.

Corresponding Author:

Hidayah Mohd Fadzil
Department of Mathematics and Science Education, Faculty of Education, Universiti Malaya
50603 Kuala Lumpur, Malaysia
Email: hidayahfadzil@um.edu.my

1. INTRODUCTION

Scientific creativity has become an important learning outcome in secondary science, technology, engineering, and mathematics (STEM) education because it enables students to generate original ideas, solve scientific problems, and apply knowledge in novel contexts [1], [2]. In an era characterized by rapid technological advancement and interdisciplinary challenges, fostering scientific creativity is increasingly recognized as essential for preparing learners to participate in scientific innovation and knowledge construction [3].

Despite growing scholarly attention, research on scientific creativity remains conceptually fragmented. Studies differ in theoretical perspectives, methodological approaches, and empirical focus, particularly regarding the relationships among teacher psychological traits, instructional interventions, and assessment practices in secondary STEM contexts [4], [5]. This lack of conceptual integration limits the development of coherent evidence to inform science education policy and practice.

To address this gap, the present study conducts a preferred reporting items for systematic reviews and meta-analyses (PRISMA)-guided systematic review of Scopus and Web of Science indexed journal articles published between 2021 and 2025 that examine scientific creativity in secondary STEM education. The review synthesizes evidence on theoretical perspectives, teacher psychological traits, instructional interventions, and assessment approaches, with the aim of providing an integrated understanding of how these factors contribute to the development of scientific creativity.

This review aims to synthesize empirical evidence on how teacher psychological factors, instructional interventions, and assessment approaches contribute to the development of scientific creativity in secondary STEM education. Specifically, the review addresses the following research questions:

- What theoretical frameworks underpin research on scientific creativity in secondary STEM education?
- How do studies conceptualize scientific creativity and examine the roles of teacher psychological traits, instructional interventions, and assessment approaches in fostering scientific creativity?
- What research gaps and recommendations emerge for future studies on scientific creativity in STEM education?

Through this synthesis, the review seeks to strengthen conceptual coherence in scientific creativity research and inform future research, educational practice, and policy development in STEM education.

2. LITERATURE REVIEW

This review synthesizes theoretical and empirical research on scientific creativity, teacher psychological traits, instructional interventions, and assessment approaches, emphasizing their interconnections in secondary STEM education.

2.1. Scientific creativity

Scientific creativity refers to the generation of original and scientifically appropriate ideas through the integration of domain knowledge and creative cognition [6]. Core models describe creativity in science as involving problem identification, problem solving, and product innovation supported by fluency, flexibility, and originality [7]. Research further highlights the influence of affective and motivational factors, such as curiosity and intrinsic motivation, in shaping creative scientific thinking [8]. Broader creativity theories emphasize the interaction of domain-relevant skills, creative processes, and task motivation in scientific inquiry and experimentation [9], [10]. However, variations in how scientific creativity is defined and measured across studies indicate the need for more coherent conceptual frameworks in STEM education.

2.2. Teacher psychological traits

Teacher psychological traits, including beliefs, motivation, and creative self-efficacy, play a significant role in shaping classroom environments that support scientific creativity [11]–[13]. Teachers with stronger creative self-efficacy are more likely to adopt inquiry-oriented and open-ended instructional practices [14]–[16]. Research also indicates that teaching experience, reflective practice, and emotional resilience contribute to the integration of creativity within science instruction [17], [18].

2.3. Instructional interventions

Instructional approaches such as inquiry-based learning, problem-based learning, and design-oriented activities are widely associated with enhanced scientific creativity because they encourage exploration, experimentation, and interdisciplinary reasoning [19], [20]. Digital technologies and collaborative learning environments further expand opportunities for creative engagement in STEM learning [20], [21]. Meta-analytic evidence suggests that interventions combining cognitive challenge with motivational support are more effective than traditional instruction [22]. However, the effectiveness of these approaches often depends on teachers' psychological readiness and pedagogical competence [23].

2.4. Assessment approaches

Assessing scientific creativity remains challenging due to conceptual and methodological diversity [24]. Traditional measures often focus on divergent thinking and problem-solving tasks but may lack contextual sensitivity [7]. Recent studies emphasize multidimensional assessment approaches, including rubrics, portfolios, and formative feedback, to capture both creative processes and outcomes [25], [26]. Aligning assessment strategies with instructional objectives is therefore essential for improving validity and comparability across studies [27].

Overall, scientific creativity in secondary STEM education emerges from the interaction of teacher psychological traits, instructional design, and assessment practices [28]–[30]. However, existing research often examines these dimensions separately. This review addresses this limitation by synthesizing recent empirical studies that integrate these factors to better understand how scientific creativity can be effectively fostered in STEM education.

3. METHOD

A systematic literature review (SLR) was conducted to synthesize recent research on scientific creativity in science and STEM education, focusing on instructional interventions, psychological influences, and assessment practices. The review followed the PRISMA 2020 framework [31] to ensure transparency and methodological rigor throughout the identification, screening, eligibility, and synthesis stages. The population, concept, and context (PCC) framework guided the scope of the review. The population included secondary students and pre-service science teachers, the concept focused on scientific creativity encompassing psychological, instructional, and assessment dimensions, and the context was secondary STEM education. The review included studies published between 2021 and 2025. The flow diagram is for Study Selection shown in Figure 1.

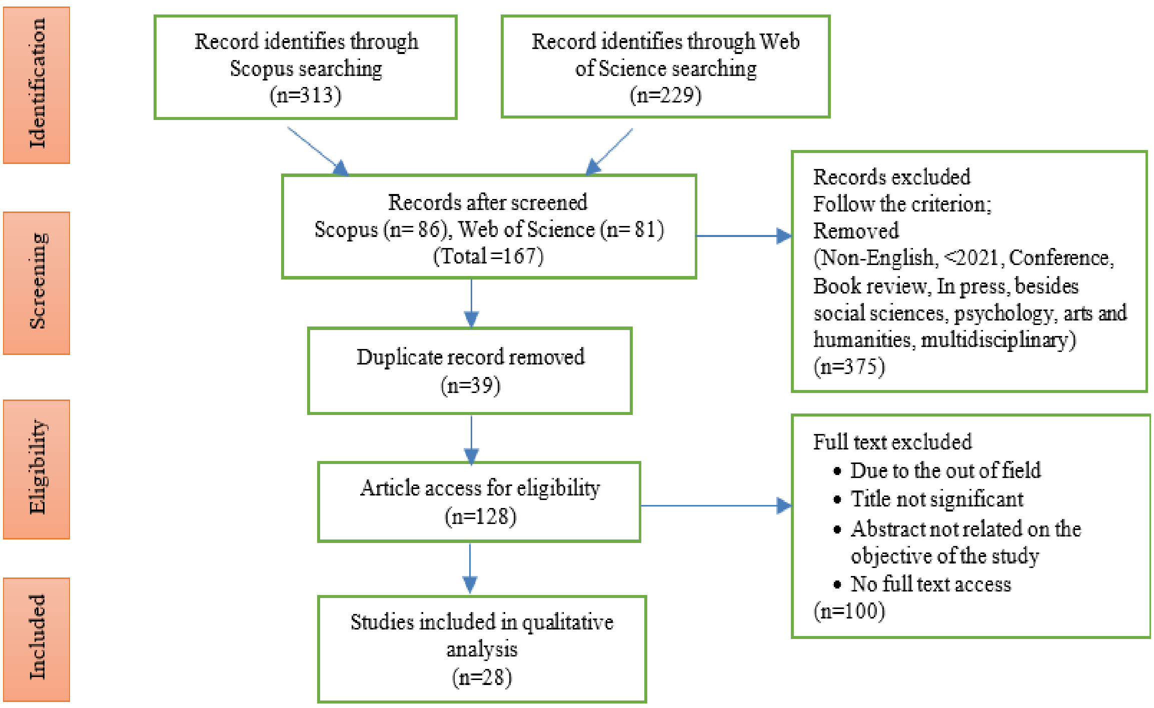

Figure 1. Flow diagram of the proposed searching study

3.1. Identification

Relevant studies were identified through systematic searches in Scopus and Web of Science, selected for their comprehensive coverage of education and psychology research. The search was conducted in May 2025 and yielded 542 records (Scopus=313; Web of Science=229). Search terms related to scientific creativity, science education, and STEM learning were combined using Boolean operators (AND, OR). Filters for publication year (2021-2025), document type (journal articles), subject areas, and language (English) were applied to ensure relevance. Full search strings are presented in Table 1 for transparency and replicability.

3.2. Screening

During the screening phase, retrieved records were evaluated using predefined inclusion and exclusion criteria to ensure relevance and methodological quality. Studies were excluded if they were non-English, published before 2021, or classified as conference papers, book chapters, reviews, or in-press articles, as well as those outside the targeted subject areas as shown in Table 2. A total of 375 records were excluded, leaving 167 articles (Scopus=86; Web of Science=81) for further review. After removing 39 duplicates, 128 unique studies remained for eligibility assessment and data extraction. This process ensured the inclusion of relevant and methodologically appropriate studies on scientific creativity in STEM education.

Table 1. The search string

Database	Search strings
Scopus	TITLE-ABS-KEY ("scientific" AND ("creativity" OR "imagination" OR "ingenuity") AND ("science learning" OR "science education" OR "stem education" OR "stem learning")) AND PUBYEAR > 2020 AND PUBYEAR < 2026 AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "PSYC") OR LIMIT-TO (SUBJAREA , "ARTS") OR LIMIT-TO (SUBJAREA , "MULT")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) Date of Access: May 2025
Web of Science	TS=(scientific AND (creativity OR imagination OR ingenuity) AND ("science learning" OR "science education" OR "stem education" OR "stem learning")) AND PY=(2021 OR 2022 OR 2023 OR 2024 OR 2025) AND DT=(Article) AND LA=(English) Date of Access: May 2025

Table 2. The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Time line	2021–2025	< 2021
Literature type	Journal (article)	Conference, book, review
Publication Stage	Final	In Press
Subject area	Social Sciences, psychology, arts and humanities, multidisciplinary	Besides social sciences, psychology, arts and humanities, and multidisciplinary

3.3. Eligibility

The 128 screened articles underwent full-text evaluation to determine their relevance to the research objectives and compliance with the inclusion criteria. Studies were excluded if they lacked empirical data, did not address scientific creativity in science or STEM education, focused only on general creativity without educational application, or had no accessible full text. Following this assessment, 100 articles were excluded, leaving 28 studies that met all eligibility criteria for the final synthesis. These studies formed the evidence base for analyzing the psychological, instructional, and assessment dimensions of scientific creativity in STEM education.

3.4. Research designs of included studies

The 28 studies included in this review employed diverse research designs, including quantitative approaches (quasi-experiments, surveys, and correlational studies), qualitative methods (interviews, classroom observations, and reflective inquiry), and mixed-methods designs. Quantitative and quasi-experimental studies predominated, reflecting the field's focus on examining the effects of instructional interventions on scientific creativity. Qualitative and mixed-methods studies provided additional insights into participants' psychological processes and learning contexts.

3.5. Data abstraction and analysis

The 28 eligible studies were analyzed using an integrative thematic approach to identify patterns and methodological trends in scientific creativity research within STEM education. A structured extraction matrix was used to record publication details, research design, psychological factors, instructional interventions, assessment methods, and key findings. Synthesized results were summarized in Table 3 (see Appendix) [5], [32]–[58]. Reliability was ensured through independent coding by two researchers with consensus discussion, and the analysis was reviewed by three domain experts. This process identified three main themes: teacher psychological traits, instructional interventions, and assessment approaches related to scientific creativity.

3.6. Quality appraisal

A quality appraisal was conducted to ensure the methodological rigor of the 28 included studies. Using a six-criterion expert review framework, three experts in science education and educational psychology independently evaluated each study based on research clarity, relevance to STEM education, methodological appropriateness, conceptual definition of key constructs, integration with prior literature, and acknowledgment of limitations. Each criterion was rated on a five-point scale, and mean scores were calculated across reviewers. Studies with an average score above 3.0 were retained. Discrepancies were resolved through discussion to ensure inter-rater reliability, and only studies meeting acceptable quality standards were included in the final synthesis.

3.7. Limitation

Several limitations should be acknowledged. First, because the search was conducted before the end of 2025, relevant studies published later or not yet indexed in Scopus or Web of Science may have been excluded. Second, the review focused on secondary STEM education and studies examining teacher psychological traits, instructional interventions, and assessment approaches related to scientific creativity, thereby excluding broader creativity research and other educational contexts. Third, variations in how scientific creativity was defined and measured across studies may have affected comparability. Finally, although expert appraisal and consensus procedures were applied, some subjectivity in qualitative evaluation may remain.

4. RESULTS AND DISCUSSION

Table 4 summarises the quality appraisal of the 28 included studies across six criteria. Overall, the studies demonstrated moderate to high methodological and conceptual quality, particularly in the clarity of research purpose and relevance of contribution. Several studies achieved high mean scores, indicating strong research design, theoretical grounding, and transparent reporting [5], [38], [56]. All studies exceeded the minimum quality threshold of 3.0. Studies scoring between 4.0 and 5.0 were classified as high quality, while those between 3.0 and 3.9 were considered moderate quality. No studies were excluded at this stage, as those below the threshold had already been removed during earlier screening. The thematic synthesis of the final 28 studies yielded four overarching themes:
- Conceptualizations of scientific creativity in STEM education.
- Educational interventions that enhance scientific creativity in secondary STEM contexts.
- Psychological and cognitive factors influencing scientific creativity among pre-service teachers.
- Assessment and measurement approaches for scientific creativity in science education.

All themes were validated through independent expert review to ensure domain relevance and conceptual precision.

Table 4. Quality assessment results for selected studies (PS1-PS28)

Study	Clarity	Relevance	Rigor	Conceptual	Comparative	Limitations	Mean
Eroglu and Bektas [32]	5	5	4	4	4	4	4.33
Anh *et al*. [33]	4	4	3	4	3	3	3.50
Jalaludin *et al*. [34]	4	4	3	3	3	3	3.33
Cakir and Guven [35]	5	5	4	4	4	4	4.33
Panergayo and Prudente [5]	5	5	5	5	5	4	4.83
Xu *et al*. [36]	5	5	5	5	4	4	4.67
Tran *et al*. [37]	4	4	3	4	3	3	3.50
Chang *et al*. [38]	5	5	5	5	5	4	4.83
Hong *et al*. [39]	5	5	5	5	4	4	4.67
Marangio *et al*. [40]	5	5	4	5	4	4	4.50
Guven *et al*. [41]	4	4	4	4	3	3	3.67
Gök and Sürmeli [42]	4	4	3	4	3	3	3.50
Zhang *et al*. [43]	5	5	5	5	4	4	4.67
Prahani *et al*. [44]	4	4	3	3	3	3	3.33
Lee and Tan [45]	5	5	4	5	4	4	4.50
Ates and Aktamis [46]	4	4	4	4	3	3	3.67
Xiang *et al*. [47]	5	5	5	5	4	4	4.67
Sun *et al*. [48]	5	5	4	4	4	4	4.33
Roth *et al*. [49]	4	4	4	4	4	3	3.83
Henze *et al*. [50]	4	4	3	3	3	3	3.33
Haim *et al*. [51]	4	4	4	4	3	3	3.67
Koç and Büyük [52]	4	4	3	3	3	3	3.33
Li *et al*. [53]	5	5	4	4	4	4	4.33
Ünlü *et al*. [54]	5	5	4	4	4	4	4.33
Aschauer *et al*. [55]	5	5	5	5	4	4	4.67
Lai *et al*. [56]	5	5	5	5	5	4	4.83
Chiang *et al*. [57]	5	5	4	4	4	4	4.33
Hebebci and Usta [58]	4	4	3	3	3	3	3.33

Note: clarity=clarity of purpose; relevance=relevance and contribution; rigor=methodological rigor; conceptual=conceptual definition; comparative=comparative context; and limitations=acknowledgment of limitations.

4.1. Theme 1: conceptualizations of scientific creativity in STEM education

The reviewed studies presented diverse conceptualizations of scientific creativity that shaped intervention design and assessment practices. Some studies defined scientific creativity as a domain-specific cognitive capacity emphasizing divergent thinking, problem solving, and scientific reasoning [7], [48], whereas others adopted process-oriented perspectives highlighting inquiry, experimentation, and knowledge construction in authentic STEM contexts [2]. Recent studies increasingly applied multidimensional frameworks integrating cognitive, motivational, and sociocultural elements based on established creativity theories [9]. These conceptual differences influenced measurement approaches, with cognitively oriented studies using psychometric tests and performance tasks, while process-oriented studies employed contextualized assessments [8], [36]. This diversity indicates the absence of a unified theoretical framework and the need for greater conceptual coherence in scientific creativity research.

4.2. Theme 2: educational interventions to enhance scientific creativity

Evidence consistently indicates that student-centered, inquiry-based, and design-oriented pedagogies support scientific creativity in secondary STEM education [4], [16]. Constructivist approaches, particularly the 5E model, engineering design activities, and technology-supported learning environments, were widely applied and shown to enhance creative thinking and problem solving [59], [60]. Collaborative and scaffolded strategies, such as KLEWS charts and virtual collaboration platforms, further supported creative engagement and reasoning [33], [34], [42]. However, many interventions were short-term and context-specific, limiting evidence regarding long-term impact and transferability. Future research should adopt longitudinal and cross-cultural designs to strengthen the evidence base.

4.3. Theme 3: psychological and cognitive factors influencing scientific creativity in pre-service science teachers

Research on psychological factors largely focused on pre-service teachers, reflecting their developmental stage in professional learning. Findings indicate that creative engagement is influenced by motivational factors, creative self-efficacy, reflective practice, and professional identity formation. Experiential and technology-supported activities enhanced creativity and decision-making confidence [35], while intrinsic motivation and reflective practice supported the development of creativity-oriented teaching identities [40], [47]. These findings align with Amabile’s Componential Model of Creativity but also suggest that research often examines individual traits in isolation, highlighting the need to consider broader socioemotional and contextual influences in teacher education.

4.4. Theme 4: assessment and measurement of scientific creativity in science education

Assessment approaches demonstrated increasing methodological diversity alongside persistent challenges related to validity and contextual relevance. Advances include context sensitive instruments and classroom-based creativity scales that support formative evaluation [25]. Emerging applications of artificial intelligence, machine learning, and eye tracking enhance measurement precision but raise ethical, accessibility, and interpretive concerns [43]. Continued variation in defining creative performance limits comparability across studies, underscoring the need for hybrid assessment models that integrate quantitative rigor with qualitative insight while remaining practical and inclusive [45].

Overall, the findings suggest that scientific creativity development depends on the interaction of conceptual frameworks, instructional design, teaching psychological factors, and assessment practices. Effective STEM pedagogy is typically inquiry-driven and technology-supported, while teachers’ creativity-oriented practices are shaped by motivational and reflective processes. Valid assessment requires context-sensitive approaches that capture both creative processes and outcomes. Consequently, scientific creativity should be viewed as a multidimensional competency that emerges from the dynamic interaction of cognitive, motivational, and contextual factors. Advancing this agenda requires stronger alignment among teacher education, curriculum design, and assessment practices, supported by interdisciplinary research that enhances both theoretical clarity and educational practice.

5. CONCLUSION

This systematic review identifies scientific creativity as a key competency in secondary STEM education that should be integrated into instructional goals. Evidence indicates that student-centered and inquiry-based pedagogies, including the 5E model, engineering design activities, and technology-supported learning, effectively promote creative thinking, problem solving, and conceptual understanding. However, existing studies are often limited by short intervention periods, narrow participant samples, and context-specific designs, which restrict generalizability. In addition, teacher psychological factors such as creative self-efficacy and motivation remain underexplored despite their influence on creativity-supportive classroom environments. Future research should therefore adopt longitudinal designs that examine the interaction of teacher factors, pedagogy, and assessment practices. Overall, scientific creativity emerges from the interaction of cognitive, motivational, and contextual factors. Accordingly, curriculum, assessment, and teacher education programs should systematically incorporate creativity to support students' capacity for scientific innovation.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Wan Nur Hafizah Wan Hussain	✓	✓	✓		✓	✓	✓	✓	✓		✓		✓	✓
Hidayah Mohd Fadzil		✓		✓						✓		✓		
Edy Hafizan Mohd Shahali	✓	✓		✓						✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

INFORMED CONSENT

This study did not involve human participants from whom informed consent was required.

ETHICAL APPROVAL

This systematic literature review followed PRISMA guidelines and did not require ethical approval, as it involved no primary data collection and included only published studies with existing ethical clearance.

DATA AVAILABILITY

This systematic review is based solely on secondary data from peer-reviewed articles indexed in Scopus and Web of Science (2021-2025), with all sources publicly accessible and fully referenced.

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APPENDIX

Table 3. Number and details of primary studies database

Study	Participants	Intervention/focus	Psychological/cognitive factors	Assessment methods
Eroglu and Bektas [32]	Secondary students	5E-based STEM instruction	Creativity, attitudes, NOS views	Scientific creativity test, achievement test
Anh *et al.* [33]	Secondary students	KLEWS chart scaffold	Creative thinking, reasoning	Creativity rubric, performance tasks

Table 3. Number and details of primary studies database (continue)

Study	Participants	Intervention/focus	Psychological/cognitive factors	Assessment methods
Jalaludin *et al.* [34]	Secondary students	Virtual collaboration tools	Engagement, creativity, process skills	Survey scales, creativity test
Cakir and Guven [35]	Pre-service teachers	Robotics and engineering design	Creativity, decision-making, self-efficacy	Creativity scale, reflective tasks
Panergayo and Prudente [5]	Meta-analysis	Design-based learning (DBL)	Creativity (aggregated outcomes)	Meta-analytic effect size synthesis
Xu *et al.* [36]	Secondary students	Instrument validation	Scientific creativity (construct focus)	C-SCA psychometric validation
Tran *et al.* [37]	Secondary students	STEAM-based curriculum	Creative thinking, engagement	Creativity tests, student products
Chang *et al.* [38]	Meta-analysis	STE(A)M interventions	Creativity outcomes (general)	Meta-analysis
Hong *et al.* [39]	Secondary students	Scale development	Classroom creativity	Science classroom creativity scale
Marangio *et al.* [40]	Pre-service teachers	Reflective pedagogy intervention	Identity, creativity, critical thinking	Interviews, reflective journals
Guven *et al.* [41]	Secondary students	Arduino + 5E model	Motivation, creativity	Creativity test, motivation survey
Gök and Sürmeli [42]	Secondary students	Toy design (engineering design)	Creativity, imagination	Scientific creativity scale
Zhang *et al.* [43]	Secondary students	AI-based assessment	Cognitive patterns of creativity	Eye-tracking, ML analytics
Prahani *et al.* [44]	Secondary students	Online Scientific Creativity Learning	Engagement, creative thinking	Creativity test
Lee and Tan [45]	Secondary students	Task-specific assessment design	Creativity (domain-specific)	Rubric-based assessment
Ates and Aktamis [46]	Secondary students	CoRT + PBL modules	Metacognition, creativity	Creativity test, perception scale
Xiang *et al.* [47]	Secondary students	No intervention (network analysis)	Motivation, creative engagement	Motivation scale, creativity test
Sun *et al.* [48]	Secondary students	Digital mind mapping	Collaborative cognition	Discourse analysis, creativity tasks
Roth *et al.* [49]	Secondary students	No intervention	Personality traits, creativity	Creativity test, personality inventory
Henze *et al.* [50]	Pre-service teachers	Teacher training program	Interest, engagement	Survey, qualitative reflections
Haim *et al.* [51]	Secondary students	Scientific creativity program	Divergent thinking	Performance tasks
Koç and Büyük [52]	Secondary students	Robotics activities	Attitude, creativity	Creativity scale, attitude scale
Li *et al.* [53]	Secondary students	Digital assessment environment	Scientific thinking	Online assessment analytics
Ünlü *et al.* [54]	Pre-service teachers	Inquiry-based lab design	Reflection, novelty	Portfolio, rubric scoring
Aschauer *et al.* [55]	Secondary students	Instrument validation	Divergent problem-solving	Psychometric validation
Lai *et al.* [56]	Secondary students	Experimental creativity training	Cognitive flexibility	Creativity tasks, semantic analysis
Chiang *et al.* [57]	Secondary students	No intervention	Resilience, creativity	Interview, creativity rubric
Hebebci and Usta [58]	Secondary students	Integrated STEM practices	Critical thinking, creativity	Creativity test, problem-solving test

BIOGRAPHIES OF AUTHORS

Wan Nur Hafizah Wan Hussain is a PhD candidate in the Department of Mathematics and Science Education, Faculty of Education, Universiti Malaya, Kuala Lumpur, Malaysia. Her research focuses on primary science education, particularly scientific creativity, science process skills, and science pedagogy. She holds a Master's degree in Science Education from Universiti Kebangsaan Malaysia (UKM). She can be contacted at email: 22098238@siswa.um.edu.my.

Hidayah Mohd Fadzil is an associate professor in the Department of Mathematics and Science Education, Faculty of Education, Universiti Malaya. She obtained her PhD in Science Education from Universiti Malaya through the university's fast-track program and was a recipient of the Ryoichi Sasakawa Young Leaders Fellowship Fund (SYLFF) from the Nippon Foundation, Japan. Her research interests include science practical work, STEM education, and 21st-century skills in science education. She can be contacted at email: hidayahfadzil@um.edu.my.

Edy Hafizan Mohd Shahali is a senior lecturer in the Department of Mathematics and Science Education, Faculty of Education, Universiti Malaya. He obtained his PhD and Master's degree in Science Education from Universiti Kebangsaan Malaysia (UKM). His research interests include science education, STEM education, and teacher professional development. He can be contacted at email: edyhafizan@um.edu.my.