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A Method for Developing Items to Assess Earth Science Creativity

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지구과학 창의력 평가 문항 개발 방법에 관한 연구

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Abstract: This study suggests methods of assessing scientific creativity and developing items, which can be achieved when both earth science knowledge and general creativity are applied at the same time. According to the results of this study, the cognitive ability gaps between creativity and scientific creativity were clearly defined by the terms' operational definition. Four factors in the subcategory of scientific creativity-fluency, flexibility, elaboration, and originality-were selected, and the possibility of developing items out of these factors was discovered. The operational definitions of the four factors were given and the criteria for assessment and scoring were set. The validity, reliability, discrimination, and difficulty, which were the conditions required for the assessment instruments, were verified through three field trials of inputting the assessment instruments for scientific creativity. The assessment instruments were composed of 8 items with 2 items for each factor. The average item fitness index obtained was 0.99, Cronbach , the item inter-consistency was 0.79, the inter-rater reliability of each item was 0.78, the inter-rater reliability of each factor was 0.75, the item discrimination power was 0.19, and the item difficulty was 0.00. Because the results were within the permitted limit of the conditions required for assessment instruments, the assessment instruments developed for scientific creativity in this study can be said to be very favorable.

Keywords: scientific creativity, item response theory, item fitness, item inter-consistency reliability, point-biserial correlation index

요 약: 본 연구에서는 지구과학 지식과 창의력을 동시에 적용해야 해결할 수 있는 지구과학 창의력을 평가할 수 있는 문항의 개발 방법을 제시하고자 하였다. R&D과정을 거친 본 연구의 결과는 첫째, 조작적 정의를 통해 창의력과 과학 창의력간의 인지능력 차이를 명료화하였고 둘째, 과학창의력을 구성하는 하위 요소들 중에서 문항 개발이 가능하다고 판단된 유창성, 융통성, 정교성, 독창성을 선정하여 각각에 대한 조작적 정의를 내린 후 각 요소들에 대한 평가와 채점의 준거를 제시하였다. 셋째, 평가도구의 구비 조건인 타당도, 신뢰도, 변별도, 난이도를 검증하기 위하여 3번의 현장 검증을 실시하였으며, 본 연구에서 개발한 지구과학창의력 평가도구는 각 하위 요소별로 2문항씩 총 8문항으로 구성되어 있다. 넷째, 문항합치도 지수 평균은 .99, 문항 내적 합치도 지수인 Cronbach α값은 .79, 각 문항별 평가자간 신뢰도는 0.78, 각 하위 요소별 평가자간 신뢰도는 0.75, 변별도 지수인 점이연상관 지수는 .19, 문항 난이도 지수는 .00이었다. 이와 같이 평가도구의 구비조건들이 허용 범위 내에 있는 것으로 볼 때 본 연구에서 개발한 지구과학 창의력 평가도구는 유용한 것으로 판단할 수 있다.

주요어: 과학창의력, 문항반응이론, 문항합치도, 문항 내적 합치신뢰도, 점이연상관지수.

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Introduction

There are three kinds of objectives to pursue in science education: the educational general objectives that consist of cognitive, affective, and psychomotor domain; the peculiar objectives that are mainly reached by science education; and the objectives that are needed in educational paradigm shifts.

The following statement from the Ministry of Education and Human Resources Development back in 1997 showed the characteristics of science education in the 7th curriculum that reflected educational paradigm shifts: "Pay attention not to conveying fragmentary knowledge about science to students but to teaching them to understand the basic concepts in a correlated and integrated manner and to cultivating creativity, openness, objectivity, rationality, and cooperation."

This ensured that creativity is an axis of education required in the 21st century (Woo, 2000). The test for creativity was also used as an important factor in adopting test instruments for discriminating the gifted (Song, 1990). Kim (1998) said that Renzulli put an emphasis on scientific creativity as a factor of selecting gifted children with scientific inclination. Tannenbaum (1986) alternatively used the terms creativity and giftedness. These observations show that creativity is an important factor in the objectives of science education or science education for the gifted.

While 70% of the studies on creativity were related to creativity training programs, a few studies on domain-specific creativity were conducted (Lee, 1988). According to Cho (2001), most programs for rearing creativity thinking were focused on domain-generality, which is content-free, rather than domain-specificity, which is content-laden.

From these perspectives, it can be seen that most studies on creativity education had focused on developing and applying the programs to rearing content-free creativity. Torrance (1972) reported that subject-specific approach included in general education had a good effect on creativity education when 142 pieces of article related to creativity were divided into types of education methods and the proportion of success.

The creativity assessment instrument developed by Torrance has been the most widely used (Han *et al.*, 2001). And domestically, the creativity assessment instrument developed by Jeong and Lee in 1993 (Baek, 2002) and Torrance's Korean version translated by Kim (1999) were mostly preferred.

These creativity assessment instruments were to assess content-free creativity that had nothing to do with concepts of specific subjects and the degree of acquiring knowledge.

Some studies emphasized the basic knowledge-based approach in specific domains. They also accentuated knowledge and skills related to creativity, knowledge and skills in specific domains, characteristics, motivation, and environmental elements, among others (Amabile, 1983; Simonton, 1990).

Some previous studies indicated that it was more effective to teach and assess creativity using the content-laden approach than the content-free approach (Han, 2000; Baer, 1998).

On the other hand, some studies put emphasis on the need for knowledge and skills in general domains, motivational elements, knowledge and skills in specific domains, critical thinking, and divergent thinking in creativity (Kim *et al.*, 1997). Still, some studies reported that creativity took a role of a loop that connected cognitive domains with affective domains because creative ability came from some basic frame (Hong, 1999).

Though there was has been no mutual agreement yet regarding domain-generality and domain-specificity, recent studies on creativity put an emphasis on behavior characteristics in domain-specificity and creative problem solving (Han and Marvin, 2002). In addition, empirical evidences for domain-specificity have been suggested (Han, 2001; Baer, 1991, 1994; Gardner, 1993).

Even though creativity education in domain-specificity is being emphasized this way, creative factors in the problem solving process are rarely considered in most science education studies. Houtz (1994) reported that creativity education would fail if teachers did not include precise recognition of creativity and did not apply strategic effort for developing creativity. Hong (1999) also presented his view that developing and teaching creativity as well as studies on creativity could be improved if scientific creativity were assessed and evaluated correctly.

As previously mentioned, studies on improving and assessing creativity were generally inclined toward content-free. But since a lot of researches conducted locally and internationally indicated the limits of the content-free approach, there is definitely a need for a study on creativity education in science subject domain and for development of methods for creativity assessment.

This study thus had the following objectives: 1) To define clearly the cognitive ability gaps between creativity and scientific creativity by providing their operational definitions; 2) To select four factors, which can be developed as items, in subcategory of science creativity such as fluency, flexibility, elaboration, and originality, and to give the operational definitions of these four factors; 3) To develop assessment items for scientific creativity to determine when earth science knowledge and scientific creativity are applied at the same time; 4) To verify the developed items through field trials conducted three times for the purpose of meeting the conditions required for assessment instruments; and 5) To suggest methods of developing assessment items for scientific creativity.

Methodology

Assessment instruments for scientific creativity were developed through R&D, which can be solved when earth science knowledge and general creativity are applied at the same time. To determine whether the assessment instruments developed met the required conditions or not, field trials were performed. The following describe in detail the methods used in this study.

Analysis of previous studies on creativity and its subcategory

Creativity and its subcategory were analyzed and synthesized based on previous studies (Song, 1990; Jeong and Lee, 1993; Lim, 1993; Hong, 1999; Woo *et al.*, 2001; Baek, 2002; Torrance, 1972; Perkins, 1988; Ochse, 1990; Lubart, 1994; Baer, 1997; Hennessy and Amabile, 1998; Fishkin *et al.*, 1999; Sternberg, 1999). The results were used as the basic data to form the operational definition of scientific creativity and to select and define the subcategory factors.

Operational definition of creativity and science creativity

Previous studies gave operational definitions of creativity and scientific creativity. A checklist was made to verify the definitions of creativity and scientific creativity made in this study and 6 science education experts were asked to examine it thoroughly. From the science education experts' assessments, the concepts of creativity and scientific creativity were formulated and necessary revisions were made.

Selecting subcategory in scientific creativity and operational definition

The four factors selected in the subcategory were given operational definitions. Some scholars agreed that items using these factors could be developed. Likewise, a checklist was made to verify the definitions of these four scientific creativity factors in subcategory that were given in this study, and 6 science education experts were asked to evaluate it, after which the necessary revisions were made.

Developing assessment items for scientific creativity

Four earth science teachers including the author of this paper developed the assessment items. The developers majored in earth science education, were trained in the course of science education for gifted students, and had more than 10 years of educational career. A seminar was held to come up with the operational definitions of scientific creativity and its subcategory. This was followed by an intensive workshop held to identify methods in developing assessment items, determine the conditions required for assessment instruments, and specify the characteristics of items according to partial crediting.

Because factors in the scientific creativity subcategory were not clearly classified, the ability of each factor could be assessed by classifying results responded to one item into related factors specifically. But items that could be assessed independently were developed in this study by verifying content validity between each item and the subcategory factor. 1

Results and Discussion

The following describe the results of this study.

The operational definitions of creativity and scientific creativity

After giving the first definitions based on previous researches on creativity and scientific creativity, the definitions were revised by 6 science education experts. After analyzing and synthesizing the characteristics of the terms, the final operational definitions were given as listed in Table 1.

Selecting subcategory factors of scientific creativity and their operational definitions

Four subcategory factors of scientific creativity, which are fluency, flexibility, elaboration, and originality, were selected. Some scholars agreed that by using these factors, items could be developed. After giving the first definitions of subcategory factors of scientific creativity, the definitions were revised by 6 science education experts. The final operational definitions of the four subcategory factors of scientific creativity were formulated after thorough analysis and synthesis. The following Table 2 lists these definitions.

Developing assessment items for scientific creativity

Assessment items for scientific creativity were developed. Creativity as well as earth science knowledge were both needed for this. Four earth science teachers including this researcher developed 48 assessment items (four developers×four subcategory factors×three items) through a six-month-workshop. All the developers majored in earth science educa-

Table 1. Operational definitions of creativity and scientific creativity.

Classification	Operational Definitions
Creativity	Ability to produce new things by compounding or combining something, and to solve problems based on general domain knowledge, specific domain knowledge, and creative motivation and environment.
Scientific Creativity	Ability to creatively solve various scientific problem situations based on basic scientific knowledge and process.

Table 2. Operational definitions of subcategory factors of scientific creativity.

Subcategory Factors of Scientific Creativity	Definitions
Fluency	Ability to produce as many ideas as possible for solving problems in specific science problem situations.
Flexibility	Ability to find various solutions in specific science problem situations by changing fixed thinking methods and the viewpoint itself.
Elaboration	Ability to develop old ideas into delicate, exquisite, useful, and valuable ones in specific science problem situations.
Originality	Ability to produce unique ideas in specific science problem situations.

Table 3. Criteria of assessment and scoring.

Subcategory Factors of Scientific Creativity	Assessment Criteria	Scoring Criteria
Fluency	The number of produced different ideas	The more items are answered, the higher score received. One point is given to each answer.
Flexibility	Variety among produced ideas	Answers are grouped by category, and one point is given to each category. The rest is given one point per answer.
Elaboration	Specific degree of produced ideas	One point is given to each specific factor.
Originality	Unique degree of produced ideas	In comparison with the norm group, 0 point is given to a very normal idea, one point is given to a normal idea, and 2 points are given to a unique idea. A very unique idea that others could not produce is given bonus point.

Table 4. Descriptive statistics for the first field trial.

Conditions Item No.	Fitness Index		Inter-Rater Reliability	Point-Biserial Correlation	Item Difficulty	Comparison
	Infit	Outfit				
1	1.0	1.0	.85	.15	-.34	adopted
2	0.8	0.9	.20	.14	.34	cancelled
3	0.9	1.0	.55	.23	-.36	adopted
4	0.7	0.9	.71	.12	.80	adopted
5	1.4	0.8	.81	.06	.52	adopted
6	1.0	1.1	.89	.08	-.14	adopted
7	1.5	1.1	.78	-.06	.09	cancelled
8	1.3	0.8	.55	.18	.31	adopted
9	1.1	1.4	.68	.13	1.70	cancelled
10	1.2	0.9	.78	.12	-.73	adopted
11	1.0	1.1	.86	.14	-.03	adopted
12	2.1	1.3	.74	.14	-.28	cancelled

tion. Of the first developed items, 16 (four subcategory factors×four items) were selected and identified by the developers to be suitable for assessing scientific creativity. Six science education experts were then asked to evaluate the selected 16 items in terms of clarity and in relation to the subcategory factors of scientific creativity. Of the 16 items, only 12 (four subcategory factors×three items) were found to be equipped with the required basic conditions and were selected. The order of items was repeatedly rearranged for fluency, flexibility, elaboration, and originality.

Setting the criteria for assessment and scoring by each subcategory factor

After setting criteria for assessment and scoring based on previous researches on subcategory factors of creativity, the criteria were revised and amended by 6 science education experts. After thorough analysis and synthesis, the final criteria for assessment and scoring by each subcategory factor of scientific creativity were set (Table 3).

The first field trial

After verifying content validity, the test paper that consisted of 12 items was input to 91 11th grade students in liberal high school. The FACETS program was used to calculate validity and item difficulty by using raw data, while SPSSWIN 10.0 (Windows version) was used to calculate inter-rater reliability and point-biserial correlation (Table 4).

As shown Table 4, the inter-rater reliability of item 2 was low. For item 7, because its point-biserial correlation was low, discrimination of it meant very low. And the difficulty of item 9 showed 1.70, meaning it was a very difficult item. The item fit-

Table 5. Item fitness index for the second field trial.

Item No.	1	2	3	4	5	6	7	8	sum
Infit	1.0	0.9	1.0	0.8	1.2	1.2	1.1	1.1	1.00
Outfit	1.1	1.1	0.9	0.9	1.1	0.9	1.0	0.7	.98

Table 6. Inter-rater reliability for each item for the second field trial.

Item No.	1	2	3	4	5	6	7	8
Correlation	.84**	.87**	.55*	.72**	.82**	.79**	.84**	.57*

*p<0.01, **p<0.001

Table 7. Inter-rater reliability for each subcategory for the second field trial.

Subfactors	Fluency	Flexibility	Elaboration	Originality
Correlation	0.78**	0.70**	0.59**	0.73**

**p<0.001

ness of item 12 represented exceeded 1.2, which meant its validity was low. As the result, items 2, 7, 9, and 12 were excluded in the final test, while the other eight items were appointed as assessment instruments for scientific creativity. The order of items in the final test was rearranged to be 1 (geology), 6 (meteorology), 3 (geology), 4 (meterology), 5 (meterology), 10 (astronomy), 11 (geology), and 8 (meterology). Item 5 is shown below.

Item 5] Make a list of the examples using principle of convection current in our living surrounding as many as possible.

The second field trial

Eight assessment items for scientific creativity were composed of two items for each subcategory factor after the first field trial. To verify the conditions and the required time for scientific creativity assessment instrument, the second field trial was conducted. The subjects were 120 11th grade students in liberal high school. The program for calculating validity, reliability, difficulty, and discrimination was the same as the method used to analyze the results of the first field trial.

Validity

To determine the validity of the assessment instruments, item fitness index was calculated using FACETS program (Table 5). The item fitness index of item 5 was 1.2, so items were amended and revised more clearly. The other items were within permitted limit.

Reliability

To determine the reliability of the assessment instruments, Cronbach α, item inter-consistency was calculated as 0.71. The inter-rater reliability of the total score for each item is shown in Table 6 and inter-rater reliability of the total score for each subcategory factor of scientific creativity is shown in Table 7.

As shown in Table 6, the correlation coefficient of inter-rater reliability of most items was within the permitted limit. But the reliability of items 3 and 4 were relatively lower. The scoring criteria were specifically set step by step, and the points for each step were obviously given.

As shown in Table 7, the inter-rater reliability of each subcategory factor of scientific creativity was comparatively satisfying. Inter-rater reliability in fluency and originality factors showed high correlation coefficient of more than 0.70. The raters' viewpoints of elaboration particularly showed difference among four subcategory factors. Classifying categories of answers to items specifically for elaboration could raise inter-rater reliability higher.

Table 8. Point-biserial correlation index for the second field trial.

Item No.	1	2	3	4	5	6	7	8	Sum
Correlation	.13	.23	.19	.22	.15	.24	.01	.30	.18

Table 9. Item difficulty index for the second field trial.

Item no	1	2	3	4	5	6	7	8	Sum
Difficulty Index	-0.74	-0.45	-0.28	-0.11	-0.02	0.19	0.00	1.41	0.00

Table 10. Item fitness index for the third field trial.

Item No.	1	2	3	4	5	6	7	8	Sum
Infit	0.9	1.0	0.9	0.9	1.0	1.1	1.0	1.1	0.99
Outfit	1.0	1.1	1.1	0.8	1.0	0.9	1.1	0.9	0.99

Discrimination

To find discrimination of the assessment instruments, point-biserial correlation index was calculated (Table 8).

As shown in Table 8, because there were no items calculated at negative number in point-biserial correlation index, it can be said that most items have the capacity to discriminate higher-group students from lower-group students. Because item 7 had near 0 point-biserial correlation index and was similar to contents already learned in ordinary experience or science class, it was amended as an item more focused on assessing scientific creativity.

Item Difficulty

To determine item difficulty of the assessment instruments, the FACETS program was used. The results are shown in the following Table 9.

As shown in Table 9, the difficulty of item 1 showed that it was an easy item, so it was modified to become more difficult. On the other hand, the difficulty of item 8 showed that it was too difficult, so it was modified to become easier. As the result, discrimination was adjusted higher.

To verify the time required to complete the instrument

When examinees solved the assessment items for scientific creativity assessment instrument, indicating the starting and finishing time on the right top of the test paper was instructed of them. The time required for the test was appointed as the average time for 120 students to solve all items. Therefore, the time required for completing assessment instruments for scientific creativity developed in this study was set at 120 minutes (2hours).

The third field trial

Based on the results of the second field trial, the final scientific creativity assessment instrument was revised and improved. To verify the conditions required for the instruments, the third field trial was conducted. The subjects were 124 11th grade students in liberal high school. The following show the analyses of the results.

Validity

To know the validity of the assessment instruments, item fitness index was calculated (Table 10). The item fitness index of most items was within permitted limit.

Reliability

To know the reliability of the assessment instruments, Cronbach , item inter-consistency, was calculated as 0.79. The inter-rater reliability of total score for each item is shown in Table 11. The inter-rater reliability of total score for each subcategory factor of scientific creativity is shown in Table 12.

The table shows that the inter-rater reliability of

Table 11. Inter-rater reliability for each item for the third field trial.

Item No.	1	2	3	4	5	6	7	8
Correlation	.83**	.88**	.70*	.71**	.83**	.78**	.85**	.72*

*p<0.01, **p<0.001

Table 12. Inter-rater reliability for each subcategory factor for the third field trial.

Factors	Fluency	Flexibility	Elaboration	Originality
Correlation	.79**	.70**	.71**	.81**

**p<0.001

Table 13. Point-biserial correlation index for the third field trial.

Item No.	1	2	3	4	5	6	7	8	Sum
Correlation	.12	.24	.20	.19	.16	.25	.11	.28	.19

Table 14. Item difficulty index for the third field trial.

Item No.	1	2	3	4	5	6	7	8	Sum
Difficulty index	-0.28	-0.51	-0.17	-0.12	-0.08	0.28	0.01	0.87	0.00

each item was comparatively satisfying. The results among inter-raters of each item developed in this study can be said to agree.

As shown in Table 12, the inter-rater reliability of each subcategory factor of scientific creativity was comparatively satisfying. The results among inter-raters of each subcategory factor of scientific creativity can also be said to agree.

Discrimination

To determine discrimination of the assessment instruments, point-biserial correlation index was calculated (Table 13).

As shown in Table 13, because no item was calculated to have negative point-biserial correlation index, it can be said that most items have the capacity to discriminate higher-group students from lower-group students.

Item Difficulty

To identify item difficulty of the assessment instruments, the FACETS program was used(Table 14).

As shown in Table 14, because the item difficulty index of most items was within the permitted limit, there will be few difficulties to solve the items developed in this study.

Conclusion

The purpose of this study is to suggest a scientific creativity assessment instrument that can be solved when both earth science knowledge and general creativity are applied at the same time. The results of the experiments indicate that the cognitive ability gaps between creativity and scientific creativity were clearly defined by the operational definitions based on analysis of previous researches and studies on creativity.

Four subcategory factors-fluency, flexibility, elaboration, and originality were selected to develop items for assessment of scientific creativity. The operational definitions of these factors were formulated and the criteria for assessment and scoring were also set.

The assessment instruments for assessing scientific creativity were developed. They were composed of 8 items with two items for each subcategory factor of scientific creativity.

The basic conditions required for the assessment instruments were verified on three field trials. The FACETS program based on item response theory was used to verify validity and difficulty while SPSSWIN 10.0 (Windows version) was used to verify reliability and discrimination.

The average item fitness index was 0.99, Cronbach α, the item inter-consistency, was 0.79, the inter-rater reliability of each item was 0.78, the inter-rater reliability of each factor was 0.75, the item discrimination power was 0.19, and item difficulty was 0.00.

Because the results were within permitted limit of the conditions required for assessment instruments, the assessment instruments developed for scientific creativity in this study can be said to be very favorable.

The scientific creativity assessment instrument developed in this study can be a reliable alternative method to assess the students' achievement proficiency of earth science creativity. It can also be used as a material to test to what degree creativity is reflected in developing a training program for teachers focusing on scientific creativity education, scientific creativity curriculum, and educational materials. In addition, they can be used as a useful guide to develop the instruments for discriminating gifted students with scientific inclination and designing the curriculum and teaching-learning materials for them.

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