Considering Criteria to Make Test Questions of Scientific Creative Problem Solving for Science Gifted Education*

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Abstract

The science gifted education center needs a guideline in order to develop the test questions for creative scientific problem solving for identifying science gifted students, We present the following criteria for planning the guideline:
1) thinking process, 2) inquiry process skill, 3) requiring multiple answers,
4) preferring higher-order thinking ability, 5) preferring non-typical and/or interdisciplinary problems, 6) preferring scientific contents of testee' level, 7) preferring objective measurement.
The importance of each criteria can be varied depending upon the goals and directions of the science gifted education centers.

Key words: creativity, science, creative science problem solving

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I. Introduction

We are living in an age when everyone has a very small mobile phone and accesses information from the world at home and when research for extending human life can be successful in the next 10 years. Then, who has imagined and invented such products? Scientists and technologists have. They are creative experts who tend to identify problems with questions, inquire and contemplate every question, and attempt to solve it.

Who are creative scientists? How can creative scientists be nurtured? How can we measure potential for being creative scientists? Can it be measured through our intelligence quotient, academic record, parents' checklist, or scientific achievement?

Nowadays, people have much interest in creativity. Recently, lots of research results about it have come out. The educational circles give much attention to creativity, every academic meeting addresses creativity, and many programs have been designed to develop creativity. However, in fact, no one has shown clearly the whole picture of creativity and measured it correctly. It is much like blind men who have touched an elephant and try to describe it only based on the experience of each of them. Each of the many scholars who have studied creativity explains only a part of it. In spite of that, endeavors are continually being made to interpret and measure creativity, and more endeavors are necessary for the future of education and the development of human beings.

As evident in the U. S. A. and Russia, a national belief in the creative potentiality of humans and possibility for developing that potentiality is closely interrelated with the leading status of those countries in the world (Lee, 1991).

Scholars who have studied gifted education and creativity (Feldman, Csikszentmihalyi, & Gardner, 1994) claim that unsystematically identifying and training creativity leads to the clear waste of talents.

In reality, creativity is much stressed and the importance of creativity is made much of in gifted education. In contrast, students are primarily evaluated based on their academic achievements. Song (1998) points out that tools for identifying giftedness in Korea are ever measured mainly through convergent thoughts which give clear answers, since the tools must establish objectivity. Test results from using these tools have great influence on education in this country where school education is executed largely for the purpose of entering superior colleges.

This situation is also true with science. Even though it is an accepted fact that scientists cannot be nurtured apart from imagination or creativity with which accumulated experiences and knowledge can be utilized in a fresh and meaningful way, in the field of scientific gifted education, creativity is not often measured. Sometimes general creativity, mainly including divergent thinking, is examined. However in order to identify and select students who have the creative abilities to solve scientific problems, more specific and appropriate tools are required. Scientific creativity cannot be found out through the existing tests for identifying creativity by measuring convergent thoughts mainly to solve intellectual problems or through the tests of general creativity mainly measuring divergent thoughts.

Recent studies on creativity report that creativity can no longer be measured by the existing methods using convergent thoughts and it is important to understand and measure students' creativity in a specific area (Csikszentmihalyi, 1990; Feldman, 1994; Gardner, 1983). A commonly used intelligence or creativity test cannot identify scientific ability in a defined area of science. Some scholars insist that there is no general creativity skill and that universal creative thinking useful to various areas can no longer be supported, and that creativity in specific areas should be considered (Csikzentmihalyi, 1990; Gardner, 1993; Wallach, 1985).

The limitations of the tools used to examine creativity in all the areas call for the development of more specific test tools in each area. Given these limitations, it is of critical importance and urgent to develop appropriate tools to examine creativity to solve scientific problems. This study is not aimed at developing such test tools to identify students who have the creativity to solve scientific problems. Instead, since most of the science gifted education centers have used the test for science creative problem solving as a tool for identifying science gifted students, we have attempted to identify criteria to be considered in designing the test tool, based on literature from the gifted and science education. Furthermore we will present examples of some test problems based on the aspect list, which give sound direction to make the test tools that are not easy to get validity and reliability for the purpose. At least it is hoped that those tools will serve to identify superior scientific giftedness and contribute to the development of the potentiality and nurture of excellent scientific gifted students for the benefit of our society and nation.

II. Literature Review

A. Creativity to Solve Scientific Problems

1. Creativity

The concept of creativity is complex and multi-lateral and therefore difficult to define (Davis, 1997) so that a long time of study and elaboration of many scholars has not yet led to agreement about its definition but produced only varied perspectives. Guilford (1967) regards divergent thought, which is a portion of his intelligence structure model, as a type of thinking leading to creativity and contends that creativity has the power to produce something new and original. Taylor (1988) claims that creativity is a process with which a novel product, which is accepted as continuous, useful, and satisfactory by a group with a specific purpose, is made. Sternberg (1994) defines creativity as the ability to produce something both new and suitable to a problematic situation.

In addition, there are various definitions of creativity and many approaches to understanding it. Most of them have commonly agreed to the fact that creativity is related to newness, usefulness, novelty, and suitability.

2. Creative Problem Solving

Creative problem solving is an ability to creatively approach challenging problems and effectively solve them. In other words, it is the power to come up with new, flexible, and original ideas to resolve impending problems, and furthermore, to address elaborately or generalize the ideas (Guilford, 1967).

Isaksen and Treffinger (1985) say that creative problem solving is a process of problem solving by creative thinking with the help of the interactions between convergent and divergent thinking. Davis and Rimm (1989) say that more creative thinking is needed when problems arise, when difficulties are encountered, when some missing information is detected, when true problems are sought, when problems must be clarified or simplified, or when the same problems need to be defined in other ways.

3. Scientific Creativity

De Vito (1989) says that science is the most suitable subject to creativity. He also says that scientists are the most creative people in our society. Science is being developed by their creative production, and in particular, the characteristics of scientists are very similar to those of creative people.

Gardner (1983) who has analyzed intelligence in multiple domains says that personal ability displayed in a specific domain cannot guarantee the ability in another domain and that a man can be said to be creative only in a specific field where he/she is now serving. Also, a creative person has professional knowledge only in his own field (Policastro & Gardner, 1999). In the case of science, the expansion of scientific creative thinking requires varied theoretical, technical, and experiential science knowledge(Shin, 2001). According to Shin, domain-specific knowledge and skills in creativity rather than domain-general has to be emphasized. Lipps (1999) says that scientific creativity may be a process of problem finding through observations and may be a process of developing various hypotheses with which to logically explain the results of the observations. Park (2004) states that the scientific creativity is the combination of scientific inquiry skills, scientific knowledge contents, and thinking processes for scientific creativity such as divergent, convergent, and associational thinking.

B. Tools to Measure Creativity

Though creativity cannot be simply defined, endeavors have been continually made to create tools to measure creativity through various approaches. Three different methods which are the most commonly used to measure creativity include 1)paper and pencil method which regards creativity as a process of recognizable thoughts, 2)paper and pencil method which checks personality and attitude toward creativity, and 3) a method uses evaluation scales of teachers, colleagues, and specialists. These methods are examined further below.

1. Method of Using Paper and Pencils to Test Creative Thinking

Guilford (1967) contended that creativity can be learned in everyday life and must be studied through psychological measurements comprising paper and pencil tests (Sternberg & Lubart, 1999). Representative tools to test creative thinking include the Unusual Uses Test of Guilford and the Torrance Tests of Creative Thinking (TTCT).

Guilford, based on his Structure-of-Intellect model and analytic study of each factor, defined intelligence such as originality, fluency, flexibility, sensibility, synthesizing ability, analyzing ability, and complexity, and he described these abilities as examples of divergent thinking. He suggested that divergent thinking is related the most to creativity and claims that creative thinking plays the most important role in solving problems. Many scholars agree with his claim. His Unusual Uses Test is designed to encourage testees to think of as many uses as possible of common things such as ordinary bricks. Such a test of divergent thinking ability is different from the traditional IQ test in that it does not demand only one answer but multiple responses. It is widely used to measure creativity and also useful to many relevant studies (Sternberg & Lubart, 1999).

Torrance's Tests of Creative Thinking are classified into a language test and a diagram test. The former is composed of five sub-tests and should be conducted in 45 minutes. It can be conducted with kindergarteners up to graduate school students, and Sub-tests of the language test include Ask and Guess, Product Improvement, Unusual Uses, Unusual Questions, and Just Suppose. The diagram test is conducted in 30 minutes and is composed of Picture Construction, Picture Completion, and Circles. Its sub-tests include originality (originality of responses), fluency (the number of appropriate responses), flexibility (the number of categories of responses), and elaboration (the number of precise aspects of responses).

In general, it has been pointed out that Tests of Creative Thinking are only applicable to a part of creativity (Davis, 1997). Still, it is a representative tool to measure creativity and has contributed to the development of tools to measure creativity.

2. Method of Using Paper and Pencils to Check Personality and Attitude toward Creativity

Scholars who regard creativity as a factor of personality have developed this method, whose representative test is GIFT (Group Inventory for Finding Creative Talent). This test was developed by Davis and Rimm (1982) and is composed of about 30 Yes-No questions. It is mainly used to measure self-confidence, independence, energy, adventurous spirit, curiosity, humor, complexity, and tolerance for ambiguity.

Also, this method often includes creative behavioral characteristics from among the behavioral characteristics checklist of Renzulli (1983) for gifted children. The behavioral characteristics such as curiosity, original thought, expressive ability, imagination, sensitiveness, challenge to authorities, and endurance to criticism are measured with four possible responses from "almost always" to almost never".

Checklists and questionnaires are designed in consideration of typical personalities of creative people, and they are highly correlated to tools which measure other creative abilities (Davis, 1997). This type of test can give a certain supplement to solve the interpretational difficulties of the existing tools to test creativity but has its limits in terms of validity given the fact that persons who are tested measure their own creative attitudes.

3. Method of Using Evaluation Scales of Teachers, Colleagues, and Specialists

The measuring method using the evaluation scales of teachers is often used as a criterion in the process of justifying creativity tests. Usually, teachers are asked to evaluate the creativity of students on a 5-point or 7-point scale. This method is mainly used in any educational sites since creativity is very useful to such a site. Mun and Ha (1999) point out that the method is evidently useful to directly observe and evaluate students' creativity but the problem is that these evaluation methods are not yet satisfactorily developed.

III. Considering Criteria for Making the Test of Creative Scientific Problem Solving

In order to develop the test of creative scientific problem solving, scientific gifted education centers must set up the goals and directions of its education, with which to define the concepts of the test. They should also prepare test questions after examining relevant documents. To examine the facial reliability, the guideline to make the test question should be distributed to science gifted specialists, who shall evaluate whether the test questions are in conformity with them. To measure the validity and difficulty of developed test questions, a pilot test should be conducted, the results of the pilot test must also be investigated, and the test questions analyzed and amended. However, in reality, in Korea, the validity and difficulty can only be estimated by the person who makes the test questions because of the concern that the test questions may be leaked out to public. However, a grading standard rubric shall be prepared and amended by the suggestions of the science gifted specialists, and then the test questions shall be finally adopted. In this process of making the test of creative scientific problem solving, establishing guidelines is very important, Accordingly we should consider the following criteria for measuring scientific creativity as suggested by gifted education and science education in making the guidelines.

Based on our review of the literature, we identified the following criteria to form guidelines with which preliminary test questions can be prepared and distributed to the specialists to examine the facial reliability. With them, the validity and difficulty may also be crudely estimated.

A. Thinking Process : It is advisable to evaluate the process of creatively solving scientific problems suggested by Isaksen and Treffinger (1985). That is to say, test questions shall reflect a process of problem solving with creative thinking interacting between convergent and divergent thinking. This process is also related to scientific inquiry process of thinking (Park, 2004).

B. Inquiry Process Skill : As mentioned by Davis and Rimm (1989), if problems are to be identified, difficulties are to be discovered, or some missing information to be detected, then real problems should be selected to measure scientific creativity. Furthermore, important criteria of the problem can be identified and sometimes the problem can be clarified or simplified and subordinate problems from the problem can also be identified. Sometimes, the same problem can be treated in other ways, or more widely and openly considered. Test questions that need to be newly defined require more creative thinking and more creative ways of problem solving. This comment is also strongly related to finding problems, one of scientific inquiry process skill in the science education. We intend to add more scientific process skills mentioned by Park (2004) to make the test.

C. Requiring Multiple Answers : Test shall be prepared so that not only one answer can be given but multiple creative answers. This is related to fluency, flexibility, and originality (Torrance, 1966).

D. Preferring Higher-Order Thinking Ability : Test shall be prepared so that students are required to use higher-order thinking abilities of applying, analyzing, synthesizing, and evaluating (Bloom, 1956).

E. Preferring Non-Typical and/or Interdisciplinary Problems : Tests shall be prepared focusing on non-typical and/or interdisciplinary problems with which students are not familiar (Kaplan 1974).

F. Preferring Scientific Contents of Testee's Level : Test shall be prepared so that students can solve it with the scientific concepts that they have learned in ordinary science classes that they attend.

G. Preferring Objective Measurement : Test shall be prepared so that it may not be scored by subjective judgment. An objective rubric should be implemented.

The weight assigned to each criteria listed above can be adjusted depending upon the goals and directions of the science gifted education centers.

Ⅳ Examples of Test Questions for Creative Scientific Problem Solving in Earth Science

Instead of giving the test tool for creative scientific problem solving with the certain validity, reliability, and difficulty, we only present 3 examples using by the criteria we are suggesting. The facial reliability of examples was tested by five science gifted education specialists following the guidelines including the criteria listed above. These examples show some directions to make the test in the science gifted education center.

A. Observation Corresponding to Theory

This question (Example 1) is aimed at estimating the time of a solar eclipse based on the observations suggested in the pictures and to compare the time with the theoretically obtained time that can be acquired using theoretical sketch in science textbook. Thus, this question shows that scientific results can be acquired through experiments or observations and those results should be verified using applicable in theories (Emphasizing criteria 2). The picture shown in this question is provided to help solve the problems and lead to the solution of the problems in various ways (Emphasizing criteria 1, 3). At this time, students can intuitively use what they have learned in the science textbooks and use theoretical model sketches from the textbooks (Emphasizing criteria 6). Furthermore the sub-questions can be solved by using higher order thinking abilities such as applying, analyzing, evaluating and integrating the concepts they have already learned through their school life (Emphasizing criteria 4). The question set is really non-typical compared to the questions they experienced in their schools(Emphasizing criteria 5).

B. Combination of Earth Science, Physics, and Mathematics

This question (Example 2) is aimed at determining the speed of the volcano eruption of Io, one of the satellites of Jupiter. The picture inside Example 2 was taken by a spaceship called Voyager. The question is constructed to be interdisciplinary with 5 sub-questions (Emphasizing criteria 5). For example, the sub-question (1) asks for the mathematical concept of parabola and physical concept of parabolic motion in math and science textbooks (Emphasizing criteria 6). In addition, the whole question involves calculations about a different planet from the Earth (flexibility). The other sub-questions require a combination of both divergent and convergent thinking and higher-order thinking abilities with inquiry process skills using the picture only (Emphasizing criteria 1, 2, and 4). The objectivity of grading (Emphasizing criteria 7) can be established.

Solar Eclipse

The following picture shows a total eclipse of the sun on June 21, 2001 in Zambia, Africa.

1) Roughly, what are the right ascension and declination of the sun and the moon? Explain how the values have been calculated.
2) Calculate the approximate time of the eclipse, using only the picture. Describe what kinds of methods are employed.
3) What kinds of methods should be used to take a picture of the above phenomenon?
4) Explain the causes of solar eclipses by drawing an appropriate sketch.
5) Roughly calculate the time of the eclipse using the sketch you drew in 4).
6) Compare the time acquired from 2) with the time from 5). Explain why the time difference exists, if there is any difference.

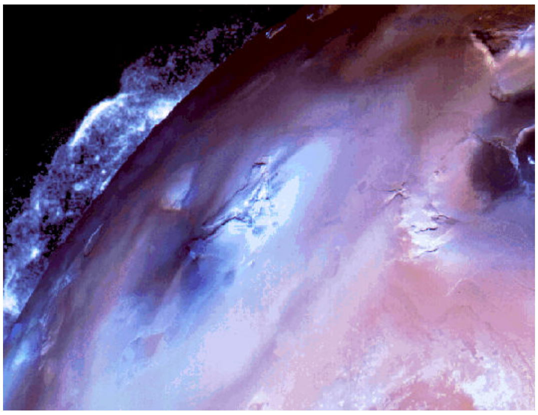
Example 1. Question set for observation corresponding to theory

C. Converting Situation

Students are very familiar with the knowledge and concepts which are useful to solve the question (Emphasizing criteria 6).

Io volcano

The following picture shows Io, one of the satellites of Jupiter and was taken by the explorer Voyager in 1979. You can see the explosion of a dome-shaped volcano over the surface of Io in the upper left corner in the picture.



1) Explain why the appearance of the volcano eruption is dome shaped by employing sketch.

2) Calculate approximate values of d/R and H/R using the size of Io (radius=R), the scale of volcano eruption (height=H, lower diameter of the eruption=d) and this picture.

3) Describe the volcano eruption's height (H) and the radius of the bottom of the volcano eruption (d) in the picture, using the volcano eruption's initial speed (Vo) and Io's gravitational acceleration (g).

4) Supposing Vo is constant, what is the value of d/H acquired by the calculation in 3)? In contrast, what is the approximate value of d/H in the picture? Explain the difference between the two values.

5) Calculate the approximate values of Vo using both H and d (here, g=1.8 m/sec2, R=3,630 km). Examine if the two calculated values support the reasons in 4)

Example 2. Question set for combination of earth science, physics, mathematics

Diurnal motion of stars

The picture below concerns the diurnal motion of Polaris.

1) List all the things to be observed in the picture (divergent thinking, precise observational ability).

2) List all the astronomic facts related to answer 1) (divergent thinking, connection and application of the observed results to existing astronomical knowledge).

3) When declination of Polaris is 89.264° what is the declination of Star A approximately? (convergent thinking, cause and effect)

(Hint: Length of traces of a star L is shown in a formula: $L = \dfrac{t\,F\,cos\,(\delta)}{13,751}$. Here, t is exposed time (sec), F is the focal distance of camera, and δ is declination of a celestial sphere.) (application)

각	cos 값	각	cos 값	각	cos 값	각	cos 값	각	cos 값	각	cos 값
0	1.0000	15	0.9659	30	0.8660	45	0.7071	60	0.5000	75	0.2588
1	0.9998	16	0.9613	31	0.8572	46	0.6947	61	0.4848	76	0.2419
2	0.9994	17	0.9563	32	0.8480	47	0.6820	62	0.4695	77	0.2250
3	0.9986	18	0.9511	33	0.8387	48	0.6691	63	0.4540	78	0.2079
4	0.9976	19	0.9455	34	0.8290	49	0.6561	64	0.4384	79	0.1908
5	0.9962	20	0.9397	35	0.8192	50	0.6428	65	0.4226	80	0.1736
6	0.9945	21	0.9336	36	0.8090	51	0.6293	66	0.4067	81	0.1564
7	0.9925	22	0.9272	37	0.7986	52	0.6157	67	0.3907	82	0.1392
8	0.9903	23	0.9205	38	0.7880	53	0.6018	68	0.3746	83	0.1219
9	0.9877	24	0.9135	39	0.7771	54	0.5878	69	0.3584	84	0.1045
10	0.9848	25	0.9063	40	0.7660	55	0.5736	70	0.3420	85	0.0872
11	0.9816	26	0.8988	41	0.7547	56	0.5592	71	0.3256	86	0.0698
12	0.9781	27	0.8910	42	0.7431	57	0.5446	72	0.3090	87	0.0523
13	0.9744	28	0.8829	43	0.7314	58	0.5299	73	0.2924	88	0.0349
14	0.9703	29	0.8746	44	0.7193	59	0.5150	74	0.2756	89	0.0175
15	0.9659	30	0.8660	45	0.7071	60	0.5000	75	0.2588	90	0.0000

4) What kind of methods should be used to create the above pictures? (observational and/or experimental abilities)
5) What kind of a picture may be taken when the diurnal motion of the same star is shot at a similar altitude towards the southern sky from the same place? Explain the reason after drawing a rough picture of it. (expectation, what, how, and why according to observational conditions)
6) What kind of a picture may be taken when the diurnal motion of the same star is shot at the same time for the same exposure from the same place in the same way one week later? Explain the reason after drawing a rough picture of it. (expectation, what, how, and why according to astronomical concepts and observation conditions)
7) Can the period of the diurnal motion of a star be calculated employing the drawing of 6)? (problem finding and/or problem solving)
8) Can the period of the annual motion of a star be calculated employing the pictures of 6)? (problem finding and/or problem solving)

※ type 1

9) What is the relationship between the result of the above 7)and the rotational period of the earth in case the Earth moves? What is the relationship between the result of the above 7) and the period of the diurnal motion of the night sky in case the earth does not move? (Connection of observed result with astronomic concepts)
10) What is the relationship between the result of 8) above and the period of the revolution of the Earth when Earth moves? What is the relationship between the result of the above 8) and the period of the annual motion of the night sky when the Earth does not move? (Connection of observed result with astronomic concepts)
11) What kind of a picture may be taken when the same method are used at the moon, utilizing the results of 9) and 10)? Explain why after drawing a rough picture of it (flexibility, application)
12) Can the observed facts of the diurnal or annual motion of a star be interpreted as the result of the earth's revolution and rotation if the result of the above 11) is used (correcting wrong hypothesis)?

※ type 2

9) How can it be understood that the earth is moving, utilizing the results of the above 7) and 8) and the technology for taking pictures such as those above? Propose your own ideas and explain the reason (divergent and convergent thinkings, inquiry process skills, and higher thinking abilities).

Example 3. Question set for dealing with converting situation

Multiple answers can be drawn from the picture and connected to scientific concepts in the science textbook in the first two sub-questions (Emphasizing criteria 1, 3). Convergent thinking, inquiry process skills and higher-order thinking abilities are needed to solve subsequent sub-questions up to 8) (Emphasizing criteria 1, 2, 4, 6). When the situation is converted, the ability to test for a certain knowledge is especially needed even if it is said to be wrong in the science textbook. The question can be suggested either in a closed state (Type 1; scaffolding type) or in open state (Type 2). Type 1 is comparatively closed so that students can logically follow sub-questions. Therefore the grading rubric can be easily constructed. On the other hand, Type 2 is largely open so that it is not easy to make the grading rubric (Emphasizing criteria 7).

V Conclusion and Implication

As shown in the examples, the test questions to measure the scientific creative problem solving can be constructed according to the guidelines considering the criteria which are based on the literature review of gifted education and science education as follows;

1) Thinking process,
2) Inquiry process skill,
3) Requiring multiple answers,
4) Preferring higher-order thinking ability,
5) Preferring non-typical and/or interdisciplinary problems,
6) Preferring scientific contents of testee' slevel,
7) Preferring objective measurement.

The weight assigned to each criteria can be adjusted depending upon the goals and directions of the science gifted education centers. Therefore, test questions must equally comprise various abilities related to the creativity to solve scientific problems. It is preferred to include interdisciplinary questions because they demand more creative answers. When questions are too open, the grading rubric may be so vague or inconsistent that it should be elaborated. Finally the test questions once used may not be used again. Therefore, the capacity of teachers who make the test questions is more important than any other factors. For this purpose, teachers who are involved in the science gifted education centers should participate in teacher training program, incessantly need to do research related to science gifted education, apply the results of their research to actual tests, and reflect the results in the creation of tests.

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