Review of a scientific creativity test of the three-dimensional model

W Wiyanto* and I Hidayah
Faculty of Mathematics and Natural Sciences, Universitas Negeri Semarang, Indonesia

*Corresponding author: wiyanto@mail.unnes.ac.id

Abstract. Research on scientific creativity as a domain-specific creativity has begun to develop. A literature review on scientific creativity has been carried out using identification, screening, eligibility, and inclusion procedures, with paper sources from the IJSE, DOAJ, ERIC, IOP Science, ScienceDirect, and Springer Link websites, in the 2001-2019 period. There were 49 papers on scientific creativity that were published in that period. The results of this study indicate that the scientific creativity test developed by Hu and Adey is the beginning of increasing scientific creativity research as a domain-specific creativity. Therefore, a further review of Hu and Adey's test needs to be done in order to reveal the characteristics and development of the test. To achieve this goal, 49 papers were scanned with the keyword “Hu and Adey”, and finally 26 papers were obtained. The results of this further review show that Hu and Adey's test has the following characteristics: using a classical approach (creativity is divergent thinking); using domain of science, covering the three dimensions (product, trait, and process); using the essay test format; and promoting more objective scoring. Hu and Adey's scientific creativity test has been referenced, applied and developed by several researchers. The benefit of this literature review is to show the advantages of the scientific creativity test required to measure one of the twenty-first century skills.

1. Introduction
Scientific creativity is creativity in a specific domain, namely the domain of science. The development of scientific creativity is based on a general consensus that comes from the opinion of researchers. In addition, the development of scientific creativity is an implication of a research result.

The general consensus holds that domain-specific knowledge and skills are the main components of creativity. This was confirmed by Alexander [1], that knowledge and skills based on specific disciplines or domains are needed in creative thinking. Previously, other researchers, namely Albert, Gardner, and Feldman also concluded that creativity is a specific domain [2]. Likewise Barron and Harrington [1], they suspect that more specific aspects of different thought domains may underlie creative productivity.

According to the results of research by Sternberg [2], the correlation coefficient of creativity between different fields is only 0.37. The correlation coefficient between the different fields is low. This means that people who have high creativity in one field are not necessarily high in other fields. The results of this study support a previously accepted general consensus, namely creativity as a specific domain. The consensus implies that general creativity tests cannot be used to measure creativity in a particular field.

Based on the general consensus and the results of Stenberg's research, Hu and Adey concluded that the scientific creativity of secondary school students is a special domain creativity, so it cannot be
measured by general creativity tests, or even by domain-specific creativity tests for different age groups. Therefore, Hu and Adey developed a special scientific creativity test for secondary school students [2]. Hu and Adey published the results of their research in 2002. Since then, scientific creativity has been researched and discussed, however, its development has not yet been considered established. This is interesting to study further, therefore, a literature review was carried out with the aim of answering research questions: (1) what are the characteristics of the Hu and Adey test, and (2) how is the development of its application. This research is a continuation of previous research that studies scientific creativity in a wider scope [3].

2. Methods
This research is a further review that specifically studies Hu and Adey's paper entitled "A Scientific Creativity Test for Secondary School Students" as the main paper, and other papers that refer to it. Previously, a systematic review was carried out using four main steps, namely identification, screening, eligibility, and included, the procedures of which are shown in Figure 1 [3].

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

In the previous review, the identification stage of the search for a paper was carried out by writing the keyword 'scientific creativity' in the search box for the IJSE, SE, JRST, ERIC, DOAJ, IOP Science, ScienceDirect, and Springer Link websites. A search was carried out for publications in the 2001-2019 period. At the screening and eligibility stage, all papers that have been identified based on title, abstract, keywords, and topic relevance are downloaded. Papers of 'book review', 'book chapter', 'responses', 'comments' and 'editorial' types were excluded from the analysis. In addition, papers with full text written in 'non-English languages' were also excluded. In the previous study, 49 papers on scientific creativity that were published in the 2001-2019 period were obtained. The results of this study indicate that the scientific creativity test developed by Hu and Adey is the beginning of increasing scientific creativity research as a domain-specific creativity.
In this further review, in addition to using Hu and Adey's paper [2], 26 other papers that refer to it are also used. A total of 26 other papers were scanned from 49 papers of scientific creativity by writing the keywords "Hu and Adey". The next step, namely the included step, the main paper and other papers referring to it are analyzed to reveal (1) the characteristics of the Hu and Adey test and (2) the development of its application.

3. Results and Discussion

The results of the search for publications for the 2001-2019 period obtained 2,566 papers on scientific creativity, 49 of which were eligible for further analysis, and the results have been reported in previous studies [3]. In the period 2001-2019, IJSE and CRJ were among the scientific journals that published many papers on scientific creativity. Both are reputable journals that have become references to many researchers. This shows that scientific creativity is an interesting topic.

From 2001 to 2019, research on scientific creativity published in the IJSE was the result of collaboration between Hu from China and Adey from the UK [2]. This paper is the main object of this research. Some time later, Hu and Adey's paper was followed by the publication of 26 other papers that were relevant and referred to it. Among them, in 2014, 2015, and 2016, Hu and Adey's research was followed by publication authors from Taiwan [4,5], USA [6], and Korea [7], respectively. Other papers on scientific creativity were mostly published in journals indexed by ERIC, followed by ScienceDirect, IOP Science, and Springer Link [3].

Hu and Adey developed a three-dimensional model of scientific creativity which consists of: the first dimension is a personal or individual characteristic or trait, the second dimension is the product, and the third dimension is the process. Hu and Adey used the three-dimensional model as a basis for developing a scientific creativity test for secondary school students consisting of 7 task items.

In the dimension of individual characteristics, Hu and Adey adopted the definition of creativity used by Torrance [8]. Torrance uses the aspects of fluency, flexibility, and originality to represent the characteristics of individual creativity. Fluency is the ability to generate similar ideas. Flexibility is the ability to generate a variety of categories of ideas. Originality is the ability to generate rare ideas. Fluency, flexibility, and originality show the personal qualities that Hu and Adey use as components of the first dimension.

Creative products can be divided into four aspects, namely technical products, scientific knowledge, science phenomena, and science problems. Technical products are concerned with the ability to think about improving a product like a simple machine. Science knowledge is related to scientific understanding of an object and its use in the field of science. Science phenomena are related to the ability to understand or describe a condition, situation, or object. Science problems are related to sensitivity to a problem in science, including the ability to formulate problems and find solutions to problems. The four scientific products are used by Hu and Adey to represent the components of the second dimension.

The third dimension is the creative process. In this case, Hu and Adey use aspects of creative imagination and creative thinking to represent the dimensions of the creative process. Imagination is a mental representation of objects or events that are not physically visible, while thinking is manipulating internal representations of the real external world. When someone is asked the question what if there is no Earth's gravity, then he will imagine about the possibilities that could occur as an implication of this absence of gravity. It is different if someone is shown a real object, for example a piece of cloth, then they are asked what the cloth can be used for. The question of the earth without gravity involves the process of imagination, while the question of using cloth tends to use the thought process. However, some cases or problems can involve using both, thinking and imagining.

The three-dimensional scientific creativity model developed by Hu and Adey is also called the Scientific Creativity Structure Model (SCSM). The three-dimensional model of SCSM is shown in Figure 2. There are three dimensions and nine aspects, namely the product, trait, and process dimensions each having four, three, and two aspects, thus forming a block composed of 24 cells. In Figure 2, cell 1 shows dimensions (fluency × science problem × thinking), cell 2 shows dimensions (fluency × science problem × imagination), cell 3 has dimensions (flexibility × science problem × thinking), and so on.
Figure 2. The Scientific Creativity Structure Model (SCSM)

Based on the three-dimensional structure model, Hu and Adey describe the seven essay test items as shown in Table 1. Each task item is related to the three dimensions, but it does not necessarily contain the nine aspects, so the seven questions do not fill all cells. For example, dimensions (fluency × science knowledge × imagination), (flexibility × science knowledge × imagination), and (originality × science knowledge × imagination) are absent from the seven items. The reason is that the limitations of paper and pencil tests for secondary school students make it impossible to write questions about cells (science knowledge × imagination).

In the 7 task items developed by Hu and Adey, the content of task 5 seems less representative of the science domain. Some researchers also deleted task 5, including Antink-Meyer and Lederman [9] and also Ozdemir and Dikici [10], because an infinite number of responses is possible, so that if it is achieved by students, then the scoring will be impossible. In addition, Bernal et al [11] also did not use task number 5 because of its low reliability.

Table 1. The scientific creativity test

| Item | Task                                                                 | The measured dimensions                                      |
|------|----------------------------------------------------------------------|--------------------------------------------------------------|
| 1    | Please write down as many as possible scientific uses as you can for a piece of glass. For example, make a test tube. | fluency, flexibility, originality, science, knowledge, thinking |
| 2    | If you can take a spaceship to travel in the outer space and go to a planet, what scientific questions do you want to research? Please list as many as you can. For example, are there any living things on the planet? | fluency, flexibility, originality, science, problems, imagination |
| 3    | Please think up as many possible improvements as you can to a regular bicycle, making it more interesting, more useful and more beautiful. For example, make the tyres reflective, so they can be seen in the dark. | fluency, flexibility, originality, technical, product, imagination |
4. Suppose there was no gravity, describe what the world would be like?

*For example, human beings would be floating.*

5. Please use as many possible methods as you can to divide a square into four equal pieces (same shape). *Draw it on the answer sheet.*

6. There are two kinds of napkins. How can you test which is better? Please write down as many possible methods as you can and the instruments, principles and simple procedure.

7. Please design an apple picking machine. Draw a picture, point out the name and function of each part.

The scoring of 7 task items is carried out on the trait dimensions, namely aspects of fluency, flexibility, and originality (Table 2). One task item represents two or three aspects of the trait. The score for each task from items 1 to 4 is the sum of the respective scores for fluency, flexibility, and originality. The fluency score is determined by counting the number of responses given by the subject or respondent. Each correct response is assigned a score of 1, regardless of quality. The flexibility score for each task is obtained by counting the number of approaches or fields used in the answer, where each field category is given a score of 1. An originality score is developed from tabulating the frequency of all responses from all subjects or respondents. The percentage for each response is calculated based on the ratio of the frequency of each response to the sum of all responses from all respondents. If the response probability is less than 5%, 2 points are awarded; if the probability is 5 to 10% it is given 1 point; if the response probability is greater than 10% it is given 0 point.

The score for task item 5 is the sum of flexibility and originality scores. The flexibility score is obtained by calculating the number of functional parts of the apple picking machine. Each function gets 3 points. The originality score of task 7 was calculated like the originality score on the previous item, and the score was 1 to 5 points. The originality score system for tasks 1 to 4, 5, 6, and 7 differs due to the different difficulty levels.
Table 2. Scoring of the scientific creativity test

| Trait        | Operational Definition | Scoring Procedure                                      | Score                                      | Task Item |
|--------------|------------------------|--------------------------------------------------------|--------------------------------------------|-----------|
| Fluency      | Number of responses    | Responses counted                                       | score of 1 for each response/method | 1, 2, 3, 4, 5 |
| Flexibility  | Number of the response varieties/categories | Responses are organized into categories and then the number of categories is counted | Score of 1 for each variety/category of response | 1, 2, 3, 4, 5 |
|              |                        |                                                        | Maximum score of 9 points for one correct method (instrument: 3 points, principle: 3 points, procedure: 3 points) | 6         |
|              |                        |                                                        | Score of 3 for each function/component of design | 7         |
| Originality  | a measure of the rare responses (which occur only occasionally) | Responses are tabulated into the frequency of all responses of all subjects/respondents and then probability of each response is counted | Score is 2 points if probability of each response is less than 5%, 1 point if between 5% and 10%, and 0 point if greater than 10%. | 1, 2, 3, 4 |
|              |                        |                                                        | Score is 3 points if probability of each response is less than 5%, 2 points if between 5% and 10%, and 1 point if greater than 10%. | 5         |
|              |                        |                                                        | Score is 4 points if probability of each response is less than 5%, 2 points if between 5% and 10%, and 1 point if greater than 10%. | 6         |
|              |                        |                                                        | Score is 5 points if probability of each response is less than 5%, 3 points if between 5% and 10%, and 1 point if greater than 10%. | 7         |

Based on its scoring which only adds up the scores from the fluency, flexibility, and originality of the responses given by the respondents, SCSM tends to use a classic approach, creativity as a divergent production. According to the classic description, a person's creativity is measured based on his ability to think divergent, so that divergent thinking becomes the main component or characteristic of creativity. However, without convergent thinking only ideas or alternative solutions emerge, so that one best solution will not be produced as a creative product. For that reason, Yang et al [12] completed the SCSM test with a test item to reveal convergent thinking skills, so the scientific creativity test consisted of 7 open items designed to assess divergent creativity and 2 open items to assess convergent creativity.

The results of Hu and Adey's research show that the 7-item test that has been developed and validated is useful in assessing the scientific creativity of secondary school students. Internal consistency, agreement between scorers, construct validity, and face validity were found to be satisfactory. In addition, the scoring procedures described in Table 2 are clear and operational. It is hoped that this scoring system can reduce subjectivity as is commonly found in essay question scoring.

After Hu and Adey published the results of their research on the SCSM test, there were at least 26 publications that referred to it, in the period 2001 - 2019. Of that number, there were about 57% of papers related to the application of Hu and Adey's tests to research on scientific creativity, including research conducted by Huang et al [13]. There are about 12% of papers that apply the Hu and Adey test with slight modifications, one of which is Karademir [14]. There are about 23% of the papers that adopted the Hu and Adey test to be applied at different levels of education, one of which is Fadlan [15] who adopted the Hu and Adey test for his research at the higher education level. There are 8% of papers that only refer to Hu and Adey's papers without using the tests they have developed, including Ayas and Sak [16] and Devries and Lubart [17].

Ayas and Sak developed a scientific creativity test called the Creative Scientific Ability Test (C-SAT), while Devries and Lubart developed the Evaluation of Potential Creativity (EPoC). Ayas and Sak
consider SCSM less representative of the scientific domain. Meanwhile, Devries and Lubart consider SCSM, according to the definition of scientific creativity, needs to be equipped with a test to reveal convergent thinking skills. So far, there are at least three types of tests to measure scientific creativity, namely SCSM, C-SAT, and EPoC, so that in the future, the review of the comparison of the development of the three types of tests is interesting to study.

4. Conclusion
The 7-item test developed by Hu and Adey is based on the Scientific Creativity Structure Model which is derived from the nature of scientific creativity. This test has the following characteristics: using a classical approach (creativity is divergent thinking); using the domain of science, covering the three dimensions of product, trait, and process; using the essay test format; and promoting more objective scoring. Hu and Adey have shown that the internal consistency, agreement between the scorers, the construct validity, and the face validity of this test are satisfactory. So far, the SCSM has been referred to, implemented, adopted, and developed by several researchers. In the future, the work that needs to be done is to study further its validity and to compare this scientific creativity test with other types of scientific creativity tests, such as the C-SAT and EPoC.

References
[1] Dikici A, Gökhan Özdemir G and Clark D B 2020 Res Sci Educ 50 5
[2] Hu W and Adey P 2002 Int J Sci Educ 24 4
[3] Wiyanto W Saptiono S and Hidayah I 2020 J Phys.: Conf. Ser. 1567 022044
[4] Liu S C and Lin Hs 2014 Int J Sci Educ 36 10
[5] Yang K K Lee L Hong Z R and Lin Hs 2016 Int J Sci Educ 38 13
[6] Antink-Meyer A and Lederman N G 2015 Int J Sci Educ 37 10
[7] Mun J Mun K and Kim SW 2015 Int J Sci Educ 37 13
[8] Kim K H 2017 Creat Theo Res Appl 4 2
[9] Antink-Meyer A and Lederman N G 2015 Int J Sci Educ 37 10
[10] Ozdemir G and Dikici A 2017 J Educ Sci Environ Health 3 1
[11] Bernal A, Esparza J, Ruiz M J, Ferrando M and Sainz M 2017 Electron J Res Educ Psychol 15 43
[12] Yang K K, Lin S F, Hong Z R and Lin H sh 2016 Creat Res J 28 1
[13] Huang P S, Peng S L, Chen H C, Tseng L C and Hsu L C 2017 Think Skills Creat 25 1
[14] Karademir E 2016 Int J Res Educ Sci 2 2
[15] Fadlan A, Hartono, Susilo and Saptiono S 2019 J Phys Conf Ser 1321 032099
[16] Ayas M B and Sak U 2014 Think Skills Creat 13
[17] Devries H B and Lubart T I 2017 J Creat Behav 53