



Bibliometric review and analysis: scientific creativity in science education

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ABSTRACT

Scientific creativity is one of the higher-order thinking skills that is useful to everyone. Scientific creativity encourages individuals to not only generate creative ideas but also to promote ideas about appropriate technology. This article explains in detail the bibliometric analysis of scientific literature in the field of education from 2017 to 2022. The five-step method was used to conduct the literature review in this study. According to the bibliometric analysis, (1) research on scientific creativity with a high number of citations investigates the relationship between scientific creativity and the ability to think divergently and convergently; (2) There are seven clusters of distribution of scientific creativity research keywords where the variables creativity, assessment, divergent thinking, science, research, cognitive control, stroop assignment, science education, and STEM education seem to be related to scientific creativity; (3) Cognitive control, stroop assignments, research, STEM education, science education, and evaluation are some of the terms that are being used more and more frequently in articles about scientific creativity; and (4) STEM education is a significant phrase in studies that focus on scientific creativity.

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INTRODUCTION

Science defines scientific creativity as a creative thinking ability. Scientific creativity is defined by scientists as the ability to generate new ideas and products within a scientific framework. The capacity to discover and solve problems based on scientific knowledge and skills is also related to creativity. (Sidek et al., 2022). According to Hu and Adey, scientific creativity differs from other types of reactivity because it is associated with creative scientific experiments. The ability or potential to produce a specific product that is original, has social or personal value, and is designed with a specific purpose in mind using received information is referred to as scientific creativity. Unusual use, problem solving, product improvement, creative imagination, problem solving, science experiments, and product design are all examples of scientific creativity (Hu & Adey, 2002).

Scientific creativity differs from artistic and linguistic creativity in that it focuses on scientific creative experiments, discoveries, and problem solving using creative science. Scientific creativity is a type of ability that includes cognitive components. Scientific process knowledge and skills are required for scientific creativity. Creativity and analytical intelligence are two distinct but interconnected mental factors. According to this hypothesis, scientific creativity is problem sensitivity, the ability to generate new ideas that are technologically acceptable, the ability to ask questions, understand the world around you, the ability to solve problems, see solutions, design experiments, imagine, identify difficulties, and make hypotheses (Suyidno, 2015).

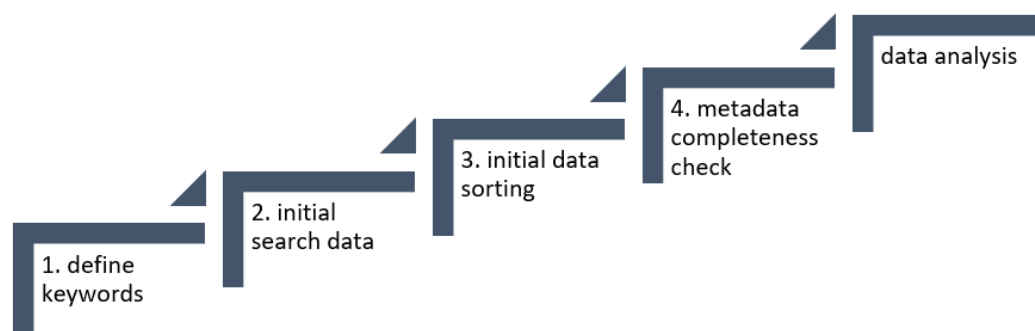
Numerous research on creativity have been conducted. According to Yang et al.'s study, someone who is creative in the arts may not be creative in the sciences. (Yang et al., 2019a). Individuals with creativity can combine current ideas or products to develop new ideas or products. (Komarudin, 2018). Scientific creativity is a topic that is still being researched. The advancement of study on scientific creativity continues to expand and evolve into a learning model, which is referred to in inquiry as a learning model for the creative process of inquiry. (Wahyudi et al., 2019).

It is necessary to conduct an analysis to determine how far research related to scientific creativity has been pursued while keeping track of the ongoing development of this field of study. This analysis seeks to identify research trends related to scientific creativity and to provide an overview of research opportunities in the field of scientific creativity. Publish or Perish (PoP) software, Mendeley Desktop, and VOSviewer were used to conduct the analysis, which was aided by bibliometric analysis.

A literature review was carried out by searching the Crossref database with the Publish or Perish (PoP) software. Mendeley Desktop software is used to add metadata to the literature obtained through PoP, and VOSviewer software is used to visualize distribution patterns. The investigation was carried on by discussing the findings and drawing conclusions based on the bibliometric literature analysis. A bibliometric analysis was performed to identify published articles on the topic of scientific creativity from 2017 to 2022. The points that will be explored in this research have been determined to better direct the analysis process, that is: 1) identify the most widely cited articles related to scientific creativity; 2) keywords in scientific creativity research; 3) keywords in the most recent scientific creativity research; and 4) research keywords most commonly used in scientific creativity research.

RESEARCH METHODOLOGY

This research is a library study with a systematic and explicit method. This study followed a five-step approach (Indarti et al., 2018) shown in Figure 1.



gambar 1. Research Methodology

Define keywords

The Publish or Perish software was used to conduct a literature search. PoP was chosen as the most effective software for assisting with article metadata tracking (Baneyx, 2008). The keyword used is "scientific creativity".

Initial search data

The Crossref database was searched for articles between 2017 and 2022. 600 documents were acquired through this technique. The search results are then saved in the Research Information Systems (RIS) format.

Initial data sorting

Following the initial phase, the 600 documents were classified according to the publication type. The focus of this study is on the types of journal articles and proceedings publications. From the sorting results based on the type of publication, 288 articles were obtained. Additionally, the categorization is done once more by considering the word "scientific creativity" as a single phrase rather than as separate words. 83 articles were produced as a result of this procedure. In addition, the search results are saved in RIS format.

Metadata completeness check

Using the Mendeley Desktop software, the completeness from the 83 articles that have been gathered was examined. Corrections are done if it's discovered that an article has inaccurate or incomplete metadata. The overall number of articles increased to 66 as a result of the discovery of some pieces that could not be finished throughout this process.

Data analysis

The RIS-formatted data generated by Mendeley Desktop's metadata editing process was further evaluated with VOSviewer software. VOSviewer can effectively analyze data and generate analytical output in the form of detailed information and very appealing graphics (van Eck & Waltman, 2010). The analysis setting in VOSviewer, for a minimum number of repetitions of a phrase is 2 such that a threshold of 18 is obtained.

Three different ways, including network visualization, overlay visualization, and density visualization, are available for VOSviewer to display bibliometric analysis mapping (Hamidah et al., 2020). The network visualization reveals keywords related with scientific creativity research, the overlay visualization provides keywords used in recent scientific creativity research, and the density visualization displays the terms most commonly used in scientific creativity research.

RESULTS AND DISCUSSIONS

As stated in the introduction, the literature review was conducted using bibliometric analysis with the assistance of PoP, Mendeley desktop, and VOSviewer software. The analysis included knowing the most cited articles related to scientific creativity, keywords in scientific creativity research, keywords in the most recent scientific creativity research, and researching keywords that are most frequently used in scientific creativity research.

Most cited articles

VOSviewer was used to analyze a total of 66 articles. Then, the citation counts in each of the 66 articles were examined. Table 1 shows the top ten articles with the most citations based on the results of this analysis.

Tabel 1. Top 10 most cited articles

No.	Author	Article title	Number of citations
1	(P. S. Huang et al., 2017)	The relative influences of domain knowledge and domain-general divergent thinking on scientific creativity and mathematical creativity	42
2	(Shi et al., 2017)	Different brain structures associated with artistic and scientific creativity: a voxel-based morphometry study	24
3	(Sun et al., 2020)	Effects of divergent thinking training on students' scientific creativity: The impact of individual creative potential and domain knowledge	17
4	(Zhu et al., 2019)	Convergent Thinking Moderates the Relationship between Divergent Thinking and Scientific Creativity	17
5	(Lehmann & Gaskins, 2019)	Learning scientific creativity from the arts	14
6	(Smyrnaïou et al., 2020)	Promoting a mixed-design model of scientific creativity through digital storytelling – the CCQ model for creativity	11
7	(Sternberg et al., 2020)	The Relation of Scientific Creativity and Evaluation of Scientific Impact to Scientific Reasoning and General Intelligence	9
8	(Yang et al., 2019b)	Exploring the significant predictors of convergent and divergent scientific creativities	9
9	(C.-F. Huang & Wang, 2019)	Comparative Analysis of Different Creativity Tests for the Prediction of Students' Scientific Creativity	8
10	(Astutik & Prahani, 2018)	Developing Teaching Material for Physics Based on Collaborative Creativity Learning (CCL) Model to Improve Scientific Creativity of Junior High School Students	7

According to Table 1, research on scientific creativity with a high number of citations investigates the relationship between scientific creativity and the ability to think divergently and convergently. Hu et al.'s aims at identifying how domain-general divergent thinking abilities, subject-specific scientific creativity, and mathematical creativity are related. Additionally, this study aims to look into how domain knowledge and divergent thinking abilities affect scientific and mathematical creativity. The Scientific Creativity Test (SCT), Mathematical Creativity Test (MCT), and Novel Creativity Test (NCT), which measures domain-general divergent thinking skills, were used in the research to gauge participants' creativity in certain fields. The study's findings revealed that SCT linked with MCT and MCT correlated with NCT (P. S. Huang et al., 2017).

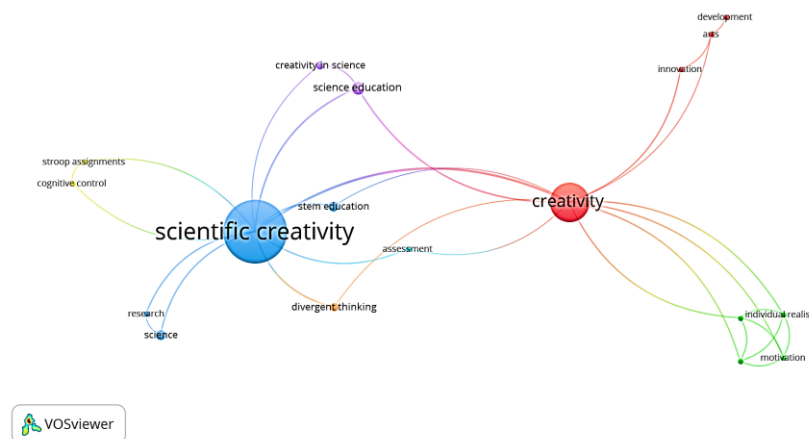
According to Zhu's research, convergent thinking interacts with the fluency and flexibility of divergent thinking in scientific creativity. Between convergent and divergent thinking, divergent thinking specifically predicts creativity in teenage scientific creativity in individuals with high convergent thinking (Zhu et al., 2019). Meanwhile, Sun conducted research on the impact of a divergent thinking training program that helps high school students master a series of divergent thinking strategies and apply them in tasks connected to scientific creativity. The findings indicated that following instruction, the students' scientific creative performance improved. (Sun et al., 2020).

Many studies have been conducted to investigate brain activity in relation to scientific creativity. Shi et al., a study that carefully examines variations in brain regions accountable for creative and scientific creativity in large samples. This study, which examined 356 healthy young adults, used voxel-based morphometry (VBM) to identify localized variations in whole-brain gray matter volume (GMV) between artistic and scientific creativity (as measured by the Creative Achievement Questionnaire). Research has shown that the regional GMV Supplementary Motor Area (SMA) and Anterior Cingulate Cortex (ACC) are strongly inversely connected to artistic creativity. Scientific creativity, on the other hand, was significantly positively linked with regional GMV in the left middle frontal gyrus (MFG) and left inferior occipital gyrus (IOG). The salience network (SN) is generally associated with artistic creativity, whereas executive attention networks and semantic processing are associated with scientific creativity (Shi et al., 2017).

By analyzing patterns of brain activation during the mental evolution of scientific creation, Ghosh et al. conducted study into the biological basis of scientific creativity. According to this study, the prefrontal, parietal, and occipital lobes are in charge of creative thinking and scientific planning, whereas the frontal and prefrontal lobes are in charge of inductive learning (Ghosh et al., 2019). The multifaceted relationship between visual ability, visual cognitive style, and creativity was examined by Kozhevnikov et al (artistic and scientific). The results indicate that cognitive style and the appropriate type of visual ability both start to develop at the same time as domain-specific visual creativity, and that socio-cultural influences, as reflected by cognitive style, also have an impact on the growth of creative performance in particular domains, beyond abilities (Kozhevnikov et al., 2022).

keywords in scientific creativity research

The network visualization obtained through VOSviewer is presented in Figure 2.



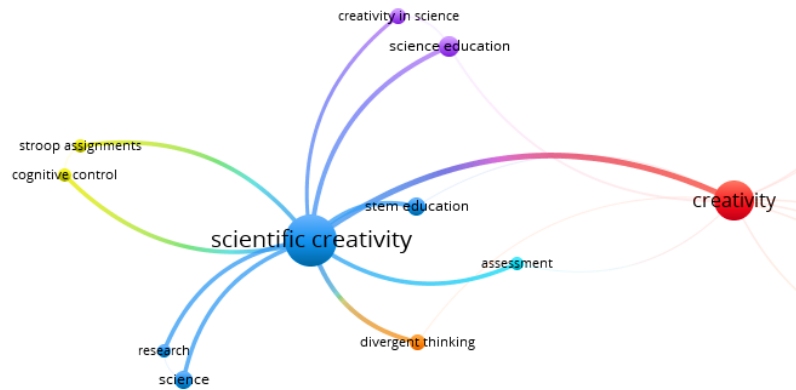
Gambar 2. Network visualization

Based on Figure 2, it is identified that there are seven research clusters. Each cluster displays the research keywords that were used. The seven clusters can be observed in Table 2.

Tabel 2. Distribution of clusters and keywords

No.	Cluster	Number of keywords	Research keywords
1	Red (1st)	4	Arts (2), creativity (21), development (2), innovation (2).
2	Green (2nd)	4	Individual realism (2), motivation (2), pessimistic induction (2), selective realism (2).
3	Blue (3rd)	4	Research (2), science (4), science creativity (38), STEM education (4).
4	Yellow (4th)	2	Cognitive control (2), stroop assignment (2)
5	Purple (5th)	2	Creativity in science (3), science education (5)
6	Light blue (6th)	1	Assessment (2)
7	Orange (7th)	1	Divergent thinking (3)

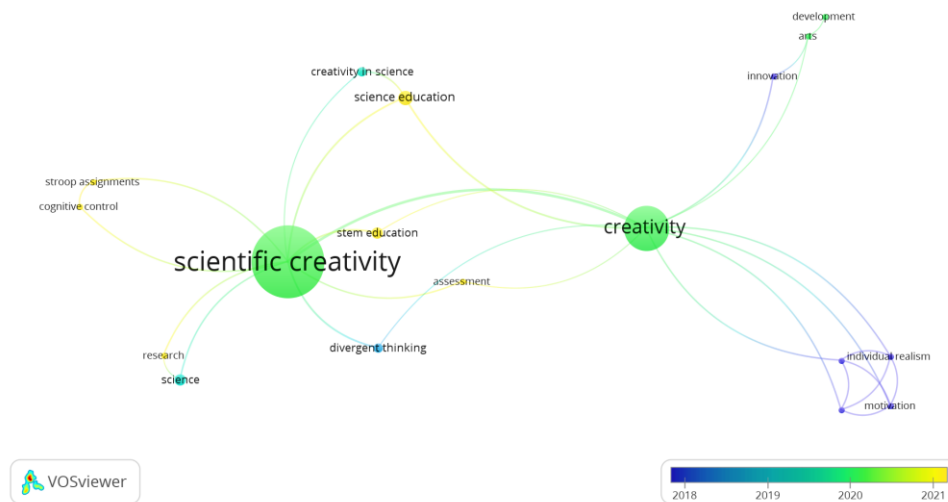
A representation of the scientific creativity network is shown in Figure 3. The variables creativity, assessment, divergent thinking, science, research, cognitive control, stroop assignment, scientific creativity, science education, and STEM education seem to be connected to scientific creativity.



Gambar 3. Scientific creativity network

keywords in the most recent scientific creativity research

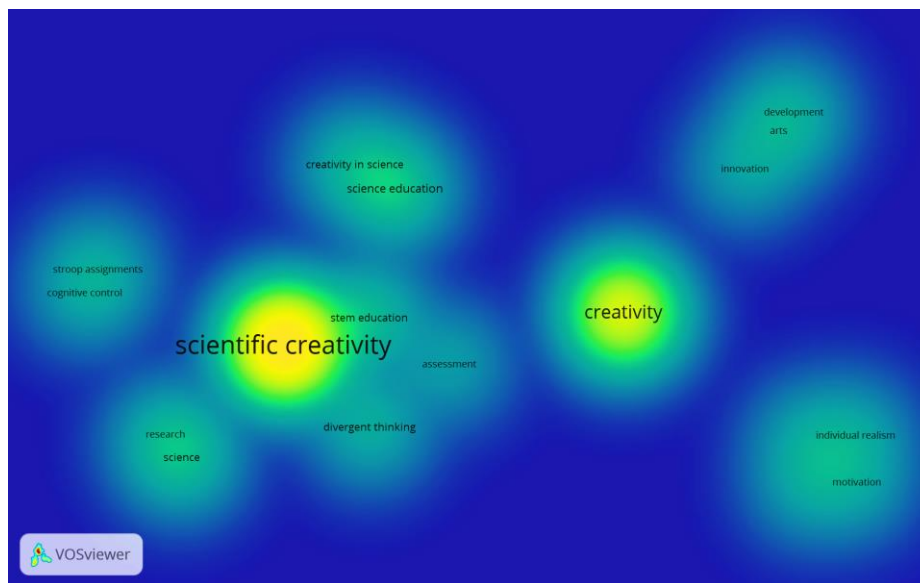
The overlay visualization is presented in Figure 4. The overlay visualization shows the publication period. Keyword publication update rates are highlighted in green and yellow. If it is close to yellow, it indicates that the publication is getting newer, and if it is close to blue, it indicates that the publication is getting older. The keywords that are being published more and more recently in relation to scientific creativity are cognitive control, stroop assignment, research, STEM education, science education, and assessment.



Gambar 4. overlay visualization

research keywords that are most frequently used in scientific creativity

Figure 5 shows the density visualization. The density visualization describes research keywords that are closely related and commonly used. STEM education, according to Figure 5, is a keyword or research that is closely related to scientific creativity research.



Gambar 5. Density visualization

According to Hebebcı and Usta's research, STEM integration has a positive effect not only on scientific creativity, but also on problem solving skills and students' critical thinking dispositions (Hebebcı & Usta, 2022). Uğraş used a mixed method research to examine the impact of STEM activities on seventh-grade students' STEM attitudes, scientific creativity, and motivational beliefs, as well as students' perceptions on STEM education. This study discovered that before and after STEM activities are introduced, there are differences in STEM attitudes, scientific creativity, and student motivation. Pupils reported that STEM education boosted their creativity and motivation (Uğraş, 2018). Rasul et al. used STEM activities to perform research on junior high school students. Elements of scientific creativity are divided into three aspects: scientific processes, inquiry skills, and creative thinking. According to this study's findings, students receiving assistance show substantial differences from students not receiving intervention, as well as a beneficial impact on aspects of the scientific method, inquiry abilities, and creative thinking (Rasul et al., 2018).

Eroğlu and Bektaş conducted research to determine the impact of 5E-based STEM learning methodologies on academic achievement, scientific creativity, and perspectives on the nature of science in the context of the atomic system and periodic table in grade 9 students. This study came to the conclusion that 5E-based STEM learning can enhance students' academic performance, creativity, and perspectives on the nature of science (Eroğlu & Bektaş, 2022). Jongluecha and Worapun used 6E-based STEAM, with the study concluding that the 6E learning approach was effective in transmitting science knowledge to grade 3 students. It also helped individuals improve their critical thinking and creative ability. As it offers proof of its impact on younger participants of learners, this study makes a contribution to the field of STEAM education (Jongluecha & Worapun, 2022). Gök and Sürmeli integrated engineering design process-based activities for designing scientific toys into integrated STEM learning. According to the study's findings, high school students' scientific creativity grew as a result of activities based on the engineering design process that involved creating scientific toys (Gök & Sürmeli, 2022).

The scientific creativity of second, third, and fourth graders enrolled in a STEM course was assessed by Genek and Küçük over the course of one academic year. The instruments for this study were the Student Demographic Questionnaire and the Scientific Creativity Exam. The results suggest that students' levels of scientific creativity varied statistically significantly depending on

their grade level. Other factors (gender, number of siblings, parent's occupation, favorite topic, most successful subject, future job) did not show any discernible variations (Genek & Küçük, 2020).

In addition to STEM, Astutik and Prahani use PheT simulations to implement the Collaborative Creativity Learning (CCL) paradigm to boost students' scientific creativity. According to the findings of this study, integrating the CCL model with PhET simulations can help students learn science more creatively (Astutik & Prahani, 2018). In addition to assessment tools, Astutik and Prahani created teaching materials based on collaborative creativity learning, with the goal of increasing students' scientific creativity (Astutik & Prahani, 2018). Online Scientific Creativity Learning (OSCL), created by Prahani et al., aims to improve students' scientific creativity. The Scientific Creativity Test Instrument (SCTI) was used in this study to assess students' scientific creativity. The study concluded that OSCL can be used as a learning innovation in science education to boost students' scientific creativity (Prahani et al., 2021).

Demirhan and Ahin examined the efficacy of hands-on modeling and conventional teaching techniques in improving the academic accomplishment, problem-solving abilities, and scientific creativity of science teacher candidates. The study's findings demonstrate that modeling exercises can raise academic achievement. Moreover, modeling exercises that are semi-structured and unstructured are more successful at raising academic accomplishment than modeling exercises that are regimented (Demirhan & Şahin, 2021). Through digital storytelling exercises, Chen, Liu, and Cheng explore scientific creativity. Giving students homework can improve their scientific creativity, according to research. (Chen et al., 2022).

Research on assessment of scientific originality was done by Ramly et al. Based on SCSM, Torrance's test of creative thinking, and literary-based elements of scientific creativity, Ramly et al. developed a test of scientific creativity in chemistry (Ramly et al., 2022). Aschauer et al. created a science test that assesses several problem-solving skills as an instrument for gauging scientific creativity (Aschauer et al., 2022). Meanwhile, Huang and Wang modified the Science Performance Test (SPT) and the Domain-General Creativity Test (DGCT) to create a test of scientific creativity. The results showed that, compared to the SPT, the DGCT gave a more accurate image of students' scientific originality (C.-F. Huang & Wang, 2019). In order to better understand how high school students interact with technologically supported scientific creativity tasks, Sun et al. conducted an exploratory study. They focused on how they come up with ideas in small groups by utilizing pertinent thinking techniques, interacting with others, and using computer-based building. using mind maps to encourage group discussion. Building mind maps helped students remember ideas for elaboration and evaluation, sparked new discussion threads, and controlled task progress, according to an analysis of group conversation epistemic networks. The high-performing group engaged in more divergent thinking, mind mapping, and regulative discussion than the low-performing group while also making these activities more directly tied to idea generating (Sun et al., 2022).

Many studies link cognitive control to scientific innovation. According to Zhang et al., junior high school students' cognitive control abilities were compared to both their artistic and scientific creativity. The findings indicated that there was no statistically significant difference between students who were more creative in science and those who were more creative in art (Zhang et al., 2020).

Several research exist that go beyond what has already been said in regards to scientific innovation. Three basic criteria—*intra-scientific* (logical and empirical); *extra-scientific* (socio-cultural); and *personal*—are used by Gubanov to define scientific creativity (mental) (Gubanov et al., 2019). Dikici uses structural equation modeling to investigate the connection between students' knowledge of the scientific method and their scientific creativity. The findings demonstrated that scientific process abilities influenced the association between gender and scientific creativity, as well as the associations between age and scientific creativity and grade level and scientific creativity (Dikici et al., 2020). Kapri investigates the connection between scientific creativity and

scientific temperament. The findings revealed a significant correlation between students' scientific creativity and scientific temperament (Kapri., 2017). The behavioral traits of scientific creativity were examined with regard to parents' and teachers' perceptions, and student perceptions were contrasted with those of parents and teachers. The comparison's findings indicate that parents are more focused on issues relating to learning, teachers are more focused on issues relating to thinking, and students are more focused on activities like creating and experimenting. This research identified the behavioral traits that ought to be promoted in order to foster adolescents' scientific creativity at home and at school (Lee & Park, 2021).

By evaluating scientific theories, which are essentially the creative works of the great historical scientists Galileo, Newton, and Einstein, Jun Oh examines scientific creativity by focusing on intellectual abilities (thinking) in the cognitive element. Great scientists' investigations on creativity in the cognitive realm also relate to affective traits (motivations, task commitment, etc.) and their environmental influences (incubation period) (Oh, 2021).

CONCLUSION

This literature review analyzes 66 papers in total. According to the findings of the analysis, scientific creativity research involving a wide number of sites is related to the capacity for divergent and convergent thought. The keywords assessment, divergent thinking, science, research, cognitive control, stroop assignment, creativity in science, science education, and STEM education are related to scientific creativity research, according to the results of the VOSviewer visualization analysis, whereas the keywords cognitive control, stroop assignment, research, STEM education, science education, and assessment are related to recent research. STEM education is the most closely blamed and frequently used keyword.

According to the study's findings, it is possible to conclude that there are areas of research that can be pursued in relation to scientific creativity, one of which is through utilizing a range of approaches, methodologies, and/or learning models. There is also a possibility to do research on scientific creativity assessment measures.

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