Scientific creativity: a literature review

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Abstract. Much research has been done on creativity and the results can be easily found in journals, however, research on scientific creativity as a domain-specific creativity is still relatively rare. Therefore, it is necessary to study the literature to reveal the scope of research on the topic of scientific creativity. To achieve this aim, a literature review was carried out with the procedure adopted from the PRISMA statement. A total of 49 articles obtained from the IJSE, DOAJ, ERIC, IOP Science, ScienceDirect, and Springer Link websites, in the 2001-2019 period, were analyzed. The results showed that the three journals that published the most scientific creativity articles were JEP, IJSE, and CRJ. And, the three countries with the most contributing authors were Turkey, Indonesia, and Taiwan. Except for one critical review article, the research types of all articles analyzed were an empirical study, which consisted of at least five sub-topics of scientific creativity.

1. Introduction

Much research has been done on creativity or creative thinking skills, and the results have been published in research journals such as the International Journal of Science Education (IJSE), Science Education (SE), and the Journal of Research in Science Teaching (JRST). In addition, research on creativity can also be searched through freely accessible web search engines that index full-text research articles, such as the Education Resource Information Center (ERIC), Open Access Journal Directories (DOAJ), and Scopus, by writing keyword ‘creativity’ in the search box.

If searching for the word creativity through an indexing website is done, so many research articles of creativity will be found. For example, through DOAJ (https://doaj.org/) more than 8,000 articles related to creativity can be found, more than 2,000 articles that have the keyword ‘creativity’, and more than 1,500 article titles that explicitly contain the word creativity. In comparison, through ERIC (https://eric.ed.gov/), more than 18,000 articles relating to creativity can be obtained. The articles were published in various journals. This shows that creativity has been applied in various fields, including in science education.

According to Matlin [1], creativity is one aspect of problem-solving, while problem-solving is a mental process, which is one of the studies in cognitive psychology. Likewise, with problem-solving, creativity is also a study of cognitive psychology that has been widely applied in various fields.

On the other hand, the research result showed that the correlation coefficient of creativity between various fields of science was only 0.37 [2]. This means that the creativity of a group of respondents in one field with another field is low correlated. Or in other words, one's creativity depends on the field. Someone who has high creativity in sports may not have high creativity in science.

Sternberg's research results support a general consensus that knowledge and specific domain skills or disciplines are a significant component of creativity. Thus, although in general, creativity has been...
widely applied in various fields, but the consensus that creativity is based on disciplines is acceptable. Starting from this thought, many experts conduct particular research on creativity in the field of science or what is often referred to as scientific creativity.

Because the study of scientific creativity is still relatively new, detailed information about this is still relatively rare. So far, a systematic review of scientific creativity is not yet available. Therefore, it is necessary to study the literature with the main aim to reveal the scope of research on the topic of scientific creativity from 2001 to 2019. This study addresses the following research questions: (1) how the publication of the scientific creativity articles distributed in the journals; (2) how authors from different countries contributed to the publications of scientific creativity; (3) how the research types of scientific creativity varied; and (4) how the research sub-topics of scientific creativity varied in the period of 2001 to 2019.

2. Methods
Based on the research questions, this study reviewed the scope of scientific creativity research systematically. The systematic review was conducted using a modified procedure that adopted from the Preferred Items for Systematic Reviews and Meta-Analysis (PRISMA) Statement [3]. This procedure consists of four main steps, namely: identification, screening, eligibility, and included. The flowchart of the research procedure in this study is shown in Figure 1.

![Figure 1. The research procedure](image)

In the identification step, searching for articles was done by writing the keywords of ‘scientific creativity’ in the search box’s website of the IJSE, JRST, SE, DOAJ, ERIC, IOP Science, ScienceDirect, and Springer Link. Searching was made for publication in the period of 2001 to 2019.

In the screening and eligibility steps, all articles that have been identified based on title, abstract, keywords, and topic relevance were downloaded. The full-text articles were scanned for checking the suitability of the topic for research purposes. The articles of the types of ‘editorial,’ ‘commentary,’ ‘responses’, ‘book chapters’, and ‘book reviews’ were excluded from being analyzed. In addition, articles with full-text written in ‘non-English languages’ were also excluded.
The next step, the included step, all eligible articles were studied and analyzed in order to get a synthesis or conclusion. The analysis was carried out, including distribution of publications, author's nationality, research type, and research sub-topic.

The publication's distribution of scientific creativity was obtained by identifying and classifying the journal names of each article. All eligible articles were downloaded, and the journal names were recorded. Journal classification was done to determine the top five journals that contributed to the publication of articles.

The authors' nationalities were analyzed and scored quantitatively to show the country ranks of publications. The author nationality contribution score was calculated using the following formula [4]:

\[ Score = \frac{(1.5^{n-i})}{\sum_{i=1}^{n} 1.5^{n-i}} \]

where \( n \) is the total number of authors, and \( i \) is the order of the specific author. The allocation of scores obtained from this formula for articles with 1 to 7 authors is presented in Table 1.

### Table 1. Score allocation for multi-author research articles

| Number of Authors | Order of specific author | 1  | 2  | 3  | 4  | 5  | 6  | 7  |
|-------------------|-------------------------|----|----|----|----|----|----|----|
| 1                 | 1                       |    |    |    |    |    |    |    |
| 2                 | 0.60                    | 0.40|    |    |    |    |    |    |
| 3                 | 0.47                    | 0.32| 0.21|    |    |    |    |    |
| 4                 | 0.42                    | 0.28| 0.18| 0.12|    |    |    |    |
| 5                 | 0.38                    | 0.26| 0.17| 0.11| 0.08|    |    |    |
| 6                 | 0.37                    | 0.24| 0.16| 0.11| 0.07| 0.05|    |    |
| 7                 | 0.35                    | 0.24| 0.16| 0.10| 0.07| 0.05| 0.03|

Research types were obtained by analyzing and classifying each article. Articles are classified into five categories, namely (1) empirical research article, (2) position article, (3) theoretical article, (4) review; and (5) other [4]. Meanwhile, to determine the research sub-topic, each published article was categorized into one of the following five categories: (1) test development, (2) teacher perception, (3) scientific creativity level, (4) variables relationship, and (5) teaching strategy.

### 3. Results and Discussion

Search for articles was done through the IJSE, JRST, SE, DOAJ, ERIC, IOP Science, Science Direct, and Springer Link website, for publications in the period 2001 to 2019, by writing the exact phrase 'scientific creativity' listed in the title, abstract, or author-specified keywords of articles. Furthermore, identification was refined by adding restrictions in the field of science education. A total of 2,566 articles were collected. Based on the results of screening for the suitability of the type and sub-topic of the articles for the purpose of this study, there were 42 out of 2,566 articles eligible for further analysis. The distribution of articles based on the search sources is shown in Table 2.

There was one full-text non-English article, besides that, the two articles obtained from DOAJ were the same as those obtained from ERIC [5, 6], so that all three articles were excluded or not analyzed further. Finally, there were 49 full-text articles included in the category of articles that met the requirements for analysis.

A total of 49 articles were published in 20 international journals. Journal of Education and Practice (JEP), International Journal of Science Education (IJSE), Creativity Research Journal (CRJ), Journal of Physics: Conference Series (JPCS), and Procedia - Social and Behavioral Sciences (PSBS) were the top five journals that published articles on scientific creativity. JEP (www.iiste.org) published 6 articles;
IJSE (Taylor & France), CRJ (Taylor & Francis), JPCS (IOP Science), each published 5 articles; and PSBS (Springer) published 4 articles.

Table 2. The results of the identification and screening of the article

| Step             | Number of articles (N) | Total |
|------------------|------------------------|-------|
|                  | IJSE | JRST | SE | DOAJ | ERIC | IOP Science | Science- Direct | Springer Link |       |
| Identification   | 722  | 291  | 281| 9    | 585  | 148         | 204             | 326          | 2,566 |
| Screening        | 5    | 0    | 0  | 4    | 26   | 6           | 7               | 4            | 52    |
| Eligibility (included) | 5    | 0    | 0  | 1    | 26   | 6           | 7               | 4            | 49    |

So far, IJSE is one of the reputable journals in the field of science education that many researchers refer to, and CRJ is also a reputable journal that publishes many studies on creativity. In the 2001-2019 period, IJSE and CRJ were among the journals which published many articles on scientific creativity. This means that scientific creativity is an interesting topic to be studied, both in terms of the aspects of science education and the study of creativity.

In the period 2001 to 2019, the first research on scientific creativity at IJSE was the collaborative work of Hu from China and Adey from the UK [2], which was published in 2002. A little later, in 2014, 2015, and 2016, it was followed by publication of authors from Taiwan [7, 8], USA [9], and Korea [10]. The other articles on scientific creativity were the most published in journals indexed by ERIC, followed by ScienceDirect, IOP Science, and Springer Link (Table 2).

Table 2 shows that many articles in science education that use the term scientific creativity, however, articles about scientific creativity that are defined as domain-specific creativity in science education, have not been widely published. In reputable international journals in the field of science education, which is often used as a reference for researchers, only the IJSE had published five articles, while in JRST and SE, they had not been found. One possible reason is that this topic was still relatively new, so not much research had been done.

Based on the analysis of the author's nationality, there were 18 countries whose authors contributed to the topic of scientific creativity. The ranking and percentage of these contribution scores are shown in Table 3. Turkey, Indonesia, Taiwan, China, and Kenya were the top 5 countries that were ranked first to fifth, respectively. Based on this data, authors from Europe and America have not contributed much.

Turkey was the country whose authors published the most articles of scientific creativity in the 2001-2019 period. Around 32% of authors from Turkey published their articles in JEP, 19% of authors in PSBS, and the rest were distributed in some journals. While the authors from Indonesia, the majority (75%) published their articles through the conference series, namely the JPCS and the IOP Conference Series [11]. Unlike authors from Turkey and Indonesia, authors from Taiwan, China, Kenya, and other countries were spread evenly in several journals, such as the IJSE [7, 9, 10], CRJ [12, 13], and Thinking Skills and Creativity [14].

Between 2001 and 2019, there were only 6 of 49 articles collaborated by authors from two countries. Each of the six articles was the result of the collaboration of authors from China, and the UK published at IJSE [2], Lebanon and Spain published at CRJ [15], Italy and the USA published at CRJ [16], Turkey and Canada published in Research in Science Education [17], China and the UK published in Research in Science Education [18], and Taiwan and Australia were published in Thinking Skills and Creativity [19].

Based on the analysis of the type of research, almost all articles were the results of empirical research, except for one article to the kind of critical review [15]. This type of empirical research consisted of 25% of the development of instruments or tests, 44% of surveys or explorations, and 31% of
experiments. The research type of the scientific creativity test development was still relatively high (25%). This data showed that the available instruments were not yet well established; as an indication that scientific creativity was a relatively new and exciting topic for further study.

Table 3. Country ranks and percentages of authors

| Rank | Country   | Score | Percentage (%) |
|------|-----------|-------|----------------|
| 1    | Turkey    | 15.79 | 32.22          |
| 2    | Indonesia | 8.00  | 16.33          |
| 3    | Taiwan    | 5.88  | 12.00          |
| 4    | China     | 4.42  | 9.02           |
| 5    | Kenya     | 3.00  | 6.12           |
| 6    | USA       | 2.53  | 5.16           |
| 7    | Spain     | 1.53  | 3.12           |
| 8    | Estonia   | 1.00  | 2.04           |
| 9    | France    | 1.00  | 2.04           |
| 10   | Germany   | 1.00  | 2.04           |
| 11   | India     | 1.00  | 2.04           |
| 12   | Korea     | 1.00  | 2.04           |
| 13   | Slovenia  | 1.00  | 2.04           |
| 14   | UK        | 0.58  | 1.18           |
| 15   | Italy     | 0.47  | 0.96           |
| 16   | Lebanon   | 0.47  | 0.96           |
| 17   | Canada    | 0.21  | 0.43           |
| 18   | Australia | 0.12  | 0.24           |

The main topic of the research results analyzed was scientific creativity. Based on the analysis results, this main topic had at least sub-topics: test development, teacher perception, scientific creativity level, relationships between variables, and teaching strategy.

In 2002, Hu and Adey published the results of their research on tests to measure scientific creativity called The Three-Dimensional Scientific Structure Creativity Model (SSCM) [2]. SSCM covers seven essay questions, each question consists of three dimensions, namely the process, trait, and product dimensions. The process dimensions include imagination and thinking; trait dimensions include fluency, flexibility, and originality; product dimensions that include technical products, science knowledge, science phenomenon, and science problems. SSCM or often called the Hu & Adey test has been followed up and applied by several other researchers, including Samsudin et al. [11], who developed the Hu & Adey scientific creativity test for seventh-grade students on earth science context.

Some researchers tried to combine the Hu & Adey test with the critical thinking test. Rusnayati et al. [20] developed Scientific Creative and Critical Thinking (SCCT), which uses the Hu & Adey test and Assessment of Critical Thinking Ability developed by Brian et al. [21]. Other researchers, Yang et al. developed predictors of divergent and convergent scientific creativity [19], and validated an instrument of that based on the Hu & Adey test and the Sternberg & Lubart test [13]. Whereas, Huang et al. [22] combined the Hu & Adey test and the Creative Scientific Ability Test (C-SAT), which was developed previously by Ayas and Sak [23].
Other instruments, EPoC Science, to measure the potential for scientific creativity that was developed by Devries and Lubart [24]. Meanwhile, KAÇAN [25] developed the Self-assessment of Creativity Scale for measuring creative thinking and creative scientific thinking skills. Other researchers, Mun et al. [10] developed the Scientific Imagination Inventory used to measure scientific imagination, which were composed of (1) scientific sensitivity, (2) scientific creativity, and (3) scientific productivity. Marconi et al. [16] developed a multifaceted test battery for the measurement of creativity within scientists and artistic domains. Semmler and Pietzner [26] developed a scientific creativity instrument that includes the creation of concept maps and filling out a questionnaire.

Research sub-topics about teachers’ perceptions of science creativity included articles written by Liu and Lin [7], and also by Ndeke et al. [27]. Others, Demir and Sahin assessed prospective science teachers’ perceptions and levels of scientific creativity using the Hu & Adey test [28, 29, 30]. The scientific creativity level of the prospective teacher was also tested with instruments based on the Hu & Adey test by Fadlan et al. [31] and Bakaç [32]. While Demir’s research revealed how 20 science teacher candidates defined scientific creativity [33], and KAÇAN [34] examine research questions on the subject germination from the perspective of scientific creativity.

Although the amount was not too much, another research sub-topic was students’ scientific creativity level. The topics about students’ scientific creativity levels were investigated by Usta and Akkanat [35], who examined the scientific creativity level of elementary 7th-grade students. Meanwhile, Wang and Yu [36] measured the scientific creativity of engineering students.

Research sub-topics of relationships between scientific creativity and other variables were investigated by several researchers, including Dikici et al. [37, 38] who explored the strengths of relationships between 7th, 8th, and 9th-grade students’ scientific process skills, nature of science beliefs, and scientific creativity. Usta and Akkanat [35] investigated the relationship between students’ scientific creativity and views of the nature of science and attitude towards science and technology. Gupta and Sharma [39] investigated the interrelationship between the processes of science and science creativity and its relevance to a science classroom.

Other researchers, Bernal et al. [40], investigated relationships between figurative-general creativity and scientific creativity. Huang et al. [14] explored the relationship between domain-general divergent thinking abilities and domain-specific scientific creativity, mathematical creativity. Yang et al. [19] investigated the effects of creativity on the learning environment and science achievement on science inquiry and scientific creativity. Barrett et al. [12] examined three areas of adult career experiences that are common to the achievement of scientific creativity.

Several researchers investigated the relationship between gender, culture, mood, and scientific creativity, including Okere and Ndeke [5], who investigated the influence of gender and knowledge on scientific creativity among three biology students. Devers and Lubart [24] and also Aruan et al. [41] investigated the influence of students’ culture and gender on scientific creativity. In contrast, Chen et al. [42] investigated the effect of mood on problem finding in scientific creativity.

Research sub-topics of teaching strategies to improve scientific creativity were also widely studied. To improve the scientific creativity of prospective science teachers, several researchers, such as Demirhan and Sahin [43], KAÇAN [44], and Akcanca and Ozsevgec [14] implemented respectively: the hands-on modeling activities, science games and toy designs, and instructional techniques supporting scientific creativity. Other researchers, Wahyudi et al. [45] investigated the effect of teaching implementation of scientific creativity in inquiry learning to promote the critical thinking abilities of prospective teachers.

To improve the scientific creativity of secondary school students, Antink-Meyer and Lederman [9] and Hu et al. [46] investigated respectively the effect of typical academic periods and the delayed impact of the Learn to Think Intervention Program. In addition, Kartika et al. [47] and Wulansari et al. [48] determined the effect of the Creative and Critical Scientific Worksheet in improving the high school students’ scientific creativity, respectively on: the sound wave and work and energy concepts. Other researchers studied the influence of the Cognitive Acceleration through Science Education program [18]
and a new competency-based science curriculum [49] on the scientific creativity of secondary school students.

Although a little, there was also the application of teaching strategies to junior high school students, elementary schools, and gifted children. Astutik and the team studied the collaborative creativity learning model and integrated that model with the PhET simulations to improve the junior high school students’ scientific creativity [50, 51]. Yang et al. [8] explored the effectiveness of creative inquiry-based science teaching for developing the scientific creativity of elementary school students. At the same time, Karademir [52] identified the scientific creativity of gifted students through the implementation of project-based activities.

The development of the scientific creativity test by Hu and Adey [2] became the beginning of increasing research on scientific creativity as a domain-specific creativity. Research on scientific creativity then continued at least the sub-topics of teacher perception, the level of scientific creativity, the relationship between variables, and teaching strategies. In the 2001-2019 period, the most studied sub-topics were teaching strategies (28.6%), then followed by the sub-topics of variables relationships (24.5%), test development (24.5%), scientific creativity level (12.2%), and teacher perception (10.2%). In addition, the scientific creativity measurement instrument most widely used in several studies, including in teaching strategies studies, is SSCM, which was initially developed by Hu and Adey [2].

4. Conclusion
From 2001 to 2019, a total of 49 articles of scientific creativity were published in 20 international journals, and the top of five journals were JEP, IJSE, CRJ, JPCS, and PSBS. There were 18 countries whose authors contributed to the 49 articles of scientific creativity. Turkey, Indonesia, Taiwan, China, and Kenya were the top five countries that were ranked first to fifth, respectively. There were only 6 of 49 articles collaborated by authors from two countries that were China and the UK, Lebanon, and Spain, Italy and the USA, Turkey, and Canada, China and the UK, and Taiwan and Australia. The research type of the articles was empirical research, except for one article to the kind of critical review. The research topics of scientific creativity had at least five sub-topics, with the most articles were the sub-topics of test development, followed by the sub-topics of teacher perceptions, the scientific creativity level, the variables relationship, and teaching strategies. Because of the limited number of eligible articles obtained in the 2001-2019 period, trends of the research sub-topics on scientific creativity were not analyzed in this study.

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