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Mapping creativity and higher-order thinking in STEM and higher education research (2014–2024)

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ABSTRACT

The ability to think critically and creatively is a central goal of 21st-century education. This study uses scientometric and bibliometric analysis to map the development of research on creativity and higher-order thinking (HOT) from 2014 to 2024 within a Scopus-indexed STEM/science and higher education-related dataset. Using Scopus as the primary database, 799 publications were analyzed to identify publication growth, citation impact, influential authors and sources, country-level publication output, collaboration networks, and thematic structures. VOSviewer and Biblioshiny were used to visualize and examine co-authorship networks, citation patterns, and keyword co-occurrence clusters. The findings show a sharp increase in creativity and HOT-related publications, especially after 2020, indicating growing scholarly attention to critical thinking, creative thinking, technology-enhanced learning, STEM/STEAM education, and interdisciplinary pedagogy. The geographic analysis shows that Indonesia, the United States, China, Malaysia, and Taiwan were the most visible contributors in terms of publication output within the analyzed Scopus dataset. However, publication volume should not be interpreted as a complete measure of research leadership without considering citation impact, collaboration quality, policy context, and journal influence. The keyword analysis identified several major themes, including critical thinking in education, digital and technology-supported learning, STEM/STEAM and interdisciplinary learning models, student-centered pedagogy, sustainability-oriented problem-solving, teacher education, and assessment of complex competencies. Overall, the study shows that creativity and HOT research in this dataset has evolved from a primarily cognitive focus toward a broader educational agenda involving curriculum design, digital learning, teacher capacity, sustainability, and competency-based assessment. The findings suggest the need for further studies on AI-supported HOT education, cross-cultural comparisons, teacher professional development, equity in technology-enhanced learning, non-STEM contexts, and longitudinal assessment of HOT skill development.

1. Introduction

1.1 Background

In the 21st century, the ability to think creatively and engage in higher-order thinking (HOT) has become increasingly essential across various domains, particularly within education. Creativity is often defined as the ability to generate novel and valuable ideas, while HOT refers to cognitive skills such as analysis, evaluation, and creation, which go beyond rote memorization or recall of information. In this study, creativity and HOT are treated as

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complementary cognitive capacities: creativity supports the generation of original and useful ideas, whereas HOT supports the analysis, evaluation, and transformation of knowledge into reasoned action. Together, these capacities enable learners to address complex problems with innovation and adaptability, which are critical in today's fast-evolving global landscape (Liu et al., 2023; Thornhill-Miller et al., 2023).

The integration of creativity and HOT in education has gained prominence because these skills support innovation, problem-solving, critical reflection, and knowledge transfer. Their relevance is especially visible in pedagogical approaches that require learners to connect concepts across disciplines and apply knowledge to authentic problems. Science, Technology, Engineering, Arts, and Mathematics (STEAM) education, for example, encourages interdisciplinary learning and real-world application. STEAM-based curricula that use hands-on learning and experimentation can cultivate students' creative capacities and higher-order cognitive abilities (Bassachs et al., 2020). Similarly, computational thinking, which incorporates creativity, problem-solving, algorithmic thinking, and cooperation, is considered important for preparing students to participate in technology-driven learning and work environments (Liu et al., 2023). These connections are especially relevant to STEM/science and higher education contexts, where learners are often expected to analyze complex disciplinary problems, integrate knowledge across domains, and develop innovative solutions.

Educational approaches such as project-based learning (PBL), inquiry-based learning, and problem-based learning have also been used to promote HOT and creativity. These approaches require students to engage with complex, open-ended problems, evaluate evidence, construct explanations, and design solutions. Blended PBL models can enhance pre-service teachers' HOT skills by integrating digital tools and collaborative learning strategies (Hujjatusnaini et al., 2022). Problem-based learning scenarios involving socio-scientific issues can also support content knowledge and creative thinking by situating learning in real-world problems that require analysis, judgment, and innovation (Hernández-Ramos et al., 2021). Thus, HOT and creativity are not only individual cognitive outcomes but also pedagogical goals shaped by instructional design, curriculum structure, and learning environments. Recent STEM/STEAM studies further indicate that PBL, inquiry learning, blended formats, concept mapping, and digital modules can support HOT-related outcomes when learning tasks explicitly require analysis, synthesis, evaluation, collaboration, and creative reasoning (Kurniawan et al., 2023; Martawijaya et al., 2023; Pimdee, 2022; Yang et al., 2023; Zhu & Tahir, 2023).

The urgency of fostering HOT and creativity has been further highlighted by global disruptions such as the COVID-19 pandemic, which accelerated the shift toward online, blended, and hybrid learning. Digital tools and collaborative learning environments have helped maintain student engagement and support HOT skills in remote learning contexts (ElSayary et al., 2022; Lee, 2023). This shift has also expanded research attention toward technology-enhanced learning environments that can support self-regulated learning, cognitive flexibility, feedback, and collaborative knowledge construction. Emerging technologies, including digital storytelling, artificial intelligence (AI), augmented reality, virtual laboratories, and interactive learning platforms, have been explored as tools for strengthening critical thinking and problem-solving. AI-driven educational tools can support critical thinking through personalized learning experiences and real-time feedback (Jia & Tu, 2024; Nunvarova et al., 2023), while augmented reality, virtual laboratories, digital worksheets, and AI-enabled scaffolds have been reported to improve HOT-related learning when they are integrated with explicit prompts, structured feedback, and pedagogical support (Wang & Gao, 2025; T. Wu, Lee, et al., 2025; T. Wu, Sarwono, et al., 2025; Zhao et al., 2025). The pandemic also reinforced the importance of digital literacy and interactive pedagogy in supporting cognitive development in remote and hybrid learning environments (Dúo-Terrón et al., 2022; Lee et al., 2024).

Recent research also shows growing attention to instructional models designed specifically to strengthen critical thinking and HOT. The Critical Thinking Cycle Model proposed by Fikriyati et al. (2022), for instance, aims to develop both critical thinking disposition and critical thinking skills among pre-service teachers. Discovery-based learning and inquiry-driven instruction have also been emphasized as strategies for enhancing analytical and problem-solving abilities (Oyewo et al., 2022; Samad et al., 2023). Across these studies, a common pattern is evident: creativity and HOT are increasingly positioned as core learning outcomes that require active, interdisciplinary, technology-supported, and assessment-oriented pedagogies. However, these pedagogies are effective only when teachers or instructors are prepared to design open-ended tasks, scaffold reasoning, facilitate inquiry, support collaboration, and align assessment with HOT-related outcomes (Kurniawan et al., 2023; Luchang & Nasri, 2023; Zhu & Tahir, 2023).

1.2 Research Gap and Novelty

Several recent bibliometric and scientometric studies have mapped related areas, including STEM/STEAM education, 21st-century skills, creativity, critical thinking, computational thinking, and technology-supported learning. These studies generally show increasing publication activity and growing thematic attention to STEAM integration, creativity, critical thinking, problem-solving, computational thinking, and innovative capacity as core educational competencies (Jantakoon et al., 2024; Kaymakci & Can, 2023; Y. Li & Talib, 2024; Prahani, Nisa, et al., 2023; Şeker, 2025; Tran et al., 2024). Methodologically, previous mappings commonly rely on Scopus or Web of Science data and use co-authorship analysis, keyword co-occurrence, citation mapping, and network visualization tools such as VOSviewer, Bibliometrix, and CiteSpace to identify intellectual structures and collaboration patterns (Ahmed et al., 2023; Dúo-Terrón, 2023; Prahani, Dawana, et al., 2023; Tran et al., 2024; Wasak, 2024).

Although these studies provide useful foundations, many prior reviews have examined creativity, HOT, critical thinking, STEM/STEAM, mathematical creativity, language education, or physics education as separate or domain-specific topics (Gül & Ayık, 2024; Ibrahim et al., 2024; Korkmaz & Toraman, 2024; Saefudin et al., 2023; Sukmojati et al., 2025; Suprpto et al., 2024). As a result, less is known about how creativity and HOT co-emerge within the same bibliometric landscape, particularly in STEM/science and higher education-related research. The present study addresses this gap by jointly mapping creativity and HOT and by integrating publication trends, citation impact, country-level publication output, influential authors and sources, collaboration networks, keyword clusters, and pedagogical implications.

Despite this growing emphasis, several gaps remain in the literature. First, studies on creativity and HOT often use different conceptualizations, which can lead to inconsistent interpretations of learning outcomes. Fikriyati et al. (2022) highlight the need for a more standardized model to promote critical thinking skills because existing frameworks may not fully capture the complexity of HOT in educational contexts. Research on creativity within STEM and STEAM education also indicates the need for more integrated frameworks that connect creativity, critical thinking, and higher-order cognitive processes (Huang et al., 2022). This conceptual variation makes it important to examine how the research field itself is structured and how key concepts are connected across publications.

Second, while many studies support PBL, blended learning, inquiry-based learning, STEAM, and digital technologies as strategies for promoting HOT, the evidence remains distributed across different disciplines, educational levels, and methodological traditions. Hujjatusnaini et al. (2022) found that blended PBL significantly enhances pre-service teachers' HOT skills, but the specific context of the study limits the generalizability of its findings. Oyewo et al. (2022) also note that discovery-based learning can vary considerably in implementation, leading to different student outcomes. Therefore, beyond evaluating individual interventions, the field needs a broader mapping of publication trends, influential contributors, collaboration patterns, and emerging themes. Such mapping can clarify how research priorities have evolved and where future empirical work is most needed. In the present study, this mapping is specifically focused on the Scopus-indexed STEM/science and higher education-related dataset analyzed, rather than on all creativity and HOT research across every discipline and educational level.

Third, robust assessment of creativity and HOT remains a continuing challenge. Many studies discuss innovative teaching methods but provide limited evidence about their long-term impact on students' cognitive development. ElSayary et al. (2022), for example, identify the benefits of interactive technology in STEAM-oriented teacher preparation but do not provide a detailed assessment framework for measuring improvements in creativity and HOT. Rehman et al. (2023) examine challenges in students' engagement with critical thinking in mathematics but do not offer systematic solutions for assessing and addressing these difficulties. Recent studies also note that creativity and HOT assessment remains heavily concentrated in STEM-related contexts, while validated domain-specific measures for humanities, arts, social sciences, vocational education, and informal learning are still limited (González-Pérez & Soledad, 2022; Mukhlis et al., 2023; Vodă et al., 2022). This limitation indicates a need to identify whether assessment, measurement, and long-term learning outcomes have become central or peripheral themes in the broader research landscape. It also highlights the importance of treating non-STEM and non-higher-education contexts as important directions for future research, rather than as areas fully covered by the present dataset.

1.3 Research Objective and Questions

In light of these considerations, this meta-analysis aims to address critical gaps in the literature and provide a comprehensive synthesis of the relationship between SRL and academic performance in higher education. Specifically, the objectives of this study are to (1) quantify the overall effect size of SRL on academic performance in higher education, providing a reliable estimate of its impact across diverse studies; (2) examine the sources of heterogeneity in the relationship between SRL and academic performance, identifying factors that influence variations in effect sizes; (3) evaluate the role of potential mediators and moderators, such as self-efficacy, social support, and motivation, in shaping the SRL-academic performance relationship; and (4) assess publication bias and the robustness of the findings using advanced statistical techniques.

Given these conceptual, pedagogical, and assessment-related gaps, this study conducts a scientometric and bibliometric analysis of creativity and HOT research from 2014 to 2024 within a Scopus-indexed STEM/science and higher education-related dataset. Unlike an intervention review that evaluates the effectiveness of specific teaching strategies, this study maps the intellectual and thematic structure of the field by examining publication output, citation impact, author and country contributions, collaboration networks, and keyword co-occurrence patterns. By doing so, the study provides evidence on how creativity and HOT research has developed, which actors and sources have shaped the field, and which themes are emerging in relation to technology-enhanced, interdisciplinary, and competency-based education. The novelty of this study lies in its integrated mapping of creativity and HOT as interconnected educational constructs and in its attempt to connect bibliometric patterns with pedagogical interpretation, rather than treating publication and keyword indicators as purely descriptive outputs.

This study is guided by the following research questions:

1. RQ1. How has publication output on creativity and higher-order thinking in STEM/science and higher education-related research evolved from 2014 to 2024?
2. RQ2. Which countries, authors, journals, and publications have contributed most prominently to creativity and HOT research within the analyzed Scopus-indexed STEM/science and higher education-related dataset?
3. RQ3. What collaboration patterns characterize creativity and HOT research within this dataset during the study period?
4. RQ4. What thematic clusters and emerging topics can be identified through keyword co-occurrence analysis of creativity and HOT research in STEM/science and higher education-related contexts?
5. RQ5. How do these bibliometric patterns reflect broader pedagogical shifts toward interdisciplinary, technology-enhanced, and competency-based education within STEM/science and higher education-related research?

By addressing these questions, this study contributes to the literature by moving beyond a descriptive summary of individual studies and offering a structured map of the development, influence, and thematic direction of creativity and HOT research within the defined STEM/science and higher education-related scope. The findings are expected to support researchers, educators, and policymakers in identifying research gaps, strengthening pedagogical design, and developing future studies on creativity and higher-order thinking. At the same time, the study acknowledges that its findings should be interpreted as patterns within the analyzed Scopus dataset, not as an exhaustive representation of creativity and HOT research across all disciplines, educational levels, and learning contexts.

2. Overview of Literature

2.1 Definition and Scope of Creativity and Higher-Order Thinking (HOT)

Creativity and higher-order thinking (HOT) are critical cognitive skills that have gained increasing attention in education, psychology, and cognitive science. Creativity is commonly defined as the ability to generate novel and valuable ideas, playing a crucial role in problem-solving, innovation, and adaptability in the modern world (Thornhill-Miller et al., 2023). HOT involves cognitive processes such as analysis, evaluation, and creation, which extend beyond basic memorization or comprehension (Hujjatusnaini et al., 2022). In this manuscript, creativity is understood as the capacity to produce original and useful ideas, whereas HOT is understood as the capacity to

analyze information, evaluate alternatives, and construct reasoned solutions. These two constructs are closely related because creative learning requires more than idea generation; it also requires judgment, reflection, and the ability to transform knowledge into meaningful action.

Within STEM/science and higher education contexts, creativity and HOT are especially important because learners are often expected to address ill-structured problems, integrate disciplinary knowledge, evaluate evidence, and design innovative solutions. In this sense, creativity and HOT should not be treated as separate outcomes. Creativity supports divergent idea generation and innovation, while HOT supports analytical reasoning, evaluation, synthesis, and justified decision-making. Together, these capacities form an integrated basis for problem-solving, inquiry, design reasoning, and knowledge transfer in advanced learning environments.

Over the past decade, various theoretical models and frameworks have been developed to conceptualize and integrate these cognitive processes into educational practices. These models emphasize different aspects of cognitive development, pedagogical strategies, and assessment methodologies, providing insights into how creativity and HOT can be effectively nurtured in learning environments. However, the literature does not always use these constructs consistently. Some studies treat creativity as a component of HOT, while others position HOT as a broader cognitive category that includes critical thinking, problem-solving, evaluation, and creative production. This conceptual variation is important for the present scientometric study because differences in terminology influence how keywords cluster, how research communities form, and how the intellectual structure of the field can be interpreted.

Recent STEM/STEAM-oriented studies further show that creativity, critical thinking, problem-solving, and collaboration are often discussed as part of 21st-century competency frameworks. These constructs are commonly linked to Bloom-like frameworks and are frequently operationalized through project-based learning, inquiry-based learning, concept mapping, digital learning modules, and STEAM-based tasks (Kurniawan et al., 2023; Pimdee, 2022; Yang et al., 2023; Zhu & Tahir, 2023). This reinforces the need to examine creativity and HOT as interconnected constructs rather than as isolated learning outcomes.

2.2 *Historical Context of Creativity and HOT Research*

Historically, creativity and HOT have been recognized as essential educational goals, with their conceptualization evolving through various theoretical perspectives. The foundation for HOT was laid by Bloom's Taxonomy of Educational Objectives, which categorized cognitive skills into lower-order thinking processes, such as recall and understanding, and higher-order thinking processes, such as analyzing, evaluating, and creating (Thornhill-Miller et al., 2023). This taxonomy underscored the importance of moving beyond rote memorization toward critical thinking, problem-solving, and knowledge creation in education. For this reason, Bloom's taxonomy remains a useful conceptual anchor for identifying why terms such as "analysis," "evaluation," "creation," "critical thinking," and "problem-solving" frequently appear in HOT-related research.

Although Bloom's taxonomy provides a useful structure, contemporary HOT research increasingly views analysis, evaluation, and creation as recursive rather than strictly linear processes. Learners may need to generate ideas, test them, revise them, evaluate evidence, and redesign solutions repeatedly when solving authentic STEM/science or higher education problems. This recursive view is important for connecting HOT with creativity because creative production often requires evaluative judgment, while critical evaluation often stimulates new creative possibilities.

In the mid-20th century, constructivist theories by Piaget and Vygotsky introduced a social and experiential dimension to learning, emphasizing active engagement and collaboration in developing cognitive skills (Markula & Aksela, 2022). These perspectives highlighted that social interaction and inquiry-driven learning are essential for fostering creativity and HOT. From a constructivist perspective, HOT develops when learners actively construct meaning, test ideas, negotiate understanding, and reflect on their learning process. From a socio-constructivist perspective, creativity and HOT also emerge through dialogue, collaboration, and participation in authentic learning communities.

With the rise of the knowledge economy and digital transformation, education systems worldwide have shifted their focus toward 21st-century skills, including creativity, critical thinking, collaboration, and communication (4Cs) (Thornhill-Miller et al., 2023). Organizations like the Partnership for 21st Century Skills have influenced curriculum design and instructional practices by encouraging the integration of creativity and HOT into

modern educational models. This shift expanded HOT research from a primarily cognitive concern into a curriculum, pedagogy, assessment, and policy concern. Consequently, contemporary studies increasingly examine how HOT is developed through interdisciplinary tasks, technology-mediated learning, and competency-based assessment.

The adoption of Project-Based Learning (PBL) as a teaching strategy has been a significant milestone. Hujjatusnaini et al. (2022) demonstrated that blended PBL significantly improves pre-service teachers' HOT skills, reinforcing real-world problem-solving and student-driven learning. Additionally, the integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) education has expanded interdisciplinary learning, allowing students to develop critical and creative thinking skills through hands-on experimentation (Bassachs et al., 2020). Together, PBL and STEAM illustrate how HOT research has moved from abstract cognitive taxonomies toward instructional models that require students to define problems, connect disciplines, design solutions, and justify decisions.

Bibliometric mappings of STEM/STEAM education and 21st-century skills show that publication activity has increased over time, with growing thematic emphasis on STEAM integration, creativity, critical thinking, problem-solving, computational thinking, and innovative capacity (Jantakoon et al., 2024; Kaymakci & Can, 2023; Y. Li & Talib, 2024; Prahani, Nisa, et al., 2023; Şeker, 2025; Tran et al., 2024). These findings suggest that creativity and HOT are not only classroom-level outcomes but also increasingly visible research themes within the broader development of STEM/science and higher education scholarship.

The COVID-19 pandemic further accelerated educational shifts, emphasizing technology adoption to support self-regulated learning and digital collaboration (Lee et al., 2024). The crisis highlighted the necessity of adaptability in teaching methodologies, reinforcing the role of online learning tools in fostering critical thinking and creativity. This context also explains why recent HOT research increasingly includes digital learning, blended learning, artificial intelligence, and interactive technologies as recurring themes. In bibliometric terms, these developments are expected to appear as emerging keyword clusters and as new connections between cognitive, pedagogical, and technological research areas.

The expansion of digital, blended, and AI-supported learning also strengthens the need for a scientometric perspective. As new tools and learning environments enter the field, bibliometric indicators can help identify whether these technologies remain peripheral topics or become central themes connected to creativity, HOT, critical thinking, teacher education, assessment, and STEM/STEAM pedagogy.

2.3 Traditional Theories and Pedagogical Approaches

Bloom's Taxonomy remains one of the most influential frameworks for understanding HOT. It categorizes cognitive learning objectives into six levels: remembering, understanding, applying, analyzing, evaluating, and creating (Thornhill-Miller et al., 2023). While this model provides a structured approach, its application can become limited when HOT is interpreted as a rigid hierarchy rather than as an interactive set of cognitive processes. For example, learners may need to analyze, evaluate, and create recursively when solving open-ended problems, rather than moving through these processes in a fixed sequence.

To address these limitations, Fikriyati et al. (2022) proposed the Critical Thinking Cycle (CTC) Model, which promotes iterative cycles of inquiry, reflection, and application to enhance critical thinking skills. Unlike Bloom's framework, which is often interpreted as a linear progression, the CTC model encourages students to engage in continuous questioning and self-evaluation, thereby strengthening metacognitive skills. The CTC model is relevant to creativity and HOT because it emphasizes reflection, evidence-based judgment, and the repeated refinement of ideas, all of which are central to creative problem-solving.

Historically, STEM education focused primarily on technical and analytical skills, often treating science, technology, engineering, and mathematics as isolated disciplines. However, Li et al. (2022) argue that traditional STEM models failed to adequately foster creativity and HOT because they prioritized procedural knowledge over problem-solving and interdisciplinary thinking. This limitation is important because HOT requires learners not only to master disciplinary knowledge but also to transfer, integrate, and evaluate that knowledge across contexts.

The STEAM education model, which incorporates the arts into STEM, emerged as a more holistic approach. Bassachs et al. (2020) highlight that STEAM-based experiential learning promotes creativity, critical reflection, and cross-disciplinary connections, aligning with the cognitive demands of the 21st century. In this sense, STEAM

functions as a pedagogical bridge between creativity and HOT: the arts support imagination and divergent thinking, while science and engineering tasks support analysis, evidence use, design reasoning, and evaluation.

Recent studies on STEM/STEAM learning also indicate that creativity and HOT can be strengthened when students engage in tasks that require analysis, synthesis, evaluation, design, and reflection. Mind maps, Ethno-STEM-PjBL, concept maps, digital modules, inquiry learning, and project-based formats have been used to scaffold creative reasoning, conceptual understanding, and HOT-related performance (Martawijaya et al., 2023; Pimdee, 2022; Yang et al., 2023; Zhu & Tahir, 2023). These approaches suggest that HOT-oriented pedagogy should combine disciplinary knowledge, authentic problems, collaborative inquiry, and explicit cognitive scaffolding.

Teacher competence is also central to the success of these approaches. Teachers and instructors need to design open-ended tasks, select appropriate technologies, guide inquiry, facilitate collaboration, support metacognitive reflection, and align learning activities with valid assessment. Studies on technology-enabled task design and teacher professional development emphasize that digital tools can support creativity and HOT only when educators understand how to integrate them with clear learning objectives and assessment criteria (Bataineh et al., 2025; Hébert & Jenson, 2021; Lee et al., 2024; Sasson et al., 2021).

2.4 Emerging Trends and New Approaches

Recent research underscores the role of PBL and inquiry-based learning in fostering creativity and HOT. Hujjatusnaini et al. (2022) demonstrate that blended PBL enhances HOT development by allowing students to engage in self-directed problem-solving and collaborative knowledge construction. These approaches are increasingly important because they align learning activities with authentic problems, encourage students to justify their decisions, and provide opportunities to produce original solutions.

Thinking-Based Instruction Theory (TBIT) has also gained attention as a curriculum framework that prioritizes active decision-making and complex problem-solving. Li et al. (2022) emphasize that TBIT encourages educators to design learning environments that challenge students to critically analyze and synthesize information, fostering deeper cognitive engagement. TBIT strengthens the conceptual basis of HOT research because it treats thinking not as a by-product of instruction but as the explicit object of curriculum design.

Technology has become a key enabler of creativity and HOT, particularly in remote and hybrid learning environments. ElSayary et al. (2022) found that interactive digital platforms improve STEAM competencies, reinforcing the importance of virtual collaboration and digital storytelling in promoting critical thinking skills. Technology-enhanced learning environments can support HOT when they provide interaction, feedback, visualization, collaboration, and opportunities for learners to construct and revise knowledge. However, technology should not be treated as inherently beneficial; its contribution depends on how it is integrated with sound pedagogy and assessment.

Recent technology-enhanced learning studies suggest that augmented reality, virtual laboratories, digital worksheets, and AI-enabled scaffolds can support HOT and motivation when they include explicit prompts, appropriate duration, structured guidance, and opportunities for self-regulated learning (Wang & Gao, 2025; T. Wu, Lee, et al., 2025; T. Wu, Sarwono, et al., 2025; Zhao et al., 2025). This indicates that technology functions best as a cognitive and pedagogical scaffold, not merely as a delivery medium.

AI-driven educational tools such as adaptive learning systems and digital mind maps have been shown to support self-regulated learning. Jia and Tu (2024); and Nunvarova et al. (2023) explore how artificial intelligence and digital storytelling enhance students' ability to synthesize information, evaluate diverse perspectives, and construct new knowledge. These studies suggest that emerging technologies are shifting HOT research toward personalized learning, multimodal representation, and data-informed feedback. At the same time, they also raise new questions about assessment validity, learner autonomy, digital equity, and the role of teachers in guiding higher-order cognitive development.

AI-supported learning is becoming particularly important in creativity and HOT research because it can provide guided prompts, adaptive feedback, peer-assessment support, and opportunities for metacognitive reflection. Recent studies and syntheses indicate that generative AI and AI-driven scaffolds may support problem-solving, critical thinking, creativity, self-regulated learning, and knowledge construction when they are aligned with student-centered pedagogy and explicit thinking objectives (Avello-Sáez & Estrada-Palavecino, 2023; Canal et al., 2024; Hwang & Wu, 2025; Zhan et al., 2025; Zhao et al., 2025). However, AI-supported learning also requires careful

governance, including AI literacy, academic integrity safeguards, ethical use, and attention to learner dependency and digital inequality.

Assessment has also emerged as a critical issue in creativity and HOT research. Rubric-based instruments, authentic and problem-based assessments, multi-representation items, two-tier instruments, and Rasch- or classical-test-theory-based validation approaches have been used to assess creativity, critical thinking, problem-solving, and HOT across several subjects (Ng et al., 2023; Sandoval, 2021; Shou et al., 2025; Siew & Basari, 2024). These approaches are important because HOT and creativity cannot be measured adequately through recall-based tests alone. They require assessments that capture reasoning processes, originality, usefulness, transfer, collaboration, and reflective judgment.

Sustainability education represents another emerging direction. It can operationalize systems thinking, ethical reasoning, and creative problem-solving through transdisciplinary pedagogy, project-based learning, living labs, biomimicry, design thinking, SDG-focused activities, and community-based projects (Amorim et al., 2025; Badarnah, 2025; Du & Xi, 2023; Henriksen et al., 2024; Lysak, 2024; Maker et al., 2023; Moreno-Pino et al., 2021). This direction is relevant to creativity and HOT because sustainability problems require learners to analyze interdependent systems, evaluate ethical trade-offs, collaborate with stakeholders, and design adaptive solutions for real-world challenges.

2.5 Conceptual Framework and Scientometric Lens

Based on the literature reviewed above, this study adopts a conceptual framework that connects four layers of creativity and HOT research. The first layer is the cognitive foundation, which includes creativity, critical thinking, analysis, evaluation, problem-solving, and creation. This layer is informed by Bloom's taxonomy and related models of higher-order cognition (Hujjatusnaini et al., 2022; Thornhill-Miller et al., 2023). The second layer is the learning foundation, which draws on constructivist and socio-constructivist perspectives that emphasize active learning, inquiry, reflection, and collaboration (Markula & Aksela, 2022). The third layer is the pedagogical foundation, which includes STEAM, PBL, inquiry-based learning, blended learning, and thinking-based instruction as instructional approaches that operationalize creativity and HOT in classroom practice (Bassachs et al., 2020; Hujjatusnaini et al., 2022; J. Li et al., 2022; Y. Li et al., 2021). The fourth layer is the technological and assessment foundation, which includes digital platforms, AI, digital storytelling, self-regulated learning, and emerging assessment challenges (ElSayary et al., 2022; Jia & Tu, 2024; Lee et al., 2024; Nunvarova et al., 2023). Within the scope of the present study, these four layers are interpreted in relation to STEM/science and higher education-related creativity and HOT research, because the dataset was constructed from Scopus-indexed publications in these areas.

The cognitive layer explains why creativity and HOT are treated as complementary constructs. Creativity supports idea generation, originality, and innovation, whereas HOT supports analysis, evaluation, synthesis, and reasoned decision-making. In STEM/science and higher education contexts, these capacities often appear together in tasks that require learners to investigate problems, interpret evidence, design solutions, and justify conclusions. The learning layer explains how these capacities develop through active construction of knowledge, dialogue, collaboration, inquiry, and reflection. The pedagogical layer explains how creativity and HOT are translated into instructional practice through STEAM, PBL, inquiry-based learning, blended learning, and thinking-based instruction. The technological and assessment layer explains how digital tools, AI-supported learning, self-regulated learning environments, and valid assessment models can support or constrain the development of creativity and HOT.

This conceptual framework informs the scientometric analysis in the present study. Publication trends are used to examine how scholarly attention to creativity and HOT has evolved over time. In this framework, publication trends are interpreted as indicators of the generative phase of the field because rising outputs may signal expanding conceptual space, growing methodological experimentation, and increasing attention to creativity, HOTS, STEAM integration, and problem-solving themes (Ariyani et al., 2022; Jantakoon et al., 2024). Citation analysis is used to identify influential studies, authors, and sources that have shaped the intellectual development of the field. Citation impact is therefore interpreted as a map of theoretical influence, because highly cited studies and co-citation patterns can indicate which frameworks, models, and empirical findings have become central to creativity and HOT research (Wasak, 2024; H. Wu et al., 2021).

Co-authorship analysis is used to examine how research communities and collaboration networks have formed around HOT-related themes. Co-authorship networks are interpreted as indicators of collaborative knowledge production because they show how researchers cluster by region, institution, discipline, or theme. These networks can reveal knowledge hubs, fragmented communities, and opportunities for stronger interdisciplinary and international collaboration in creativity and HOT research (Apiola et al., 2022; X. Chen et al., 2024; Jantakoon et al., 2024). Keyword co-occurrence analysis is used to identify how cognitive, pedagogical, technological, and assessment-related concepts cluster and interact within the literature. Keyword co-occurrence is interpreted as the semantic structure of the field because co-occurring terms such as creativity, critical thinking, problem-solving, HOTS, STEM, STEAM, digital learning, teacher education, assessment, and sustainability show how researchers connect concepts and define thematic priorities (Ariyani et al., 2022; H. Wu et al., 2021; Zhai & Razali, 2023).

In this way, the study does not treat scientometric indicators as purely descriptive outputs; rather, it interprets them as evidence of how creativity and HOT research has developed as a knowledge domain. The framework links each bibliometric indicator to a specific interpretive function: publication trends indicate growth and scholarly attention; citation patterns indicate intellectual influence; co-authorship networks indicate collaboration structures; and keyword co-occurrence indicates thematic organization. This connection strengthens the analytical role of the conceptual framework and clarifies how the bibliometric results are interpreted in later sections.

This framework also addresses the conceptual complexity of the field. Because creativity and HOT are studied across multiple educational contexts, theoretical traditions, and methodological approaches, a scientometric lens can clarify how fragmented or integrated the field is. It can also reveal whether emerging themes such as STEAM, AI-supported learning, sustainability, teacher education, and assessment are central or peripheral in the broader research landscape. At the same time, the framework requires cautious interpretation. Bibliometric patterns are shaped by database coverage, search-string design, language restrictions, indexing practices, and methodological thresholds. Therefore, the findings should be understood as a structured map of the analyzed Scopus-indexed STEM/science and higher education-related dataset, not as an exhaustive representation of all creativity and HOT research across every discipline and educational level (X. Chen et al., 2024; Sallam et al., 2024; Shomoossi et al., 2023).

3. Method

3.1 Study Design and Overview

This study employs a bibliometric analysis to examine research trends, influential contributions, and thematic structures in creativity and higher-order thinking (HOT) research from 2014 to 2024. Because the search strategy was limited to STEM/science education and higher education-related terms, the study maps creativity and HOT research within the analyzed Scopus-indexed STEM/science and higher education-related dataset, rather than all creativity and HOT research across every educational discipline and level. Unlike systematic literature reviews, which involve selecting and analyzing specific papers based on predefined inclusion criteria, bibliometric analysis provides a quantitative approach to mapping the research landscape by analyzing publication trends, citation networks, co-authorship collaborations, and keyword distributions (Appiah et al., 2022). In this study, bibliometric analysis was used not to evaluate the effectiveness of specific pedagogical interventions, but to map how creativity and HOT have developed as an intellectual and research domain within the defined dataset. This approach allows for a structured overview of the evolution of HOT research, identifying key contributors, geographical patterns, and emerging themes in the field.

Bibliometric analysis has been widely recognized as a robust method for identifying influential research trends across various disciplines (Aria & Cuccurullo, 2017). Recent bibliometric studies commonly combine performance indicators, such as publication counts, citations, and author productivity, with science-mapping techniques, such as co-authorship, co-citation, bibliographic coupling, and keyword co-occurrence, to reveal intellectual structures and collaboration patterns (Gozali et al., 2023; Nwankwo et al., 2024; Rabbani et al., 2024; Silva et al., 2022; Tomaszewski, 2023). By utilizing VOSviewer and Biblioshiny, this study visualizes the intellectual structure and knowledge clusters within HOT research. The analysis focuses on three primary dimensions: publication trends and citation impact, author and institutional collaborations, and thematic keyword co-occurrence networks. These dimensions were selected because they correspond to the study's research questions: publication and citation indicators reveal the growth and influence of the field, collaboration indicators reveal the structure of scholarly communities, and

keyword indicators reveal the conceptual and pedagogical themes that organize creativity and HOT research. These insights contribute to a better understanding of the development of HOT research, the distribution of scholarly efforts, and future research directions within STEM/science and higher education-related scholarship.

3.2 Data Collection and Bibliographic Source Selection

The dataset for this bibliometric analysis was retrieved from Scopus, a leading academic database that provides comprehensive indexing of peer-reviewed journal articles, conference proceedings, and book chapters. Scopus was selected due to its robust citation tracking capabilities, structured metadata, and interdisciplinary coverage, making it suitable for bibliometric research (Derviş, 2020). Scopus was also selected because it provides standardized bibliographic metadata, including titles, abstracts, keywords, author affiliations, citation counts, source titles, and country information, which are required for co-authorship, citation, and keyword co-occurrence analyses. The use of a single database also helped maintain metadata consistency across the dataset, although it may exclude relevant studies indexed only in Web of Science, ERIC, Google Scholar, or regional databases. The search query was designed to capture literature explicitly focused on creativity and HOT within STEM/science education and higher education-related contexts. The Boolean operators AND and OR were applied to ensure comprehensive coverage while refining the results to exclude irrelevant records.

The search was conducted in Scopus on January 20, 2025, to ensure transparency and reproducibility. The final search query was executed within the title, abstract, and keywords fields to retrieve studies that explicitly addressed creativity and HOT in education. The search strategy combined four conceptual blocks: creativity-related terms, HOT-related terms, education-domain terms, and pedagogical or assessment-related terms. Because the query included “Science education research” OR “STEM education” and “Higher Education,” the dataset should be interpreted as STEM/science and higher education-oriented. The keywords used in the data search are presented in Table 1.

Table 1. Search Criteria and Keywords Used for Data Retrieval

Criteria	Details
Database	Scopus
Search Fields	Title, Abstract, Keywords
Boolean String Used	(("creativity" OR "creative thinking") AND ("higher-order thinking" OR "critical thinking" OR "complex problem solving") AND (("Science education research" OR "STEM education")) AND ("teaching methods" OR "learning strategies" OR "instructional approaches" OR "curriculum development" OR "educational assessment")) AND (("Higher Education"))
Time Range	2014–2024
Document Type	Journal articles, conference papers, book chapters
Language	English

Following the execution of the search query, 2,703 documents were retrieved. To enhance dataset reliability, a screening process was conducted, removing duplicate records, non-relevant papers, and studies lacking complete metadata, such as missing abstracts or author affiliations. After refinement, the final dataset comprised 799 publications, which served as the foundation for bibliometric analysis.

To improve transparency, the screening process was reported using a PRISMA-style flow structure, as recommended in bibliometric and review-based studies that require explicit documentation of search, screening, eligibility, and inclusion stages (Castillo-Quñones et al., 2023; Gozali et al., 2023). Table 2 summarizes the reduction of records from the initial retrieval to the final dataset. The exact number of exclusions at each stage should be inserted from the authors’ screening log to ensure full reproducibility.

The screening process followed four stages. First, records outside the 2014–2024 publication period and records not written in English were excluded. Second, duplicate records and records with incomplete bibliographic metadata were removed. Third, titles, abstracts, and keywords were reviewed to exclude documents that used terms such as “creativity” or “critical thinking” outside educational or learning-related contexts. Fourth, only journal articles, conference papers, and book chapters that explicitly addressed creativity, creative thinking, HOT, critical

thinking, complex problem solving, teaching, learning, curriculum, or assessment in STEM/science and higher education-related contexts were retained. This procedure reduced the dataset from 2,703 initial records to 799 eligible publications.

Table 2. Screening Process for Dataset Refinement

Screening Stage	Records Removed	Records Remaining	Reason for Exclusion or Retention
Initial Scopus retrieval	–	2,703	Records retrieved using the Boolean search string
Time range, language, and document-type filtering	1,122	1,581	Records outside 2014–2024, non-English documents, or document types outside journal articles, conference papers, and book chapters
Duplicate removal	34	1,547	Duplicate bibliographic records identified through repeated DOI, title, author, or source information
Metadata completeness screening	153	1,394	Records with missing abstracts, keywords, author affiliations, or other metadata required for bibliometric and scientometric analysis
Title, abstract, and keyword relevance screening	595	799	Records not directly related to creativity, higher-order thinking, critical thinking, complex problem solving, teaching, learning, curriculum, or assessment in STEM/science and higher education-related contexts
Final dataset	–	799	Eligible records included in the bibliometric analysis

The inclusion criteria were: (1) Scopus-indexed publications published between 2014 and 2024; (2) documents written in English; (3) journal articles, conference papers, or book chapters; (4) studies addressing creativity, creative thinking, HOT, critical thinking, or complex problem solving in educational contexts; (5) studies connected to STEM/science education and higher education-related contexts based on the search strategy; and (6) records with complete bibliographic metadata required for analysis. The exclusion criteria were: (1) documents outside the selected time range; (2) non-English publications; (3) publications with incomplete metadata; (4) duplicate records; (5) records outside the STEM/science and higher education-related scope of the search strategy; and (6) studies whose use of creativity or HOT-related terms was not connected to education, teaching, learning, curriculum, or assessment.

3.3 Bibliometric Indicators and Data Processing

Several key bibliometric indicators were examined to assess the structure and impact of HOT research within the analyzed dataset. These indicators included publication trends, citation impact, authorship and institutional productivity, collaboration patterns, and keyword co-occurrence networks. Analyzing these indicators provided insights into the most active contributors, evolving research themes, and the global distribution of HOT research efforts in Scopus-indexed STEM/science and higher education-related publications.

The dataset was exported from Scopus in CSV format and processed using bibliometric tools. Before analysis, the dataset was checked for duplicate entries, missing metadata, and inconsistent terminology. Author keywords and index keywords were reviewed to reduce variation in equivalent terms, such as singular and plural forms, spelling variants, and closely related keyword expressions. A keyword harmonization process was conducted to improve semantic consistency. For example, closely related variants were reviewed to reduce fragmentation across equivalent terms where appropriate. However, original author keywords were retained when they represented conceptually distinct constructs. Author names, institutional affiliations, and country names were also checked to minimize inconsistencies that could affect collaboration and productivity indicators. Such data-cleaning procedures are important in bibliometric research because inconsistent metadata, unmerged keywords, and author-name variation can distort co-authorship and co-occurrence networks (Kaur & Saini, 2024; Roveri et al., 2025; Tomaszewski, 2023). Biblioshiny, an R-based bibliometric analysis software, was used to generate descriptive statistics, trend analysis, and geographic visualization. It enabled the identification of publication trends, leading research institutions, and country-wise research contributions. VOSviewer was employed for network analysis,

facilitating the visualization of co-authorship networks, citation relationships, and keyword co-occurrence maps (Van Eck & Waltman, 2010).

Table 3. Key Bibliometric Indicators Used in This Study

Indicator	Description	Tool Used
Publication Trends	Number of papers published annually	Biblioshiny
Citation Analysis	Most cited authors, papers, and journals	Biblioshiny
Authorship Analysis	Most prolific authors, h-index scores	Biblioshiny
Geographical Analysis	Country-wise research contributions	Biblioshiny
Co-Authorship Networks	Research collaboration between authors and institutions	VOSviewer
Keyword Co-Occurrence	Thematic clustering of research topics	VOSviewer

The indicators in **Table 3** were interpreted in relation to the study's conceptual framework. Publication trends were used to examine the growth of creativity and HOT research. Citation indicators were used to identify influential knowledge sources. Authorship and geographical indicators were used to assess the distribution of scholarly production. Co-authorship networks were used to examine collaboration structures, while keyword co-occurrence was used to identify cognitive, pedagogical, technological, and assessment-related themes within the field. This combination of performance indicators and science-mapping techniques follows common bibliometric practice because it allows researchers to examine both the productivity and the intellectual organization of a research domain (Anthony & Sharma, 2025; Gozali et al., 2023; Nwankwo et al., 2024; Silva et al., 2022).

3.4 Data Analysis and Visualization Techniques

The analysis of publication trends focused on the annual growth of research output, offering insights into how HOT research has evolved over the past decade. The number of publications per year was examined to identify periods of significant expansion or stagnation. This data was visualized using line graphs and bar charts to illustrate the trajectory of research activity over time. The analysis also explored potential factors influencing fluctuations in research output, such as changes in educational policies, technological advancements, and global initiatives emphasizing critical thinking and problem-solving skills. Because bibliometric data cannot establish causal relationships, these factors were interpreted as possible contextual explanations rather than direct causes of publication growth.

The geographical distribution of HOT research was analyzed to identify leading countries and research institutions. The institutional affiliations of corresponding authors were mapped using Biblioshiny's geographic visualization tools. This analysis provided insights into which regions are leading HOT research and where future collaborations may be beneficial. In this study, the term "leading" refers only to publication output within the analyzed Scopus-indexed dataset. The visualization of country-wise contributions revealed patterns in global research engagement, highlighting regions that have shown substantial growth in HOT research publications. In this study, geographical contribution refers to publication output within the analyzed Scopus dataset. It should not be interpreted as a complete measure of national research leadership because citation impact, funding structures, policy contexts, institutional capacity, and international collaboration quality were not fully captured by publication count alone.

Citation analysis was conducted to determine the most influential research contributions. This included examining the total number of citations per publication, the average citations per document, and the most highly cited papers. Author impact was assessed using bibliometric indicators such as the h-index and g-index, which measure both productivity and citation impact. The study also identified the most frequently cited journals publishing HOT-related research, offering insights into the academic venues that have shaped discourse in the field. Citation indicators were interpreted cautiously because citation counts can be influenced by publication age, journal visibility, database coverage, disciplinary citation practices, and self-citation patterns.

Thematic analysis of research trends was conducted using keyword co-occurrence mapping. Keywords extracted from the dataset were processed using VOSviewer to generate network visualizations, showing relationships between frequently occurring terms. The clustering of keywords revealed core research themes, emerging trends, and interdisciplinary connections within HOT research. Keyword co-occurrence analysis was used

to identify how concepts such as critical thinking, creativity, STEM/STEAM, project-based learning, digital learning, sustainability, teacher education, and assessment are connected in the literature. The resulting clusters were interpreted as thematic structures that reflect research priorities rather than as direct evidence of pedagogical effectiveness. Co-word and keyword co-occurrence analyses are commonly used in science mapping because they reveal the semantic organization of a field and help identify dominant, emerging, and peripheral themes (Gozali et al., 2023; Silva et al., 2022; Tomaszewski, 2023).

For network visualization in VOSviewer, the study used full counting, association strength, and minimum occurrence thresholds appropriate to each analysis. For keyword co-occurrence, keywords appearing at least 5 times were included. For co-authorship analysis, authors with at least 2 documents were included. These parameters enable replication and clarify how nodes and links were generated. In the VOSviewer maps, node size represents the frequency or weight of an item, link thickness represents the strength of the relationship between items, proximity indicates the relatedness of items in the network, and color represents cluster membership generated by the software's clustering algorithm.

3.5 Tools and Software Used

This study employed two primary tools for bibliometric analysis. VOSviewer was used for network visualization, allowing for the construction of keyword co-occurrence maps, author collaboration networks, and citation linkages. Its clustering algorithms facilitated the identification of thematic structures within HOT research. Biblioshiny, an R-based tool, was used for descriptive bibliometric statistics, including publication trends, geographical distribution, and journal impact analysis. These tools provided a structured framework for assessing the evolution and intellectual organization of HOT research.

The use of VOSviewer and Biblioshiny was justified by their complementary functions. Biblioshiny is suitable for descriptive bibliometric analysis because it supports data import, annual scientific production, source analysis, author productivity, citation analysis, and country-level productivity within an integrated R-based environment (Aria & Cuccurullo, 2017). VOSviewer is suitable for science mapping because it produces interpretable visualizations of bibliometric networks and allows users to examine node size, link strength, proximity, and clustering patterns in co-authorship, citation, and keyword networks (Van Eck & Waltman, 2010). The combined use of Biblioshiny and VOSviewer is consistent with recent bibliometric studies that use R-based tools for performance analysis and VOSviewer for visualizing science-mapping networks (Gozali et al., 2023; Rabbani et al., 2024; Silva et al., 2022; Tomaszewski, 2023).

Using both tools strengthened the analysis by combining descriptive indicators with network-based visualization. Biblioshiny provided quantitative summaries of research output and influence, while VOSviewer supported interpretation of intellectual structure, collaboration patterns, and thematic relationships. However, both tools also have limitations. Their outputs depend on the quality and completeness of Scopus metadata, the selected search string, threshold settings, and the consistency of author names and keywords. Therefore, the results should be interpreted as a structured representation of the analyzed dataset rather than as a complete picture of all creativity and HOT research.

To strengthen reproducibility, the study reports the database, search date, search fields, Boolean string, time range, document types, language filter, screening criteria, data-cleaning procedures, software tools, and VOSviewer thresholds. These reporting elements are important because bibliometric maps can vary depending on database coverage, export date, search-string design, thesaurus decisions, and network parameters (Castillo-Quñones et al., 2023; Kaur & Saini, 2024; Nwankwo et al., 2024).

3.6 Ethical Considerations and Limitations

This study adhered to ethical guidelines by ensuring that all data were sourced from publicly available academic databases. No human subjects, private data, or confidential information were involved. One limitation of this study is the reliance on Scopus-indexed publications, which may exclude relevant studies from Web of Science and Google Scholar. Additionally, restricting the search to English-language publications may have led to the omission of significant research contributions from non-English-speaking regions, limiting the global representativeness of the findings.

Several methodological limitations should also be acknowledged. First, the search string focused on creativity, HOT-related terms, science or STEM education, pedagogical approaches, assessment, and higher education. This focus strengthened the relevance of the dataset but may have excluded studies on creativity and HOT in non-STEM fields, informal learning contexts, or educational levels outside higher education. Second, bibliometric indicators measure publication patterns, citation relationships, and keyword structures, but they do not directly measure instructional quality, learning effectiveness, or classroom impact. Third, citation-based indicators may favor older publications because they have had more time to accumulate citations. Fourth, keyword co-occurrence patterns are influenced by authors' keyword choices and database indexing practices. Fifth, the use of a single database may introduce coverage bias because Scopus does not index all journals, conference proceedings, books, or regional publications relevant to creativity and HOT. Sixth, threshold settings in VOSviewer may affect which authors, keywords, and links appear in the final visualizations.

Despite these limitations, the use of transparent search criteria, explicit inclusion and exclusion procedures, data cleaning, and complementary bibliometric tools strengthens the reliability of the analysis. The findings should therefore be read as an evidence-based map of Scopus-indexed creativity and HOT research within STEM/science and higher education-related contexts from 2014 to 2024, rather than as an exhaustive representation of all scholarship on creativity and higher-order thinking. Future bibliometric studies could compare Scopus-based findings with Web of Science, ERIC, Google Scholar, and regional databases; expand the search strategy to non-STEM fields and other educational levels; and triangulate bibliometric findings with policy analysis, curriculum documents, funding data, and qualitative interviews with education researchers.

4. Results and Analysis

4.1 Publication Trends (2014–2024)

Figure 1 presents publication trends in creativity and higher-order thinking (HOT) research from 2014 to 2024 within the analyzed Scopus-indexed STEM/science and higher education-related dataset. **Figure 1** shows a clear increase in annual research output over the study period, with particularly rapid growth after 2020. This pattern indicates that creativity and HOT have become increasingly visible as research topics in STEM/science and higher education-related literature, especially in relation to 21st-century skills, technology-enhanced learning, interdisciplinary pedagogy, and competency-based curriculum development. This trend is consistent with recent bibliometric studies showing increased publication activity in STEM/STEAM education and related competencies, with growing attention to creativity, critical thinking, problem-solving, computational thinking, and other 21st-century skills (Jantakoon et al., 2024; Kaymakci & Can, 2023; Y. Li & Talib, 2024; Prahani, Nisa, et al., 2023; Şeker, 2025; Tran et al., 2024).

During the initial years, from 2014 to 2016, publication output was low. The dataset included 5 publications in 2014, 3 in 2015, and 5 in 2016. This limited output suggests that creativity and HOT, when combined with the specific search criteria used in this study, had not yet appeared as a consolidated research domain within Scopus-indexed STEM/science and higher education-related literature. Rather than indicating the absence of interest in HOT, the low number may reflect the narrower terminology used in early studies or the fragmented use of related concepts such as critical thinking, problem-solving, creative thinking, computational thinking, and cognitive skills. It may also reflect differences in database coverage, search terminology, and the fact that earlier studies may have discussed HOT-related competencies without explicitly combining creativity, HOT, STEM/science education, and higher education in titles, abstracts, or keywords.

From 2017 to 2020, research output showed moderate growth. Publications increased to 21 in 2017, followed by 18 in 2018 and 22 in 2019. In 2020, the number of publications rose to 47, more than double the previous year. This increase may be associated with growing scholarly attention to active learning, digital pedagogy, STEM/STEAM education, and the need to develop learners' critical and creative capacities. Similar bibliometric mappings of STEAM, STEM teacher professional development, and 21st-century skills have reported rising interest in interdisciplinary learning, creativity, critical thinking, and problem-solving during this period (Ahmed et al., 2023; Dúo-Terrón, 2023; Prahani, Nisa, et al., 2023; Wasak, 2024). However, because bibliometric data show publication patterns rather than causal relationships, this interpretation should be understood as a contextual explanation rather than direct evidence of causation.

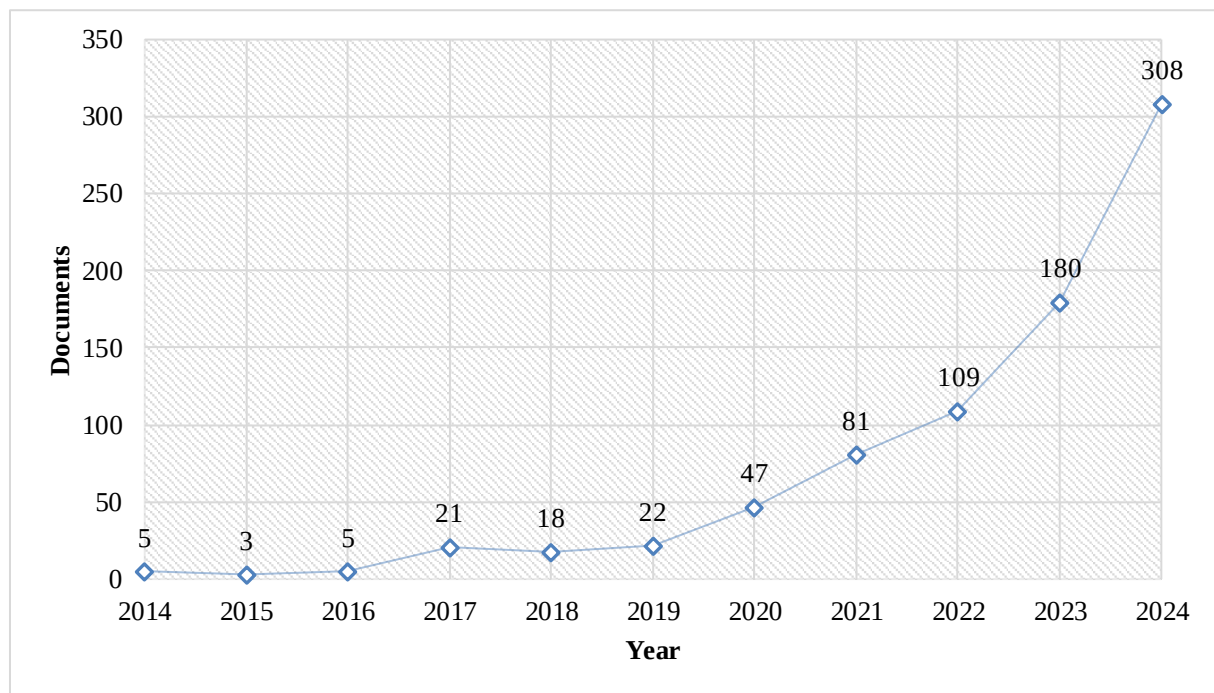


Figure 1. Publication trends in the analyzed Scopus-indexed STEM/science and higher education-related dataset, 2014–2024.

The period from 2021 to 2024 marks the strongest growth phase. Publication output reached 81 documents in 2021 and 109 documents in 2022. By 2023, the number had increased to 180, and in 2024 it reached 308 publications. The steep increase from 2021 onward suggests that creativity and HOT research within the analyzed dataset has moved from a relatively specialized area into a more visible and interdisciplinary research domain. This growth is consistent with broader educational shifts toward digital transformation, post-pandemic learning recovery, artificial intelligence in education, student-centered learning, and the integration of critical and creative thinking into curriculum and assessment. It also aligns with recent STEM/STEAM literature showing that creativity, critical thinking, and problem-solving are increasingly treated as core HOT-related competencies and are often developed through project-based learning, inquiry learning, digital modules, virtual laboratories, augmented reality, and AI-supported scaffolding (Pimdee, 2022; Wang & Gao, 2025; Yang et al., 2023; Zhao et al., 2025; Zhu & Tahir, 2023).

The trend shown in **Figure 1** is important because it provides the temporal foundation for the rest of the analysis. A growing publication base creates the conditions for more visible author communities, more specialized journals, and more complex keyword networks. Therefore, the subsequent analyses of geographic distribution, influential authors, collaboration networks, and keyword co-occurrence should be interpreted against this rapid expansion of the field. At the same time, the trend should not be generalized to all creativity and HOT research across every educational level or discipline. Because the dataset was constructed using STEM/science and higher education-related search terms, the results represent the growth of this specific Scopus-indexed research segment. Studies in early childhood education, K–12 education, gifted education, vocational education, informal learning, humanities, arts, and social sciences may follow different publication trajectories and should be examined in future comparative bibliometric research.

4.2 Geographic Distribution of Research

Figure 2 presents the geographical distribution of publications on creativity and HOT research in the analyzed Scopus dataset. Because the search strategy was limited to STEM/science education and higher education-related terms, the geographic distribution should be interpreted as country-level publication output within this specific dataset, not as a global ranking of all creativity and HOT research. Indonesia recorded the highest number of documents, with 163 publications, followed by the United States with 116 documents, China with 94 documents, Malaysia with 64 documents, and Taiwan with 51 documents. These findings show that publication output in creativity and HOT research within the analyzed STEM/science and higher education-related dataset is not

concentrated only in traditionally dominant Western research systems. Instead, the dataset indicates a strong contribution from Asian countries, particularly Indonesia and Malaysia.

Indonesia's leading position should be interpreted carefully. The result indicates that Indonesia produced the highest number of publications within the specific Scopus-indexed dataset and search criteria used in this study. It should not be equated automatically with overall global leadership in research quality or impact because publication volume does not fully capture citation influence, international collaboration, journal quality, funding structures, or policy implementation. In bibliometric interpretation, publication productivity measures output volume, whereas research leadership and intellectual influence require additional indicators such as total citations, h-index, g-index, highly cited publications, collaboration networks, journal influence, and thematic contribution (Adams & Moosa, 2024; Karaköse et al., 2024; Mukhtar & Razak, 2024). Nevertheless, Indonesia's position suggests that creativity and HOT have become highly visible topics in its educational research output within the scope of this search strategy.

The United States ranked second with 116 documents. This finding indicates that the United States remains an important contributor to the field, although its publication volume in this dataset is lower than Indonesia's. One possible explanation is that U.S.-based research on related constructs may be distributed across broader terms such as critical thinking, problem-solving, inquiry learning, STEM learning, learning sciences, or cognitive skills, and therefore may not always appear under the specific search combination used in this study. This reinforces the importance of interpreting national output in relation to search-string design and database coverage, because different terminologies can affect whether publications are captured in bibliometric datasets.

China ranked third with 94 documents, reflecting its substantial contribution to creativity and HOT research in the analyzed dataset. China's position may reflect increasing attention to innovation-oriented education, digital learning, STEM education, and the development of higher-order cognitive skills. However, as with other countries, publication output alone cannot explain the policy, institutional, or funding factors behind this pattern. Further country-specific analysis would be required to examine these factors in greater depth. Bibliometric indicators are useful for identifying visible publication patterns, but they do not directly measure national education quality, classroom effectiveness, or the success of policy implementation (Rosário & Raimundo, 2024; Yıldız et al., 2024).

Malaysia ranked fourth with 64 documents. Together with Indonesia, Malaysia's contribution highlights the growing presence of Southeast Asia in HOT-related education research. This regional pattern is noteworthy because it suggests that creativity, critical thinking, and higher-order cognitive skills are increasingly treated as priorities in educational research agendas in this region. Previous Southeast Asia-focused studies have also reported the visibility of Indonesia and Malaysia in STEM education, TVET, e-learning, and STEM-adjacent research, suggesting that national policy emphasis, institutional research capacity, and regional collaboration may contribute to publication output (Fam et al., 2024; Lin et al., 2025; Norliza et al., 2024; Obnial et al., 2024; Thi et al., 2024). However, the present bibliometric analysis can only identify the publication pattern; it cannot determine the extent to which national policies or classroom practices directly caused this output.

Other contributors included Turkey with 39 documents, India with 32 documents, Spain and the United Kingdom with 31 documents each, and Australia with 27 documents. The presence of these countries indicates that creativity and HOT research has a broad international base, but the distribution is uneven. This unevenness may reflect differences in research priorities, database coverage, publication language, academic incentives, or the terminology used to describe HOT-related constructs. It may also reflect differences in how national research systems encourage Scopus-indexed publication, international collaboration, and STEM/STEAM-oriented educational research.

Countries such as Finland, Israel, Kazakhstan, and Lithuania contributed between 10 and 12 documents each. These lower publication counts should not be interpreted as weak educational practice or limited innovation. Some countries may have strong classroom or policy practices but publish fewer Scopus-indexed studies using the specific terms included in this search. Therefore, the geographic results should be read as a map of indexed publication output rather than a direct ranking of educational quality or national innovation capacity. This distinction is important because educational quality is better inferred through multiple forms of evidence, including learning outcomes, curriculum implementation, assessment practices, teacher capacity, policy documents, and qualitative or classroom-level studies, not publication counts alone.

Overall, **Figure 2** suggests a shift in the geographical distribution of publication output, with Southeast Asia playing a highly visible role in the analyzed dataset. This finding is important because it invites further research into

how regional policy priorities, teacher education reforms, curriculum standards, publication incentives, and international collaborations may shape HOT research. It also suggests the need to distinguish between publication productivity and research impact in future bibliometric studies. Explaining this regional pattern requires policy-level and institutional evidence beyond the scope of the present bibliometric analysis. Future studies should combine bibliometric data with national curriculum documents, publication policy analysis, research funding data, citation impact indicators, collaboration-quality measures, and interviews with education researchers to clarify why Indonesia, Malaysia, and other Southeast Asian countries appear prominently in this research segment.

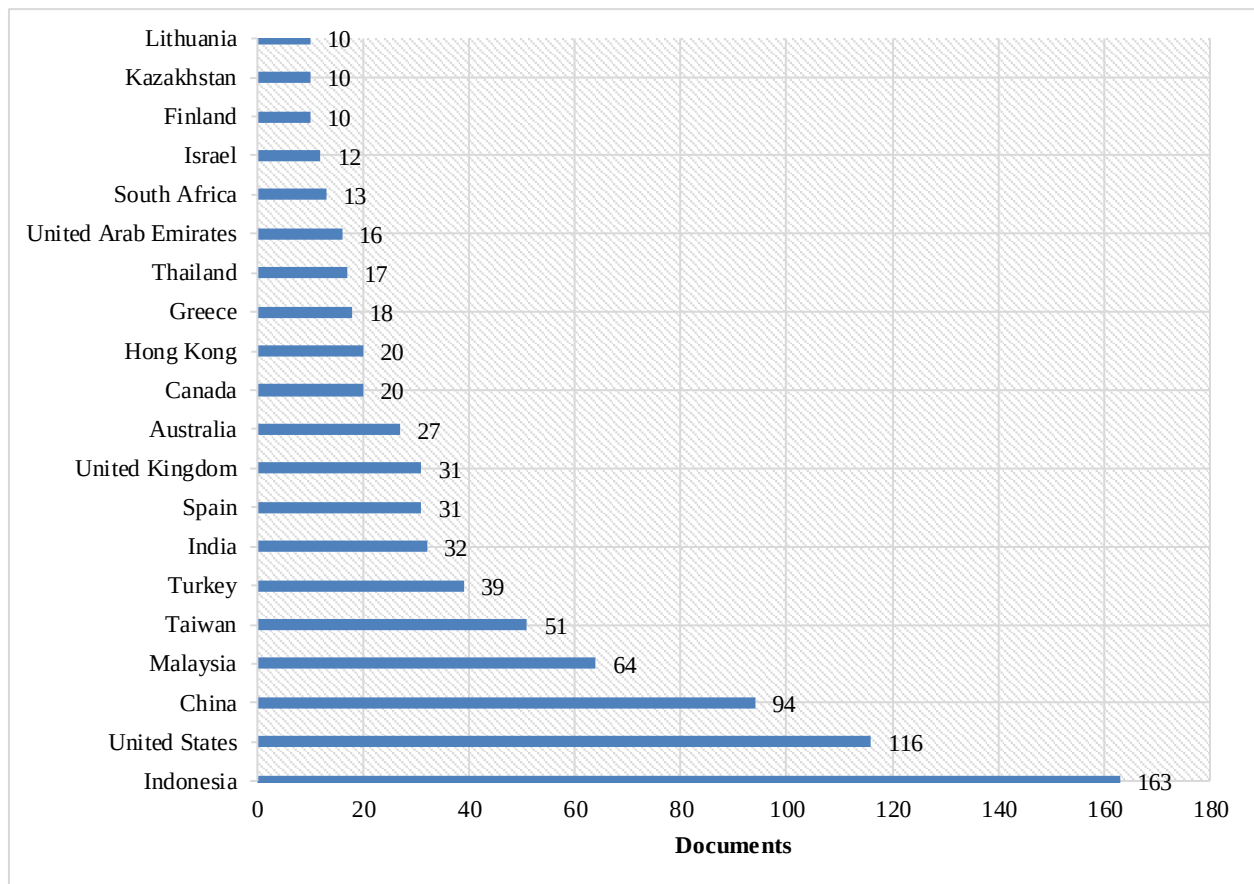


Figure 2. Country-level publication output in the analyzed Scopus-indexed STEM/science and higher education-related dataset.

4.3 The Most Productive and Influential Authors in Creativity and HOT Research

Table 4 presents the top 10 authors contributing to creativity and HOT research, based on h-index, g-index, m-index, total citations, and number of documents in the analyzed dataset. **Table 4** is interpreted within the Scopus-indexed STEM/science and higher education-related dataset used in this study. These indicators provide complementary information: document count reflects productivity, citation count reflects scholarly uptake, and index-based indicators combine productivity and citation influence. Therefore, author influence should be interpreted through multiple indicators rather than through publication count alone.

As shown in **Table 4**, Hwang G-J emerges as a leading figure, with an h-index of 6, a g-index of 9, an m-index of 1, 218 total citations, and 9 documents. This combination of productivity and citation impact indicates that Hwang G-J has contributed consistently to the field and that these contributions have been widely cited within the dataset. The strong citation profile may also reflect the author's engagement with technology-enhanced learning, digital pedagogy, and higher-order cognitive development, themes that are central to recent HOT research.

Other prominent contributors, such as Li Y and Zhan Z, also show notable h-index values of 4. Li Y contributed 6 documents and received 72 citations, while Zhan Z contributed 4 documents and received 34 citations. These profiles suggest focused and visible contributions rather than broad publication volume alone. The presence of

authors with fewer documents but meaningful citation indicators shows that influence in HOT research can emerge from concentrated contributions to specific themes, methods, or learning contexts.

Chang S-C is also notable because the author recorded 81 citations from only 3 documents. This indicates a high citation return relative to publication volume, suggesting that a small number of studies can have substantial influence when they address topics of strong relevance to the field. In contrast, authors such as Hu X and Saputro S show moderate productivity with lower citation counts, which may reflect newer contributions, more localized research topics, or shorter citation windows.

Table 4. Top 10 Most Productive and Influential Authors

Author	h_index	g_index	m_index	Citation	Document
Hwang G-J	6	9	1	218	9
Li Y	4	6	0.8	72	6
Zhan Z	4	4	1	34	4
Chang S-C	3	3	0.6	81	3
Hu X	3	3	0.429	14	4
Huang Y-M	3	4	0.5	49	4
Jatmiko B	3	5	0.6	49	5
Prahani BK	3	5	0.6	49	5
Saputro S	3	4	0.5	28	4
Shadiev R	3	3	0.6	43	3

Emerging figures such as Jatmiko B, Prahani BK, and Saputro S demonstrate the contribution of regionally grounded research to the global discussion on creativity and HOT. Their presence among the top contributors is consistent with the geographic pattern shown in **Figure 2**, where Southeast Asian countries, especially Indonesia, are strongly represented. This connection between author productivity and country-level output suggests that regional research communities may be playing an important role in expanding the field. However, regional visibility should still be interpreted cautiously because publication productivity does not automatically indicate broader intellectual leadership, citation influence, international collaboration quality, or educational impact (Adams & Moosa, 2024; Karaköse et al., 2024; Mukhtar & Razak, 2024).

Table 4 also highlights the need to interpret author influence cautiously. Bibliometric indicators are affected by publication age, co-authorship practices, journal visibility, research topic, and database coverage. Therefore, the table should be read as an indication of influence within the analyzed Scopus dataset, not as a definitive ranking of all scholars working on creativity and HOT. Even so, the results help identify key authors and research communities that shape the current intellectual structure of the field. This interpretation follows bibliometric practice in which productivity indicators are triangulated with citation-based and collaboration-based indicators to obtain a more balanced view of scholarly influence.

4.4 The Most Impactful Papers in Creativity and HOT Research

The analysis of the top 10 most impactful papers reveals key studies that have shaped the trajectory of creativity and HOT research. In this study, “impactful” refers to citation performance within the analyzed Scopus dataset. Therefore, citation counts are interpreted as indicators of scholarly visibility and uptake, not as direct measures of methodological quality or classroom effectiveness. To improve readability, the most cited papers are summarized in **Table 5**, while their conceptual and methodological contributions are synthesized narratively.

At the forefront, Kalogiannakis et al. (2021), with 315 citations, has become a foundational work in gamification for science education. This systematic literature review synthesizes trends, challenges, and opportunities, offering a comprehensive roadmap for future research. The paper’s influence lies in its capacity to bridge theoretical potential with practical applications, making it a touchstone for researchers and educators aiming to enhance student engagement and critical thinking through game-based learning.

Chen et al. (2018) further broadens the field with a meta-analysis of computer-supported collaborative learning (CSCL). With 296 citations, this study confirms the positive effects of collaboration and technology on knowledge acquisition, social interaction, and group performance. The paper’s focus on practical tools and strategies

underscores its utility for educators, making it a critical reference for integrating collaborative learning into diverse educational contexts. Together, these two highly cited works indicate that influential HOT research is strongly connected to technology-supported active learning, where learners are expected to interact, collaborate, solve problems, and construct knowledge rather than passively receive information.

Table 5. Top 10 Most Cited Papers in the Analyzed Dataset

Author(s) (Year)	Main Focus	Methodology	Citation
Kalogiannakis et al. (2021)	Gamification in science education	Systematic literature review	315
Chen et al. (2018)	Computer-supported collaborative learning	Meta-analysis	296
Strelan et al. (2020)	Flipped classroom	Meta-analysis	281
Fidan & Tuncel (2019)	Augmented reality in problem-based physics learning	Quasi-experimental study	275
National Academy of Sciences (2018)	Learning processes and learning environments	Comprehensive review/report	237
Thornhill-Miller et al. (2023)	4Cs: creativity, critical thinking, collaboration, communication	Assessment and certification framework	125
Psycharis & Kallia (2017)	Programming, reasoning, and problem solving	Quasi-experimental study	113
Quigley et al. (2017)	STEAM teaching practices	Conceptual model	108
Cruz et al. (2020)	Competency assessment in engineering education	Systematic review	99
Hodson (2014)	Nature of Science and science curriculum	Historical and critical review	99

The flipped classroom model has also been a significant area of exploration, as reflected in Strelan et al. (2020), which has garnered 281 citations. This meta-analysis demonstrates the effectiveness of flipped classrooms in improving student performance across disciplines and education levels. Its findings highlight the importance of active learning and problem-solving opportunities, providing actionable insights for educators seeking to leverage this innovative approach. The prominence of this paper suggests that HOT research is closely linked to instructional designs that reallocate classroom time from content delivery to analysis, discussion, application, and problem-solving.

Fidan and Tuncel (2019) add a technological dimension to HOT research through their exploration of augmented reality (AR) in problem-based learning. With 275 citations, their study highlights AR's potential to enhance learning achievement and engagement in physics education. The integration of AR represents a forward-looking approach to fostering creativity and critical thinking, though the study also raises important considerations about its physical and logistical challenges. This finding is pedagogically important because it shows that technology-enhanced HOT learning depends not only on novelty or immersion, but also on usability, learner comfort, instructional alignment, and the quality of problem-based tasks.

The National Academy of Sciences (2018) report offers a broader lens, synthesizing decades of research on learning processes. With 237 citations, it provides updated principles for designing effective learning environments, emphasizing the intersection of neurological, individual, and sociocultural factors. This comprehensive review underlines the importance of lifelong learning and the integration of technology in modern education, making it a cornerstone in educational research. Although this source is not a journal article, it remains relevant as a foundational learning-science reference and should be distinguished from journal-based references when meeting journal reference-count requirements.

Emerging areas of study are also represented, such as Thornhill-Miller et al. (2023), which focuses on the "4Cs" of 21st-century skills: creativity, critical thinking, collaboration, and communication. Despite being a recent publication, its 125 citations reflect the urgency of these skills in contemporary education. The proposed assessment frameworks for measuring and fostering the 4Cs offer practical solutions for integrating these competencies into formal and informal learning settings. This paper is especially relevant to the present study because it connects

creativity and critical thinking with assessment, certification, and policy-oriented implementation, which remain underdeveloped areas in much HOT research.

The impact of programming on reasoning skills and self-efficacy is explored by Psycharis and Kallia (2017), while Quigley et al. (2017) advance the STEAM model for transdisciplinary education. Both studies highlight innovative pathways to embed creativity and problem-solving in curricula, addressing critical gaps in traditional education systems. Meanwhile, Cruz et al. (2020) and Hodson (2014) emphasize the need for reliable competency assessments and authentic science education, respectively, contributing to the practical refinement of educational practices. As with the National Academy of Sciences report, Hodson (2014) should be treated as a supporting handbook chapter rather than counted toward the required minimum number of journal articles.

Taken together, these papers show that influential creativity and HOT research is organized around three connected directions: technology-supported learning, interdisciplinary curriculum design, and the assessment of complex competencies. **Table 5** also reveals an important methodological pattern. Several of the most cited works are systematic reviews, meta-analyses, conceptual models, or large-scale syntheses rather than single classroom interventions. This indicates that the field relies heavily on integrative scholarship to consolidate evidence, define conceptual boundaries, and guide future empirical work. At the same time, the inclusion of quasi-experimental studies shows continued interest in testing specific pedagogical designs such as AR-enhanced PBL and programming-based learning.

This citation profile aligns with recent bibliometric mappings of STEM/STEAM education and 21st-century competencies, which report growing attention to STEAM integration, creativity, critical thinking, computational thinking, problem-solving, and technology-supported learning (Dúo-Terrón, 2023; Jantakoon et al., 2024; Kaymakci & Can, 2023; Y. Li & Talib, 2024; Prahani, Dawana, et al., 2023; Şeker, 2025; Tran et al., 2024; Wasak, 2024). The pedagogical implication of this pattern is that creativity and HOT are increasingly studied through learning environments that combine active engagement, collaboration, technology, disciplinary integration, and authentic problem-solving. However, the result also points to continuing gaps. Assessment validity, long-term learning outcomes, transfer across contexts, and equity in access to technology-rich HOT learning remain less visible than studies on engagement and achievement. These gaps should be addressed in future research to ensure that HOT-oriented pedagogies are not only innovative but also measurable, inclusive, and sustainable.

4.5 Most Cited Journals and Publication Venues

The results identify the most cited academic journals and publication venues in creativity and higher-order thinking (HOT) research, revealing substantial variation in citation counts and publication output. This analysis is limited to the journals and venues represented in the analyzed Scopus-indexed STEM/science and higher education-related dataset. This analysis is important because journals and conferences do not only function as publication outlets; they also shape how research communities define key problems, prioritize methods, and disseminate pedagogical innovations related to creativity and HOT.

At the forefront is *Thinking Skills and Creativity*, which stands out with 520 citations despite only two published documents in the analyzed dataset. This journal's prominence reflects its highly targeted focus on creativity, critical thinking, and cognitive development, making it a key reference point for researchers in the field. The high citation-to-document ratio suggests that a small number of articles published in this outlet have had strong scholarly visibility. However, this should be interpreted as citation impact within the dataset rather than as a general ranking of journal quality.

Education Sciences and *Computers and Education* also rank highly, with 479 and 432 citations, respectively. These journals maintain higher document counts, with 22 and 8 documents, respectively, indicating a broader base of influential research. Their citation metrics underscore their role in publishing work on educational innovation, particularly studies that integrate technology, pedagogy, creativity, and critical thinking. The strong presence of these journals supports the finding that HOT research is increasingly connected to technology-enhanced learning, digital learning environments, and evidence-based instructional design.

Sustainability (Switzerland) represents an important case, with 245 citations from 25 documents. Its contribution highlights the growing intersection between sustainability education and creativity research. By addressing contemporary global challenges, the journal links HOT with societal issues such as environmental responsibility, sustainable development, engineering education, and problem-solving for real-world contexts. This

pattern indicates that HOT research is expanding beyond cognitive skill development alone and is increasingly connected to education for sustainability, civic responsibility, and applied interdisciplinary learning.

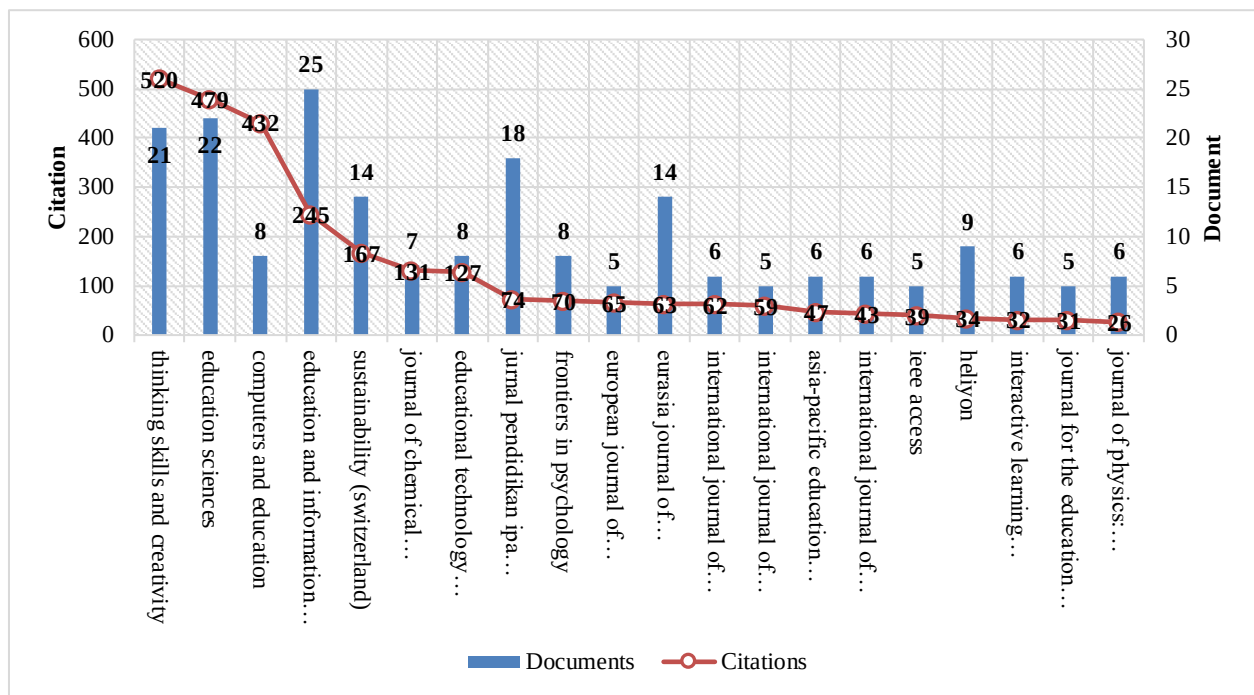


Figure 3. Most cited academic journals and publication venues in the analyzed Scopus-indexed dataset.

Other notable journals, such as the Journal of Chemical Education and Educational Technology Research and Development, contribute 167 and 131 citations, respectively. These publication venues represent more specialized areas of HOT research. The Journal of Chemical Education reflects discipline-specific efforts to foster problem-solving, scientific reasoning, and conceptual understanding, while Educational Technology Research and Development reflects the role of instructional technology in supporting higher-order learning. Together, these journals show that HOT research develops through both general education scholarship and subject-specific pedagogical inquiry.

The inclusion of Jurnal Pendidikan IPA Indonesia, with 74 citations from 18 documents, is particularly significant because it reflects the contribution of regional journals to global HOT research. This finding aligns with the geographic distribution reported earlier, where Indonesia showed a high level of publication output. The presence of this journal suggests that regional publication venues can play an important role in disseminating locally grounded studies while also contributing to international discussions on science education, creativity, and HOT. However, citation counts from regional journals should also be interpreted alongside journal indexing, readership, international collaboration, citation practices, and the age of publications.

Journals such as Frontiers in Psychology and the European Journal of Educational Research showcase interdisciplinary appeal, with contributions that link cognitive science, psychology, and educational practice. Their citation counts, 65 and 63 respectively, indicate their role in connecting theoretical and applied aspects of creativity and HOT. This interdisciplinary positioning is important because HOT is not limited to a single discipline; it draws from psychology, curriculum studies, learning sciences, science education, technology-enhanced learning, and assessment research.

Other journals, including Asia-Pacific Education Researcher, IEEE Access, Heliyon, and Interactive Learning Environments, contribute fewer documents but remain relevant through their specialized focus on technology, interactive learning, regional education issues, and STEM-related contexts. Their presence illustrates the widening scope of HOT research, especially in areas such as mobile learning, digital interaction, online learning environments, engineering education, and educational technology.

Overall, **Figure 3** illustrates a diverse publishing landscape in creativity and HOT research. Journals with high citation-to-document ratios indicate the influence of selected highly cited contributions, while journals with larger

document counts reflect more sustained publication activity. The pattern also shows that the field is distributed across three broad publication spaces: cognitive and creativity-focused journals, technology and learning science journals, and interdisciplinary or regional education journals. This distribution reinforces the view that creativity and HOT research is both conceptually broad and pedagogically applied. At the same time, journal-level findings should not be interpreted as a definitive measure of journal quality because citation patterns can be affected by publication age, database coverage, disciplinary citation norms, and the visibility of specific highly cited articles.

4.6 Author Collaboration Networks

The collaboration network visualization reveals the structure and dynamics of co-authorship among researchers in creativity and HOT research. Each cluster represents groups of authors who collaborate closely, with links indicating shared publications. The distribution and density of nodes and links highlight the prominence of certain authors and the extent of collaboration within and across clusters. Unlike simple productivity indicators, co-authorship networks show how knowledge is produced collectively and whether research communities are integrated or fragmented. In **Figure 4**, node size represents author prominence within the network, link thickness indicates the strength of co-authorship relationships, colors represent collaboration clusters, and the distance between nodes reflects the relative closeness of collaborative relationships.

One of the most significant features of the network is the central position of Hwang G-J, whose collaborations form a tightly connected group. This indicates that Hwang plays an important role in advancing the field through active partnerships. The prominence of Hwang's node and its associated links suggests influence not only through publication output and citation impact, but also through collaboration. This cluster appears to reflect a research community strongly connected to technology-supported learning, digital pedagogy, and higher-order cognitive development, which are central themes in contemporary HOT research.

In another notable cluster, Li Y emerges as a focal point of collaboration, connected to authors such as Chen, Zhan Z, and Wijaya TT. This cluster signifies a robust research network that may focus on specific themes or methodological approaches in HOT research. The density of connections within this group indicates a collaborative environment that can support innovation and sustained research productivity. The presence of subgroups linked to Li Y suggests thematic diversification within the broader domain, including possible connections among STEM/STEAM education, technology-enhanced learning, critical thinking, and mathematical or scientific reasoning.

Other clusters, such as those involving Prahani BK, Jatmiko B, and Saputro S, demonstrate regionally or thematically focused collaborations. These groups tend to have fewer connections with other clusters, suggesting that their research may be more localized or concentrated on specific educational contexts. Despite this, the tight internal connections reflect strong partnerships that are important for advancing targeted research objectives. These clusters also correspond to the strong representation of Southeast Asian publication output identified in the geographic analysis, suggesting that regional research communities are contributing actively to the expansion of HOT research.

Smaller clusters, such as those involving Huang Y-M and other authors, indicate emerging networks or niche research areas. These groups may represent newer collaborations or specialized investigations within the field. Their relatively isolated position highlights opportunities for greater integration into the broader research community. For example, stronger inter-cluster collaboration could connect specialized research on digital tools, STEM/STEAM pedagogy, teacher education, assessment, and sustainability-oriented learning. Such connections would help the field move beyond isolated innovations toward more cumulative and comparative knowledge building.

The network also reveals areas where collaboration could be strengthened. While several active clusters are visible, the lack of extensive inter-cluster connections suggests limited cross-community exchange. This pattern may indicate fragmentation in the field, where research groups work productively within their own contexts but engage less frequently in cross-national, cross-disciplinary, or cross-methodological collaboration. For HOT research, such fragmentation matters because creativity and higher-order thinking are complex constructs that benefit from diverse theoretical, cultural, and pedagogical perspectives.

This finding is consistent with recent bibliometric studies in STEM/STEAM education and related fields, which show that co-authorship and collaboration networks can reveal both productive knowledge hubs and gaps in international or interdisciplinary exchange (Ahmed et al., 2023; Dúo-Terrón, 2023; Kamarrudin et al., 2022; Prahani, Dawana, et al., 2023; Şeker, 2025; Tran et al., 2024). Overall, **Figure 4** suggests that the field has several productive

collaboration hubs but still needs stronger bridges among research communities. Future collaboration should prioritize comparative studies, shared assessment frameworks, cross-cultural research, and interdisciplinary projects that connect cognitive theory, curriculum design, educational technology, and classroom practice. Such collaboration would help transform creativity and HOT research from a set of productive but partly fragmented communities into a more integrated international research domain.

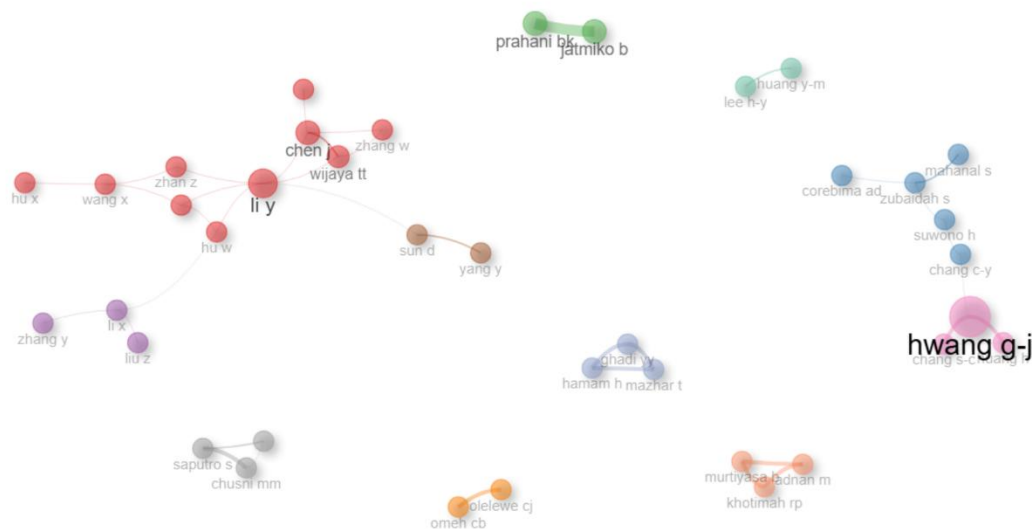


Figure 4. Author collaboration network in the analyzed Scopus-indexed dataset. Node size indicates author prominence, link thickness indicates co-authorship strength, colors indicate collaboration clusters, and proximity indicates relational closeness among authors.

4.7 Keyword Co-Occurrence Analysis

The keyword co-occurrence visualization in **Figure 5** reveals a network of research themes and their interconnections within creativity and HOT research in the analyzed Scopus-indexed STEM/science and higher education-related dataset. The clustering of keywords reflects thematic groupings, with each cluster representing a distinct area of focus. This analysis is central to the study because it shows how the conceptual structure of the field is organized. Keywords do not simply identify topics; they reveal how researchers connect cognitive constructs, pedagogical strategies, learning technologies, disciplinary contexts, and educational outcomes.

In **Figure 5**, node size represents the frequency of keyword occurrence, link thickness indicates the strength of co-occurrence relationships, colors indicate thematic clusters generated by VOSviewer, and the distance between nodes reflects the relative relatedness of keywords. Because the map contains many overlapping labels, **Table 5** is provided to summarize the major clusters, representative keywords, interpretations, and educational implications in a more accessible format.

The largest cluster, centered around “students,” “teaching,” and “education,” reflects a broad focus on pedagogy and student-centered learning. This cluster includes themes such as “higher education,” “engineering education,” and “learning approaches,” suggesting a diverse exploration of educational strategies. Topics such as “curricula,” “e-learning,” and “educational technology” indicate a strong emphasis on how technological integration and innovative methods are reshaping teaching practices. Pedagogically, this cluster suggests that creativity and HOT are increasingly studied as learning outcomes that depend on instructional design, curriculum alignment, and learner engagement rather than as isolated cognitive abilities.

The presence of “student engagement” and “sustainability” within or near this cluster reflects the growing importance of aligning education with students’ needs and global challenges. This connection is important because it positions HOT as a capacity for addressing authentic problems, not only for improving academic performance. In this sense, sustainability-related learning may provide meaningful contexts in which students analyze complex issues, evaluate competing solutions, and develop creative responses to environmental and social problems. Sustainability education can therefore serve as a context for systems thinking, ethical reasoning, stakeholder-oriented

decision-making, and creative problem-solving, especially when supported through project-based learning, design thinking, living labs, and community-based inquiry.

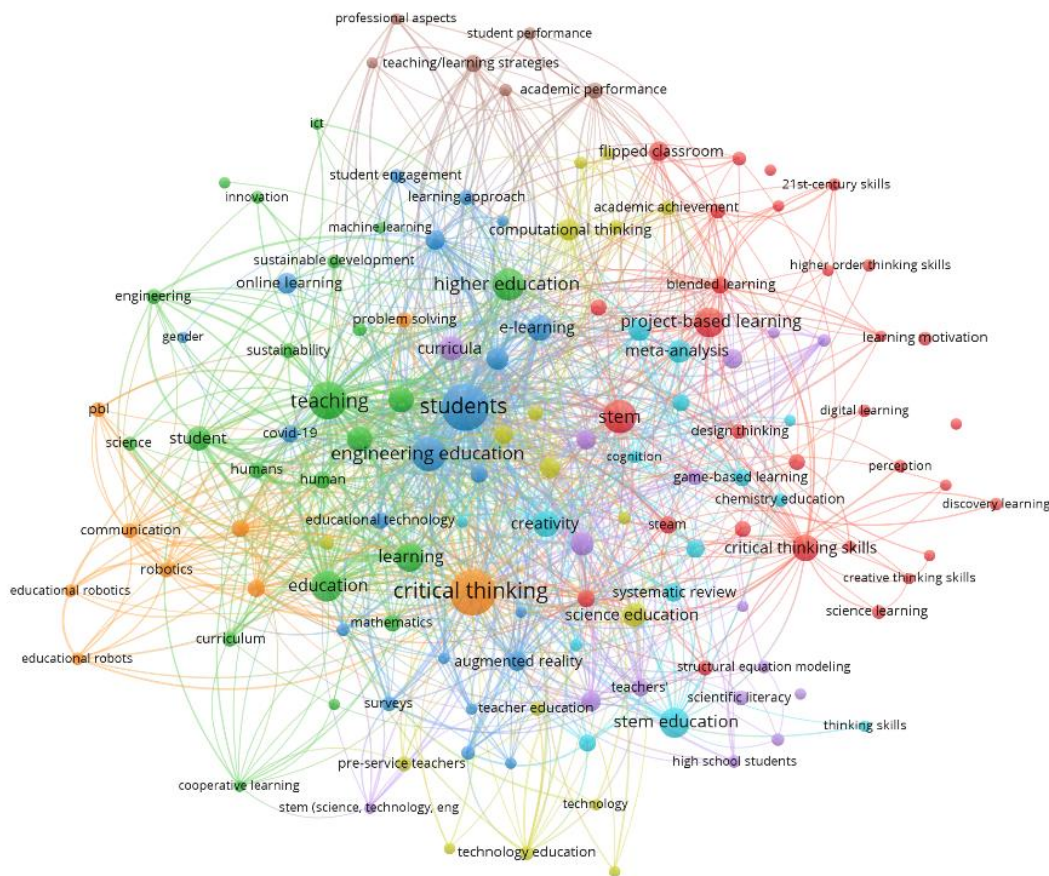


Figure 5. Keyword co-occurrence network in the analyzed Scopus-indexed STEM/science and higher education-related dataset. Node size indicates keyword frequency, link thickness indicates co-occurrence strength, colors indicate thematic clusters, and proximity indicates conceptual relatedness.

Another significant cluster revolves around “critical thinking” and “critical thinking skills.” This thematic grouping highlights research on cognitive development, reasoning, evaluation, and problem-solving, which are essential components of HOT. Subtopics such as “creativity,” “STEM education,” and “science education” demonstrate the field’s focus on fostering analytical and innovative thinking in technical and scientific disciplines. The close connection between critical thinking and creativity suggests that the field increasingly treats these constructs as mutually reinforcing. Critical thinking supports evaluation and justification, while creativity supports idea generation and solution design. This pattern is consistent with recent HOTS and STEM/STEAM literature that positions critical thinking, creativity, problem-solving, collaboration, and communication as core 21st-century competencies, often framed through Bloom-like taxonomies and the 4Cs (Aziz & Rawian, 2022; Chavda et al., 2023; Kurniawan et al., 2023; Lee et al., 2024; Razak et al., 2022; Shahril et al., 2023; Yang et al., 2023).

Related themes such as “scientific literacy,” “augmented reality,” and “teacher education” point to practical applications and the need to equip educators with tools to enhance students’ higher-order thinking abilities. Connections to “game-based learning,” “design thinking,” and “blended learning” suggest innovative pedagogical strategies aimed at improving critical thinking. The presence of teacher education in this cluster is pedagogically significant because HOT-oriented learning depends heavily on teachers’ ability to design open-ended tasks, facilitate inquiry, scaffold reasoning, and assess complex learning outcomes. Therefore, teacher professional development should be considered a central component of HOT implementation rather than a peripheral theme. Teachers also need competence in selecting and integrating digital tools, designing collaborative inquiry tasks, supporting metacognition, and aligning assessment with creativity and HOT outcomes (Bataineh et al., 2025; Hébert & Jenson, 2021; Lee et al., 2024; Sasson et al., 2021; Vásquez et al., 2023).

Table 6. Main Keyword Clusters, Interpretations, and Educational Implications

Cluster	Representative Keywords	Interpretation	Educational Implication
Student-centered pedagogy and learning environments	students, teaching, education, higher education, curricula, learning approaches, student engagement	Creativity and HOT are studied as learning outcomes shaped by instructional design, curriculum alignment, and learner engagement.	Learning environments should provide active, reflective, and collaborative opportunities for students to analyze problems, evaluate evidence, and create solutions.
Critical thinking and core HOT constructs	critical thinking, critical thinking skills, creativity, problem-solving, scientific literacy	HOT is organized around analysis, evaluation, reasoning, problem-solving, and creative production.	Tasks should explicitly require analysis, synthesis, evaluation, justification, and creative reasoning rather than recall-based responses.
STEM/STEAM and interdisciplinary learning	STEM education, science education, STEAM, project-based learning, 21st-century skills, learning motivation	STEM/STEAM contexts provide platforms for interdisciplinary inquiry, design thinking, and authentic problem-solving.	Curriculum should integrate disciplinary knowledge with real-world problems, project-based learning, inquiry, and design-oriented tasks.
Technology-enhanced learning	e-learning, educational technology, augmented reality, game-based learning, flipped classroom, digital learning, discovery learning	Digital tools are increasingly used to support engagement, visualization, collaboration, and higher-order cognitive activity.	Technology should be used with explicit HOT prompts, scaffolding, feedback, and assessment alignment rather than as a delivery tool alone.
Teacher education and professional capacity	teacher education, pre-service teachers, teaching methods, instructional approaches	HOT implementation depends on teacher capacity to design tasks, facilitate inquiry, scaffold reasoning, and assess complex learning.	Teacher professional development should focus on task design, inquiry facilitation, formative feedback, digital pedagogy, and HOT assessment.
Sustainability and authentic problem-solving	sustainability, sustainable development, engineering, robotics, communication	Sustainability-oriented research links HOT with authentic problems, systems thinking, ethical reasoning, and social responsibility.	Learning should connect HOT with global challenges through systems thinking, ethical decision-making, stakeholder engagement, and creative solution design.
Assessment and measurable learning outcomes	academic achievement, student performance, educational assessment, competency, learning outcomes	Many studies evaluate HOT-related pedagogies through achievement and performance indicators, but complex competencies require broader assessment.	Assessment should include rubrics, authentic tasks, portfolios, reflective products, multi-representation items, and longitudinal measures.

The “STEM” cluster is another prominent focus area, with keywords such as “project-based learning,” “21st-century skills,” and “learning motivation.” This cluster reflects a drive to incorporate hands-on, interdisciplinary

approaches in education, bridging theoretical knowledge with practical applications. This pattern indicates that STEM and STEAM contexts provide important platforms for HOT development because they require students to investigate problems, integrate knowledge, test ideas, and justify solutions. The inclusion of “meta-analysis” and “systematic review” also highlights efforts to synthesize existing research and identify best practices for advancing STEM education. Within this cluster, creativity and HOT are often operationalized through inquiry-based learning, project-based learning, STEAM tasks, concept maps, mind maps, Ethno-STEM-PjBL, and digital modules that require students to analyze, synthesize, evaluate, and create (Martawijaya et al., 2023; Pimdee, 2022; Razak et al., 2022; Yang et al., 2023; Zhu & Tahir, 2023).

A smaller but significant cluster is centered on “sustainability” and “sustainable development.” This grouping indicates an emerging interest in linking education with global priorities such as environmental stewardship and social responsibility. Keywords such as “engineering,” “robotics,” and “communication” suggest that sustainability is being integrated into technical and engineering disciplines, further reinforcing the relevance of HOT in addressing real-world challenges. However, the relative size and position of this cluster suggest that sustainability-oriented HOT research may still be emerging rather than fully integrated into the core of the field. Future studies should examine how sustainability education can explicitly cultivate analysis, evaluation, ethical reasoning, systems thinking, and creative problem-solving. This is especially important because sustainability problems require learners to reason across social, environmental, economic, and technological dimensions rather than solve narrowly defined academic tasks.

Another thematic grouping highlights innovative educational methods, with keywords such as “flipped classroom,” “digital learning,” and “discovery learning.” This cluster focuses on instructional designs that prioritize active and experiential learning. The emphasis on “academic achievement” and “student performance” suggests that these methods are often evaluated through measurable learning outcomes. This pattern shows that HOT research is increasingly concerned with the effectiveness of pedagogical models, but it also reveals a potential limitation: achievement and performance measures may not fully capture creativity, transfer, metacognition, or long-term higher-order cognitive development. Technology-enhanced learning, including augmented reality, virtual laboratories, AI-enabled scaffolds, digital worksheets, and game-based learning, appears most pedagogically meaningful when it is supported by explicit HOT prompts, structured feedback, teacher facilitation, and opportunities for self-regulated learning (Wang & Gao, 2025; T. Wu, Lee, et al., 2025; T. Wu, Sarwono, et al., 2025; Zhao et al., 2025).

AI-supported learning is an emerging but important direction within this broader technology cluster. Generative AI and AI-driven scaffolds may support critical thinking, creativity, problem-solving, self-regulated learning, and metacognitive reflection when they are integrated with student-centered pedagogy and explicit thinking objectives (Hwang & Wu, 2025; Zhang et al., 2025; Zhao et al., 2025). However, AI should not be treated as automatically beneficial. Its educational value depends on task design, feedback quality, academic integrity safeguards, AI literacy, and attention to digital equity.

The interconnectedness of clusters reflects the interdisciplinary nature of research in creativity and HOT. For instance, links between “critical thinking” and “science education” or between “students” and “sustainability” demonstrate the overlap of cognitive development with subject-specific and global themes. The network’s density underscores the integrative character of the field, where research in one area can inform and enrich another. At the same time, some weaker links among sustainability, teacher education, assessment, and technology suggest opportunities for deeper integration. These areas are especially important because they connect HOT research to curriculum design, teacher capacity, equity, and real-world problem-solving.

The keyword network also shows that assessment remains an important but less dominant theme compared with pedagogy, technology, and student performance. This is a critical issue because creativity and HOT cannot be fully captured through recall-oriented tests or short-term achievement scores. Recent studies suggest the need for rubric-based instruments, authentic and problem-based tasks, multi-representation items, two-tier instruments, portfolios, and validity-oriented measurement models to assess creativity, critical thinking, problem-solving, transfer, and reflection (Amrianto et al., 2024; Aryana et al., 2024; Mahmudati, 2023; Misri et al., 2021; Ng et al., 2023; Sandoval, 2021; Shou et al., 2025).

Overall, **Figure 5** highlights a dynamic and evolving research landscape. The prominence of clusters around critical thinking, STEM/STEAM, technology-enhanced learning, sustainability, and teacher education shows that

creativity and HOT research is aligned with 21st-century educational goals. More importantly, the network indicates a shift from viewing HOT as a purely cognitive outcome toward understanding it as a curriculum, pedagogy, technology, assessment, and policy issue. This broader interpretation strengthens the relevance of creativity and HOT research for modern educational practice. However, these findings should be interpreted as thematic patterns within the analyzed Scopus-indexed STEM/science and higher education-related dataset, not as a complete representation of all creativity and HOT research across every educational level, discipline, and learning context.

5. Discussion

5.1 Interpretation of Key Findings

The findings of this bibliometric analysis provide a comprehensive understanding of the research landscape on creativity and higher-order thinking (HOT) from 2014 to 2024 within the analyzed Scopus-indexed STEM/science and higher education-related dataset. The sharp increase in publications, particularly after 2020, indicates growing scholarly attention to 21st-century cognitive skills in education (Huang et al., 2022). This pattern should be interpreted as evidence of publication growth, not as direct evidence of a causal shift in global education policy. Nevertheless, the trend is consistent with broader educational attention to technology-enhanced learning, interdisciplinary pedagogy, competency-based curricula, and the development of critical and creative thinking skills.

This publication growth also supports the conceptual framework proposed in this study. Publication trends can be interpreted as indicators of the generative phase of creativity and HOT research, where rising outputs signal expanding conceptual space, methodological experimentation, and increasing scholarly attention to STEAM integration, creativity, HOTS, problem-solving, and technology-supported learning (Ariyani et al., 2022; Jantakoon et al., 2024). However, this growth should be read cautiously because bibliometric output is shaped by database coverage, search terms, publication incentives, and indexing practices.

A significant finding is the strong contribution of Indonesia in the analyzed Scopus dataset, followed by the United States, China, Malaysia, and Taiwan. Rather than positioning Indonesia as an overall global leader in HOT research, this study interprets Indonesia's position more cautiously as the highest publication output within the dataset and search parameters used in the analysis. This distinction is important because publication volume does not automatically indicate higher research quality, broader policy influence, or stronger classroom implementation. Broader claims of research leadership would require additional indicators, such as citation impact, international collaboration, journal quality, research funding, policy evidence, and classroom-level implementation. Malaysia's contribution also highlights the visibility of Southeast Asia in HOT-related research, although this regional pattern should be understood as an emerging publication trend that requires further policy-based and comparative investigation.

The visibility of Indonesia and Malaysia may reflect several interacting factors, including STEM/science education policy attention, teacher education reforms, institutional research capacity, regional publication incentives, and collaboration networks. However, these explanations remain interpretive rather than causal because the present study does not analyze policy documents, funding systems, classroom implementation, or institutional research strategies. Therefore, the geographic findings should be interpreted as a map of indexed publication productivity, not as a ranking of national educational quality or global intellectual leadership.

The collaboration network analysis highlights the influence of leading scholars such as Hwang G-J, Li Y, and Zhan Z, whose work has shaped academic discourse on HOT. The network also shows that creativity and HOT research is organized around several productive collaboration hubs rather than one fully integrated global research community. This pattern presents both strength and limitation. Strong internal collaboration can support focused research productivity, but weak connections across clusters may limit cross-cultural comparison, theoretical integration, and methodological standardization. The presence of highly cited publications and research collaborations suggests that international and interdisciplinary partnerships remain important for advancing research in this domain (Hujjatunaini et al., 2022).

Co-authorship patterns are especially important because creativity and HOT are inherently cross-domain constructs. Collaboration networks can reveal whether researchers work mainly within regional or disciplinary clusters or whether they build bridges across countries, methods, and educational contexts. In this study, several

visible hubs suggest active knowledge production, but the limited connection among some clusters indicates opportunities for stronger comparative, interdisciplinary, and international research.

The keyword co-occurrence analysis reveals several primary thematic clusters, including critical thinking in education, interdisciplinary and technology integration, student-centered learning models, STEM/STEAM-oriented pedagogy, sustainability education, teacher education, and assessment. These clusters indicate that HOT research has moved beyond a narrow focus on cognitive skills and now intersects with curriculum design, digital learning, teacher education, assessment, and real-world problem-solving. **Figure 6** visually synthesizes these relationships by presenting creativity and HOT in education as a central hub connected to critical thinking, digital learning, STEM/STEAM, student-centered learning, teacher education, sustainability, and assessment. This visual ecosystem clarifies how the field has expanded from individual cognitive development toward a broader educational agenda involving pedagogy, technology, curriculum, assessment, and policy. These findings suggest a pedagogical shift from traditional, lecture-based instruction toward interactive, problem-based, interdisciplinary, and technology-supported learning approaches that aim to enhance analytical reasoning and creative problem-solving abilities (Antonova et al., 2024).

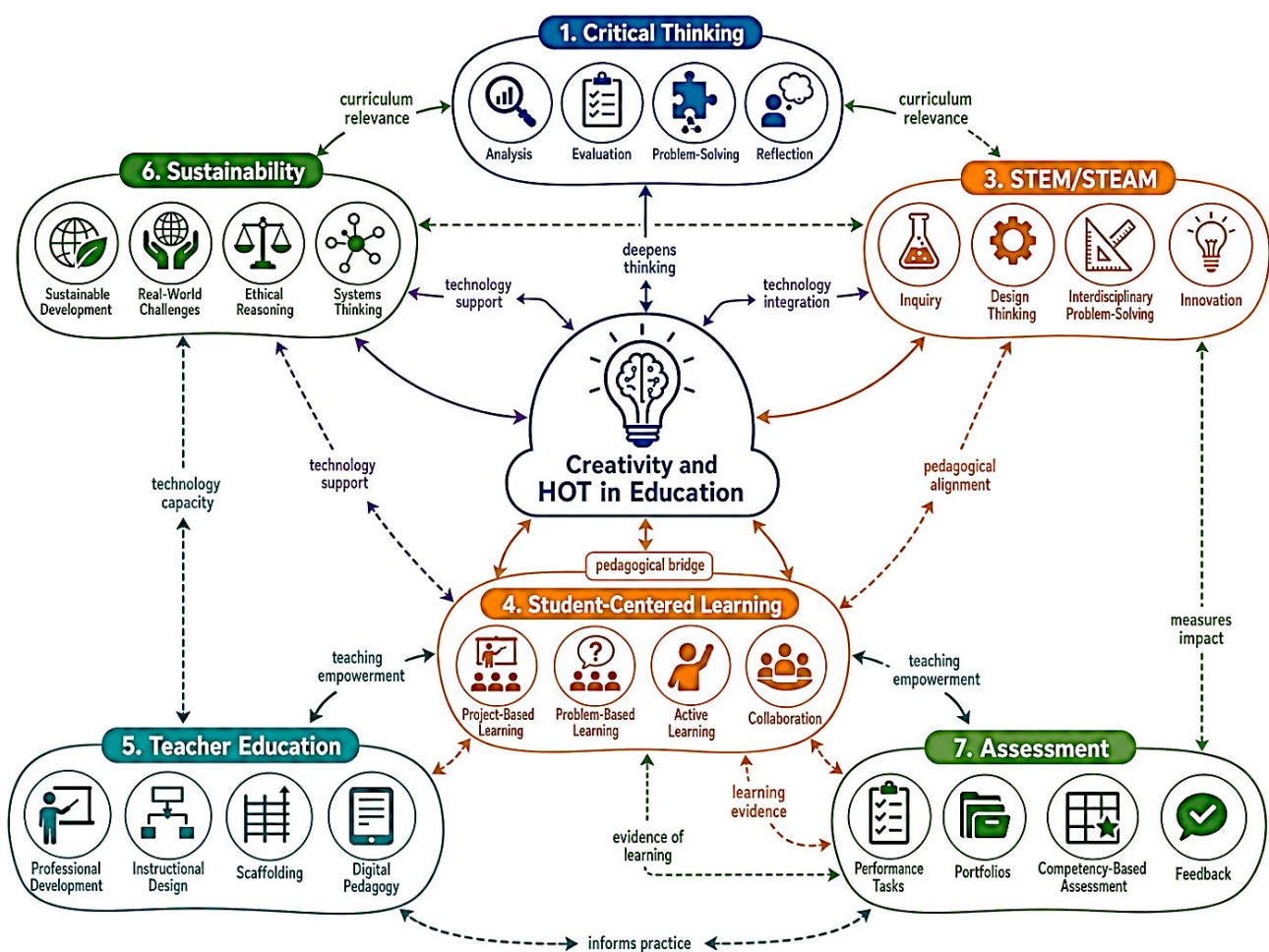


Figure 6. Author-developed synthesis of the thematic knowledge ecosystem based on keyword co-occurrence and discussion findings.

Taken together, the findings indicate that creativity and HOT research is developing along three connected directions. First, the field is expanding quantitatively, as shown by the rapid growth in publications after 2020. Second, the field is becoming more geographically diverse, with strong publication output from Asian countries, particularly Indonesia and Malaysia. Third, the field is becoming more conceptually and pedagogically complex, as shown by the links among critical thinking, STEM/STEAM, digital learning, sustainability, teacher education, and assessment. **Figure 6** supports this interpretation by illustrating these themes as an interconnected knowledge

ecosystem rather than as isolated research topics. This reinforces the view that creativity and HOT research should be understood as a multidimensional field that connects cognitive theory, instructional design, technology integration, teacher capacity, assessment practice, and real-world educational challenges.

5.2 Comparison with Existing Literature

The results of this study align closely with existing research on blended learning, project-based learning (PBL), and interdisciplinary education. Prior studies indicate that technology-supported interdisciplinary learning can enhance HOT and creativity, particularly among pre-service teachers and STEM students (Kizilay et al., 2023). The effectiveness of blended PBL has also been documented in previous literature, reinforcing its role in developing students' problem-solving and analytical skills (Hujjatunaini et al., 2022). The present bibliometric results extend these findings by showing that PBL, blended learning, and technology-enhanced learning are not isolated instructional trends; they are part of a broader thematic structure in HOT research.

This finding is consistent with recent bibliometric studies showing that publication volumes on STEM/STEAM education and related competencies have grown, with increasing thematic emphasis on STEAM integration, creativity, critical thinking, problem-solving, computational thinking, and innovative capacity (Jantakoon et al., 2024; Kaymakci & Can, 2023; Y. Li & Talib, 2024; Prahani, Nisa, et al., 2023; Şeker, 2025; Tran et al., 2024). Methodologically, these studies also commonly use Scopus or Web of Science data, co-authorship analysis, keyword co-occurrence, and visualization tools such as VOSviewer, Bibliometrix/Biblioshiny, and CiteSpace to map intellectual structures and collaboration patterns (Ahmed et al., 2023; Dúo-Terrón, 2023; Prahani, Nisa, et al., 2023; Wasak, 2024).

The importance of STEAM education is also reaffirmed in this study, aligning with research demonstrating that interdisciplinary connections between STEM and the arts promote deeper learning and cognitive flexibility (Purwaningsih et al., 2020). The integration of arts and humanities into STEM curricula encourages creative problem-solving and holistic thinking, which are essential for 21st-century skills development. However, the keyword structure also reveals an imbalance: STEM and STEAM contexts are highly visible, whereas non-STEM fields such as the humanities, arts, and social sciences appear less central. This suggests that the literature still needs stronger comparative work on how HOT is developed across disciplinary traditions beyond science and technology-focused education.

This imbalance should not be interpreted as evidence that creativity and HOT are absent from non-STEM disciplines. Rather, it partly reflects the search strategy used in the present study, which explicitly included science education, STEM education, and higher education terms. Previous studies on creativity in higher education, mathematical creativity, critical thinking in language education, and physics education show that creativity and HOT have been mapped in several domain-specific ways. The distinctive contribution of the present study lies in jointly mapping creativity and HOT within a STEM/science and higher education-related dataset and connecting publication trends, citation impact, collaboration networks, and keyword structures to pedagogical interpretation.

This study also confirms earlier research on technology-enhanced learning environments. Digital tools such as AI, gamification, and virtual learning platforms have been shown to improve students' cognitive engagement and creative capacities (Antonova et al., 2024; Putri et al., 2023). The increasing use of adaptive learning systems in education provides personalized learning experiences, enabling students to develop HOT at their own pace. The bibliometric evidence adds a field-level perspective by showing that technology-related themes are closely connected with critical thinking, student engagement, STEM/STEAM, and active learning. At the same time, the results suggest that technology is often discussed in relation to engagement and achievement, while long-term outcomes, equity, transfer of learning, and assessment validity remain less visible.

Recent studies on AI-supported learning further suggest that generative AI and AI-driven scaffolds can support critical thinking, creativity, problem-solving, self-regulated learning, and metacognitive reflection when they provide purposeful prompts, adaptive feedback, and structured inquiry support (Hwang & Wu, 2025; T. Wu, Lee, et al., 2025; Zhang et al., 2025; Zhao et al., 2025). However, these benefits depend on careful pedagogical design, AI literacy, academic integrity safeguards, and attention to digital equity. Thus, the present bibliometric findings should be interpreted as evidence of growing scholarly attention to AI and digital learning, not as direct proof that these tools automatically improve HOT.

One novel contribution of this study is its geographical analysis, which reveals a shifting distribution of publication output in HOT research. Previous research has often emphasized Western education systems, whereas

this analysis shows strong publication activity from Southeast Asia, especially Indonesia and Malaysia (Huang et al., 2022). This finding does not imply that Southeast Asia has fully displaced Western countries in research influence. Instead, it shows that the geography of publication output is more diverse than expected and that emerging research communities are contributing actively to the global HOT discourse. This distinction responds to the need for a more careful interpretation of geographical findings.

The comparison with existing literature also reveals a discrepancy between pedagogical innovation and assessment development. Many studies emphasize PBL, STEAM, AI, gamification, and digital learning, but fewer focus on how creativity and HOT can be measured consistently across contexts. This gap aligns with concerns raised in competency-based education, where complex skills such as creativity, critical thinking, collaboration, and communication require assessment tools that go beyond standardized testing. Therefore, future studies need to connect instructional innovation more directly with valid, reliable, and longitudinal measures of HOT development.

5.3 Theoretical Synthesis and Implications

This study contributes to several theoretical discussions on creativity and HOT by reinforcing and expanding existing learning models. The results do not directly validate the effectiveness of specific pedagogical approaches, because bibliometric analysis does not measure learning outcomes. Instead, the findings show that blended PBL, inquiry-based learning, STEAM, and technology-enhanced learning have become central theoretical and pedagogical reference points within the HOT research landscape. This pattern is consistent with studies emphasizing the role of active learning in enhancing students' analytical, creative, and problem-solving abilities (Hujjatusnaini et al., 2022).

The former Results section on theoretical foundations has been integrated here because the interpretation of theories belongs in the Discussion rather than in the Results. The bibliometric findings suggest that creativity and HOT research is grounded in several connected theoretical traditions: cognitive and constructivist learning theories, technological pedagogical models, interdisciplinary and transdisciplinary education, assessment and competency frameworks, and broader learning science perspectives. These traditions help explain why the keyword network contains multiple connected clusters rather than one dominant theoretical orientation.

5.3.1 Cognitive and Constructivist Foundations

The study strengthens the relevance of constructivist learning theories, which emphasize active, student-centered learning as a key driver of cognitive development (Lu et al., 2023). The keyword clusters around students, teaching, project-based learning, discovery learning, and collaborative technologies suggest that HOT is frequently conceptualized as a process developed through active knowledge construction rather than passive content reception. Cognitive theories, including Bloom's taxonomy and related models of higher-order cognition, also remain visible because the field repeatedly emphasizes analysis, evaluation, creation, critical thinking, problem-solving, and metacognition. These constructs explain why creativity and HOT are treated as complementary capacities in this study: creativity supports originality and idea generation, whereas HOT supports evaluation, synthesis, justification, and reasoned action.

Constructivist and socio-constructivist perspectives further explain why collaboration, inquiry, dialogue, and authentic problem-solving appear prominently in the keyword and citation structures. Studies on gamification, computer-supported collaborative learning, and project-based learning reflect the assumption that learners develop HOT when they actively test ideas, negotiate meaning, receive feedback, and revise their understanding. Therefore, the theoretical implication is that creativity and HOT should be conceptualized as socially situated and pedagogically mediated capacities, not merely as individual cognitive traits.

5.3.2 Technological Pedagogical Models

The results further align with cognitive load theories, which suggest that well-designed digital learning environments can optimize cognitive engagement while reducing overload (Antonova et al., 2024). However, the findings also imply that digital environments must be carefully scaffolded; otherwise, technology may increase complexity without necessarily improving higher-order cognitive engagement.

Technology-related clusters indicate that digital tools are no longer peripheral in creativity and HOT research. Flipped classrooms, augmented reality, virtual laboratories, digital worksheets, game-based learning, digital storytelling, and AI-supported scaffolds appear as contexts in which HOT is studied, implemented, and assessed. Theoretically, this suggests a shift from viewing technology as a delivery medium toward viewing it as a cognitive and pedagogical scaffold. However, technology contributes to HOT only when it is aligned with inquiry, feedback, collaboration, reflection, and assessment.

This implication is especially important for AI-supported learning. AI tools may support critical thinking, creativity, self-regulated learning, and problem-solving when they provide purposeful prompts, adaptive feedback, and metacognitive support. However, they also raise theoretical and ethical questions about learner autonomy, overreliance, authorship, assessment validity, and digital equity. Future theoretical work should therefore connect AI-supported HOT learning with self-regulated learning theory, metacognition, learning analytics, ethics, and teacher facilitation.

5.3.3 *Interdisciplinary and Transdisciplinary Models*

Another important theoretical contribution is the emphasis on interdisciplinary education. The study supports the growing body of research indicating that students who engage with multiple disciplines develop more adaptive and flexible cognitive skills (Huang et al., 2022). These findings align with transdisciplinary learning theories, which advocate for cross-domain integration as a means to foster higher-order thinking. The keyword links among STEM/STEAM, sustainability, project-based learning, communication, and critical thinking suggest that HOT is increasingly theorized as a capacity for addressing complex and authentic problems across disciplinary boundaries.

The study also contributes to the theoretical positioning of creativity within HOT research. The co-occurrence patterns suggest that creativity is often linked with critical thinking, problem-solving, STEM/STEAM, and technology-supported learning. This supports an integrated view in which creativity is not treated as a separate or purely artistic capacity, but as a cognitive and pedagogical process that works together with analysis, evaluation, reasoning, and reflective judgment.

Sustainability education strengthens this interdisciplinary theoretical direction. Sustainability-related themes suggest that HOT is increasingly connected to systems thinking, ethical reasoning, stakeholder engagement, and creative problem-solving for complex societal challenges. However, the relatively weaker links between sustainability, assessment, teacher education, and technology indicate that sustainability-oriented HOT research remains an emerging area that requires stronger theoretical integration. Future frameworks should clarify how sustainability learning develops analysis, evaluation, ethical judgment, systems thinking, collaboration, and creative solution design.

5.3.4 *Assessment and Competency Frameworks*

The bibliometric findings also highlight an important theoretical imbalance: creativity and HOT are widely discussed as desired outcomes, but assessment-related keywords appear less central than pedagogy, technology, and student performance. This suggests that the field has advanced instructional innovation faster than measurement theory. Stronger assessment frameworks are needed because HOT cannot be evaluated adequately through recall-oriented tests alone.

Validated rubrics, authentic performance tasks, portfolios, multi-representation items, two-tier instruments, and longitudinal assessment models are needed to measure reasoning processes, originality, usefulness, transfer, collaboration, metacognition, and reflective judgment (Amrianto et al., 2024; Aryana et al., 2024; Mahmudati, 2023; Misri et al., 2021; Ng et al., 2023; Sandoval, 2021; Shou et al., 2025). The theoretical implication is that creativity and HOT should be defined not only by instructional intention but also by valid evidence of learners' reasoning, creative production, and transfer across contexts.

Overall, the theoretical synthesis indicates that creativity and HOT research is developing as a multidimensional knowledge domain. It connects cognitive theory, constructivist learning, interdisciplinary pedagogy, technology-enhanced learning, teacher capacity, sustainability education, and competency-based assessment. This integrated view provides a stronger basis for interpreting the bibliometric patterns reported in this study.

5.4 Practical Implications

The findings of this study offer practical implications for curriculum design, teacher professional development, assessment models, and education policy. A central implication is the need for policymakers and curriculum developers to prioritize interdisciplinary learning models that connect HOT with authentic educational contexts. Integrating STEM education with real-world applications, such as community service projects, has been shown to improve both creativity and HOT (Huang et al., 2022). Therefore, curriculum designers should develop learning tasks that require students to define problems, analyze evidence, generate alternative solutions, justify decisions, and communicate outcomes across disciplinary contexts. **Figure 7** illustrates this translation process by showing how major research themes can inform curriculum, teaching, teacher development, assessment, and policy.

Teacher training programs must also respond to the growing role of digital learning environments. As technology becomes increasingly embedded in education, teachers need the capacity to integrate AI-driven platforms, gamification, and digital storytelling into instructional practice (Antonova et al., 2024). However, teacher preparation should not focus only on technical tool use. Professional development should also strengthen teachers' ability to design inquiry-based tasks, scaffold higher-order reasoning, facilitate collaboration, support reflective learning, address digital equity, and assess complex learning outcomes. In this regard, **Figure 7** highlights teacher development as a key bridge between instructional innovation and classroom implementation, especially through digital pedagogy, assessment literacy, scaffolding HOT, and facilitation of student inquiry.

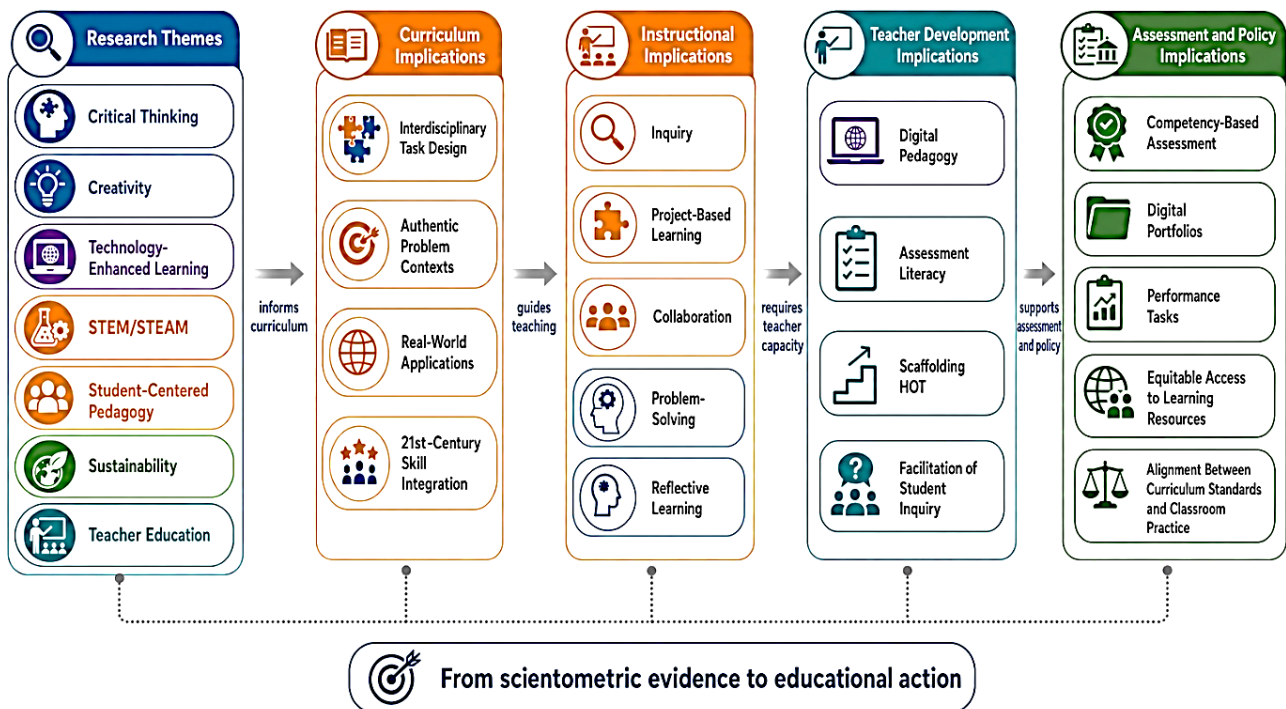


Figure 7. Author-developed framework translating scientometric findings into educational practice.

Teachers need competence in at least four areas: designing open-ended creativity and HOT tasks, integrating technology purposefully, facilitating collaborative inquiry, and using valid assessment tools. Professional development should therefore include practical training in PBL, inquiry-based learning, STEAM design, AI-supported scaffolding, formative feedback, performance assessment, and culturally responsive pedagogy. Without these competencies, HOT may remain a curriculum aspiration rather than a consistent classroom practice.

The findings also emphasize the need for assessment frameworks that can measure creativity and HOT more accurately. Traditional standardized tests may not adequately capture students' problem-solving, analytical reasoning, creative production, collaboration, and reflective judgment. Instead, competency-based assessment models should be explored, including performance-based tasks, real-world problem-solving challenges, and digital portfolios (Zhou, 2024). As shown in **Figure 7**, assessment and policy implications should include competency-based

assessment, digital portfolios, performance tasks, equitable access to learning resources, and alignment between curriculum standards and classroom practice. Such assessment models should evaluate not only final answers, but also reasoning processes, originality, usefulness of solutions, collaboration, reflection, and transfer of learning across contexts.

Technology implementation also requires careful practical safeguards. AI, AR, virtual laboratories, game-based learning, and digital worksheets should be used with explicit HOT prompts, structured feedback, teacher facilitation, and assessment alignment. Their use should also address academic integrity, data privacy, learner autonomy, and unequal access to digital resources. Thus, digital innovation should be treated as part of a broader pedagogical system rather than as an isolated solution.

For policymakers, the findings suggest that HOT development requires coherent alignment among curriculum standards, teacher professional development, digital infrastructure, learning resources, and assessment policy. Publication growth alone will not improve classroom practice unless research findings are translated into practical support systems for teachers and learners. **Figure 7** reinforces this point by positioning the pathway from research themes to educational practice as a sequence of connected actions: research informs curriculum, curriculum guides teaching, teaching requires teacher capacity, and teacher capacity supports assessment and policy. Therefore, stronger collaboration among researchers, curriculum developers, teacher educators, school leaders, and policymakers is needed to bridge the gap between HOT research and educational implementation.

5.5 Research Gaps Emerging from the Scientometric Findings

The former Results section on gaps in the literature has been integrated here because the identification of research gaps is an interpretive discussion of the bibliometric findings rather than a direct result. The gaps below are inferred from sparse keyword connections, underrepresented themes, and emerging topics in the analyzed Scopus-indexed STEM/science and higher education-related dataset. Therefore, they should be treated as directions for future research, not as definitive evidence that these topics are absent from the wider literature.

5.5.1 Integration of Sustainability and Higher-Order Thinking

While “sustainability” and “sustainable development” are visible in the network, their connections to “critical thinking,” “STEM education,” teacher education, and assessment appear underdeveloped. This indicates a gap in research linking sustainability education explicitly with HOT skills. Future studies could explore how critical and creative thinking can be systematically integrated into sustainability-focused curricula to prepare students for addressing environmental and societal challenges. Such research should examine not only whether sustainability topics increase engagement, but also how they develop systems thinking, ethical reasoning, evidence evaluation, collaborative problem-solving, and creative solution design. Living labs, community-based projects, biomimicry, design thinking, and SDG-focused learning may provide useful contexts for developing sustainability-oriented HOT.

5.5.2 Critical Thinking and Creativity Beyond STEM

The network heavily emphasizes the integration of critical thinking within “STEM education” and “science education.” However, there is limited representation of how HOT skills can be fostered in the arts, humanities, social sciences, vocational education, informal learning, and early childhood education. Future research could investigate frameworks for cultivating these skills in non-STEM fields, exploring their role in fostering creativity, ethical reasoning, cultural understanding, interpretation, argumentation, and creative expression. Because the present search strategy intentionally emphasized STEM/science and higher education-related terms, this gap should be framed as a dataset-bound limitation and a future research direction rather than as a claim that non-STEM HOT research is lacking.

5.5.3 Technology-Enhanced Learning, AI, and HOT

The strong presence of keywords such as “augmented reality,” “e-learning,” “game-based learning,” and digital learning reflects the use of technology in HOT research. However, the connections between these technologies

and specific outcomes such as creativity, transfer, metacognition, learner autonomy, equity, and long-term problem-solving remain less visible. Future studies should examine how AI, VR, AR, robotics, learning analytics, and adaptive systems support HOT across diverse learners and contexts. These studies should move beyond short-term achievement measures and examine how technology affects reasoning quality, creative production, self-regulated learning, transfer of learning, and equitable participation.

5.5.4 *Interdisciplinary Approaches to HOT*

Despite the broad thematic clusters, some links among sustainability, STEM/STEAM, teacher education, assessment, and technology remain relatively weak. Future research should bridge these domains by examining how interdisciplinary projects that combine STEM, arts, sustainability, ethics, and community problem-solving can foster creativity and HOT holistically. Comparative studies are needed to determine whether interdisciplinary learning genuinely supports higher-order cognition or simply combines subject areas without deeper cognitive integration.

5.5.5 *Equity and Inclusion in HOT Development*

Keywords such as “gender” and “students” are present, but their connections to HOT themes such as “critical thinking,” “creativity,” and “technology-enhanced learning” appear limited. Future studies should examine how diverse learners access and benefit from HOT-focused education. This direction is especially important because technology-rich and inquiry-based HOT pedagogies may reproduce inequalities when students have unequal access to digital tools, teacher support, language resources, or culturally responsive learning environments. Equity in HOT research should therefore include access to meaningful participation, culturally relevant problems, supportive feedback, valid assessment, and inclusive technology design.

5.5.6 *Assessing Long-Term Outcomes of HOT Interventions*

While the field strongly emphasizes project-based learning, flipped classroom, game-based learning, and digital learning, there are fewer visible connections to longitudinal outcomes such as career readiness, lifelong learning, and transfer. Future research should assess whether HOT-oriented instruction produces durable changes in reasoning, creativity, problem-solving, employability, civic decision-making, and lifelong learning habits. This is important because short-term gains in academic achievement do not necessarily demonstrate long-term HOT development or transfer to new contexts.

5.5.7 *Measuring and Enhancing Creativity in HOT Research*

Despite the centrality of creativity in the network, creativity is often measured inconsistently. Future studies should clarify whether creativity is assessed through originality, usefulness, divergent thinking, creative products, collaborative creativity, domain-specific performance, or transfer. More robust and domain-sensitive creativity assessments are needed across STEM, STEAM, humanities, arts, vocational education, and informal learning contexts. AI-supported assessment may offer new possibilities, but it must be validated carefully to avoid reducing creativity to superficial or easily quantified indicators.

5.5.8 *Teacher Professional Development for HOT*

Keywords such as “teacher education” and “pre-service teachers” are visible but less dominant than student-focused and technology-focused themes. Future research should investigate how professional development programs equip educators to design, implement, and assess creativity and HOT tasks. Teacher development should focus on open-ended task design, inquiry facilitation, scaffolding strategies, technology integration, formative feedback, assessment literacy, ethical AI use, and culturally responsive HOT pedagogy.

5.6 *Limitations and Future Research Directions*

This study has several limitations that should be considered when interpreting the findings. First, the dataset was limited to Scopus-indexed publications, which may exclude relevant studies indexed in Web of Science, ERIC,

Google Scholar, regional databases, or other discipline-specific repositories. Second, the search was limited to English-language documents, which may underrepresent research from non-English-speaking contexts. Third, the search strategy focused on specific combinations of creativity, HOT-related terms, STEM/science education, pedagogical approaches, assessment, and higher education. As a result, some relevant studies in non-STEM disciplines, informal learning, early childhood education, vocational education, and community-based learning may not have been captured. Fourth, bibliometric indicators can identify patterns of publication, citation, collaboration, and keyword use, but they cannot directly measure instructional quality, classroom effectiveness, student learning outcomes, or the long-term impact of HOT-oriented pedagogies.

A further limitation is that keyword co-occurrence reflects how authors and databases label publications, not necessarily the full conceptual content of each study. Citation indicators are also affected by publication age, journal visibility, disciplinary citation norms, self-citation, and database coverage. Therefore, the findings should be interpreted as a structured map of the analyzed dataset rather than as a definitive evaluation of the quality, effectiveness, or global influence of creativity and HOT research.

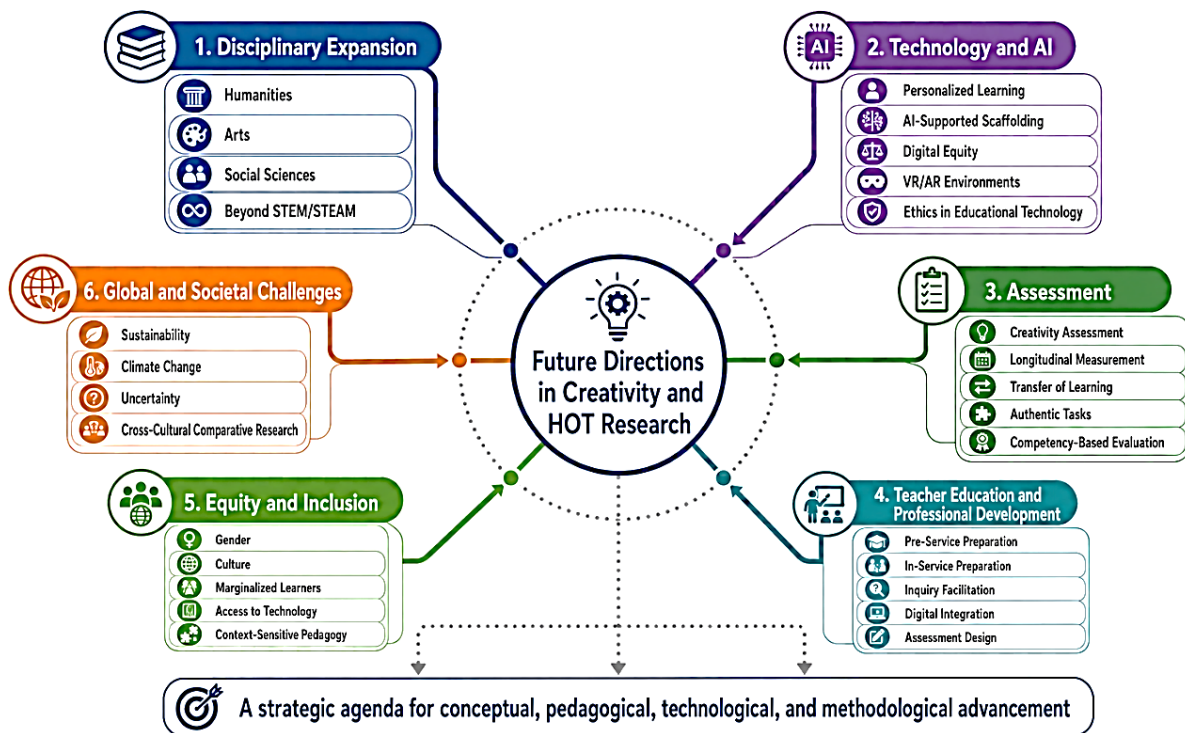


Figure 8. Author-developed future research agenda based on identified thematic gaps.

These limitations also point to important directions for future research. As summarized in **Figure 8**, future studies should expand the scope of creativity and HOT research across six major areas: disciplinary expansion, technology and AI, assessment, teacher education and professional development, equity and inclusion, and global and societal challenges. Future bibliometric studies could compare Scopus-based findings with data from Web of Science, ERIC, Google Scholar, and regional databases to provide a more comprehensive picture of the field. Researchers should also expand search terms and inclusion criteria to capture broader disciplinary and educational contexts, particularly the humanities, arts, social sciences, vocational education, informal learning, and early childhood education.

Future research should also examine how HOT research translates into classroom practice, teacher professional development, curriculum reform, and assessment design. **Figure 8** highlights the need to move beyond mapping publication trends toward developing a strategic research agenda that addresses AI-supported scaffolding, personalized learning, digital equity, creativity assessment, longitudinal measurement, authentic tasks, and competency-based evaluation. These areas are important because creativity and HOT are complex competencies that require valid assessment, sustained instructional support, and evidence of transfer across contexts.

Cross-cultural research is another important direction. Such studies can help explain why certain regions show strong publication output and how different education systems implement creativity and HOT frameworks. As indicated in **Figure 8**, future studies should also address equity and inclusion by examining gender, culture, marginalized learners, access to technology, and context-sensitive pedagogy. In addition, global and societal challenges such as sustainability, climate change, uncertainty, and cross-cultural comparative research should be integrated more explicitly into HOT research. Addressing these directions would strengthen the conceptual, pedagogical, technological, and methodological development of creativity and HOT studies.

Future studies should also triangulate bibliometric findings with qualitative and policy-oriented evidence. Interviews with researchers, teacher educators, curriculum developers, and policymakers could clarify how publication trends relate to curriculum reforms, assessment practices, teacher capacity, and classroom implementation. Longitudinal and mixed-method studies are also needed to determine whether HOT-oriented pedagogies produce durable learning outcomes, transfer, career readiness, and lifelong learning capacity.

6. Conclusion

This bibliometric analysis provides a structured map of the research landscape on creativity and higher-order thinking (HOT) from 2014 to 2024 within the analyzed Scopus-indexed STEM/science and higher education-related dataset. The findings highlight increasing scholarly attention to technology-enhanced, interdisciplinary, and student-centered learning models. The study shows that HOT research in this dataset expanded rapidly after 2020, became geographically more diverse, and was organized around themes such as critical thinking, STEM/STEAM education, digital learning, sustainability, teacher education, and assessment.

A key contribution of this study is its mapping of the intellectual structure of creativity and HOT research through publication trends, citation patterns, author productivity, geographical distribution, collaboration networks, and keyword co-occurrence. This approach clarifies not only which topics are visible in the field, but also how cognitive, pedagogical, technological, assessment-related, and policy-related themes are connected. By linking bibliometric indicators to a conceptual framework of creativity and HOT, the study shows that publication growth, citation influence, collaboration networks, and keyword clusters can be interpreted as evidence of how the field has developed as a knowledge domain.

The emergence of Southeast Asia, particularly Indonesia and Malaysia, as a highly visible contributor in publication output marks an important shift in the geographical distribution of HOT research within the analyzed dataset. However, this finding should be interpreted as a publication pattern within the analyzed Scopus dataset rather than as a complete measure of research leadership, educational quality, or classroom implementation. Future studies should combine bibliometric evidence with policy analysis, citation impact, collaboration quality, funding data, and classroom-level research to explain this regional pattern more fully.

The findings also indicate that creativity and HOT research is moving from a narrow focus on cognitive skills toward a broader educational agenda involving curriculum design, technology integration, teacher capacity, sustainability-oriented learning, and competency-based assessment. However, bibliometric analysis cannot determine the effectiveness of specific pedagogical interventions or measure students' actual HOT development. Therefore, the conclusions should be read as evidence of publication patterns, intellectual structures, and emerging thematic priorities, not as direct evidence of classroom impact.

Future research should focus on expanding interdisciplinary frameworks, leveraging AI for personalized and scaffolded learning, developing innovative assessment models, and examining the long-term effects of HOT-oriented instruction. By clarifying the development and emerging priorities of creativity and HOT research, this study can support researchers, curriculum developers, teacher educators, and policymakers in designing learning environments that cultivate critical, creative, collaborative, and adaptive learners. Future work should also extend beyond the STEM/science and higher education-related scope of this study to compare how creativity and HOT are represented across disciplines, educational levels, languages, regions, and databases.

7. Recommendation

Several promising avenues for future research emerge from this study. While HOT research has been extensively explored in STEM and STEAM disciplines, there is a need to examine its applications in non-STEM fields,

including the humanities, arts, social sciences, vocational education, informal learning, and early childhood education (Oyewo et al., 2022). Expanding research into these disciplines would provide a more holistic understanding of HOT across different academic domains. Future studies should investigate how argumentation, interpretation, ethical reasoning, cultural analysis, creative expression, professional practice, and community-based learning contribute to HOT development. Because the present search strategy emphasized STEM/science and higher education-related terms, this recommendation should be understood as a call for expanded bibliometric and empirical work rather than as definitive evidence that non-STEM HOT research is absent.

Another crucial direction is the investigation of AI-powered personalized learning environments. Future studies should explore how adaptive learning technologies can enhance creativity and HOT development through real-time feedback, personalized instruction, metacognitive prompts, and AI-driven scaffolding (Antonova et al., 2024). Such studies should also examine the risks and limitations of AI-supported learning, including learner dependency, algorithmic bias, privacy concerns, academic integrity, unequal access, and the changing role of teachers in guiding higher-order cognition. AI should be studied as part of a broader pedagogical system that includes teacher facilitation, inquiry-based tasks, assessment alignment, and ethical governance.

Additionally, more research is needed to examine the long-term impact of HOT development on career readiness, lifelong learning, civic participation, and professional adaptability. As industries increasingly prioritize critical thinking, creativity, collaboration, communication, and problem-solving skills, future studies should analyze how HOT competencies translate into workplace performance, innovation, responsible decision-making, and professional success. Longitudinal research is needed to determine whether HOT-oriented pedagogies produce durable learning outcomes beyond immediate academic achievement.

Cross-cultural research is another valuable area for exploration. Given the strong publication output from Southeast Asia in this study, comparative studies could provide insights into how different educational systems implement HOT frameworks and what best practices can be adapted globally (Huang et al., 2022). Such studies should compare curriculum policies, teacher education systems, assessment practices, classroom implementation, research funding, publication incentives, and collaboration patterns across countries. This would help distinguish between publication productivity, citation influence, policy commitment, institutional capacity, and actual classroom enactment of creativity and HOT.

Future research should also strengthen the connection between HOT pedagogy and assessment. More work is needed to design and validate instruments that can capture creativity, critical thinking, collaboration, communication, systems thinking, ethical reasoning, and problem-solving across disciplines and educational levels. Recommended assessment approaches include rubric-based instruments, authentic performance tasks, portfolios, multi-representation items, reflective products, problem-based assessments, and longitudinal measures of transfer. Addressing these areas will help ensure that creativity and HOT are not only promoted as educational ideals but also supported through measurable, equitable, and evidence-based learning practices.

Finally, future studies should use broader and more comparative bibliometric designs. Researchers should compare Scopus-based findings with Web of Science, ERIC, Google Scholar, and regional databases; include non-English publications where possible; and test alternative search strings that capture related constructs such as creative problem-solving, systems thinking, computational thinking, design thinking, metacognition, and competency-based learning. Such work would provide a more inclusive and nuanced understanding of how creativity and HOT research develops across global educational contexts.

Author contribution

Sergii Sharov: conceptualization, methodology, software, investigation, data curation, formal analysis, visualization, and writing the original draft. **Saiful Prayogi:** methodology, validation, formal analysis, supervision, visualization, and writing review and editing. **Celci Werner de Rosa:** validation, investigation, data interpretation, supervision, and writing review and editing.

Conflict of Interest

There are no competing interests.

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Ethical statement

All included studies were derived from publicly available, peer-reviewed publications, and no primary data collection involving human participants was undertaken. Thus, no ethical approval or informed consent was required for this research.

Data availability

Not applicable.

Utilization of AI statement

During the preparation of this work, the authors used ChatGPT to enhance the clarity of the writing. After using the ChatGPT, the authors reviewed and edited the content as needed and take full responsibility for the publication's content.

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