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Math Creative Problem Solving Ability Test for Identification of the Mathematically Gifted[1]

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The purpose of this study was to develop math creative problem solving test in order to identify the mathematically gifted on the basis of their math creative problem solving ability and evaluate the goodness of the test in terms of its reliability and validity of measuring creativity in math problem solving on the basis of fluency in producing valid solutions. Ten open math problems were developed requiring math thinking abilities such as intuitive insight, organization of information, inductive and deductive reasoning, generalization and application, and reflective thinking. The 10 open math test items were administered to 2,029 Grade 5 students who were recommended by their teachers as candidates for gifted education programs. Fluency, the number of valid solutions, in each problem was scored by math teachers. Their responses were analyzed by BIGSTEPTS based on Rasch's 1-parameter item-response model. The item analyses revealed that the problems were good in reliability, validity, difficulty, and discrimination power even when creativity was scored with the single criteria of fluency. This also confirmed that the open problems which are less-defined, less-structured and non-entrenched were good in measuring math creativity of the candidates for math gifted education programs. In addition, it discriminated applicants for two different gifted educational institutions and between male and female students as well.

Keywords: mathematical creative problem solving, mathematically gifted
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MSC2000 Classification: 97D40

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1. INTRODUCTION

There is no doubt in the fact that creativity is one of the most important components of giftedness. However, creativity has been understood from a very limited perspective. Creativity has been studied from one of several different perspectives for many years. Some focused on personality characteristics of the eminent scientists (Roe 1953; Mackinnon 1970; Amabile 1983), some on cognitive aspect such as divergent thinking processes (Guilford 1967; Mednick 1962), and others on social factors (Amabile 1983; Simonton 1984). These studies confused readers regarding the concept of creativity by trying to explain creativity only with one factor.

New frameworks integrating various perspectives on creativity have been suggested by several scholars. Amabile (1996) suggested creativity as composed of knowledge and abilities in specific area, creativity related skills, and motivation. Sternberg and Lubart (1999) suggested creativity as a result of interaction among cognitive processes, knowledge, thinking style, personality, motivation and environmental resources. Urban (1995) suggest componential model of creativity, in which creativity is the product of dynamic interaction of six cognitive and personal components of creativity. These new theories generally emphasize dynamic interaction among various factors related to creativity.

However, there are very few math tests based on the new framework of creativity even for the gifted (Wallach 1985). National Research Center on Gifted and Talented Education has been developing Math Creative Problem Solving Ability Test (MCPSAT) each year since 1996 for identification of the gifted in math who will study either in the gifted education centers or classes in Korea. There are 52 gifted education centers and 182 gifted education classes. The gifted education centers recruit gifted students from all or several schools in the designated school district. The gifted education classes recruit students from one school only. The mathematically gifted was defined as those who show superior ability in solving the math problems in a creative way (Kim, Cho & Ahn 2003). In other words, they have high potential to be a creative mathematician in the future and show superior Mathematical Creative Problem Solving Ability (MCPSA). MCPSA is an ability to produce new solutions by using existing knowledge base, principles, concepts, and various thinking strategies.

Conceptual frame of MCPSA has been represented in Figure 1 by Kim, Cho & Ahn (2003) through review of studies on creativity, problem solving, and giftedness (Balka 1974; Haylock 1984, 1985, 1987; Isaaksen et al. 1994; Polya 1957; Renzulli 1978, 1985; Urban 1995; Wallas 1926). The process of math creative problem solving was regarded as composed of four stages, namely, understanding of problems, planning to solve the problems, execution of the plan, and reflection of the answer and the whole problem solving process. Throughout the four stages, mathematical thinking ability, mathematical creativity, mathematical task commitment, and knowledge base are utilized for mathematical creative problem solving. Divergent thinking and convergent thinking are concurrently operated during mathematical creative problem solving. So MCPSA can be measured best when the tasks require both of the convergent and divergent thinking (Kim, Cho & Ahn 2003).

The test was developed to be used for identification of the mathematically gifted. Therefore, the target population of this test is the Grade 5 students in upper 15 % recommended by their teachers on the basis of either intelligence or achievement in math.

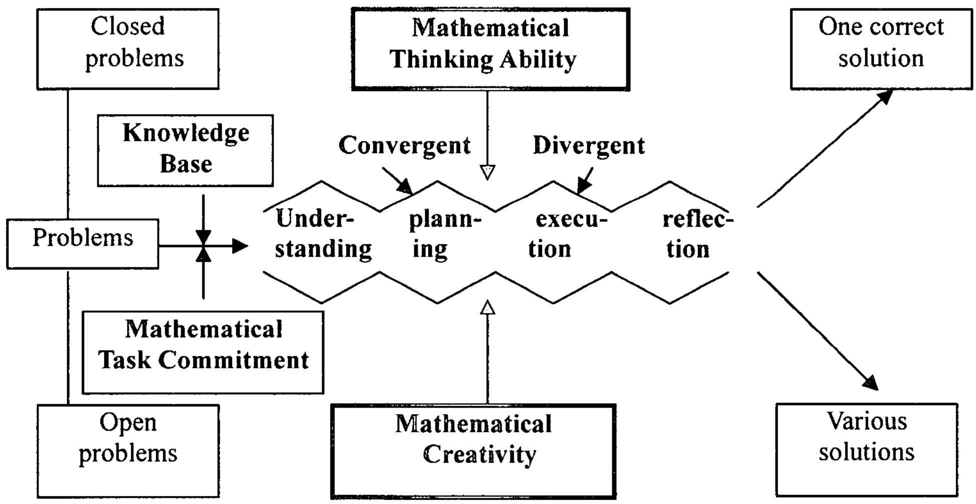


Figure 1. The Conceptual Frame of MCPSA

Depending on the degree of closedness of the problem, the problem may require one correct solution or allow various solutions. In this study, goodness of 10 open problems developed in 2005 is presented which were used for identification of the mathematically gifted. Only open problems are used for identification, since it was found that the open problems were better in evaluating the MCPSA of the gifted during the last 10 years (Lee & Hwang 2003; Hwang 2005). Open problem is defined as those problems whose starting situation and/or the goal situation are open. Problems dealt with in school mathematics are usually closed problems, or more generally closed tasks, which will not leave much room for creative thinking (*cf.* Pehkonen 1995a, 1995b). It was intended to develop less defined, less structured and non-entrenched problems so that each problem can allow students to exert creativity in solving them.

The 10 open problems required interaction of knowledge and skills in math, convergent thinking, divergent thinking, and task commitment. In the process of the development of creative problem solving test in math, the usefulness of test for identification of the mathematically gifted has been examined.

1.1. Mathematical Creativity

Mathematical creativity means an ability that can produce various solutions for a math problem (Kim, Kim, Bang, Song & Hwang 1997)... Guilford and Torrance measure creativity with four criteria as follows (Kim 1998; Pehkonen 1995a, 1995b):

① Fluency refers to generation and creation of many responses and ideas. The more the number of correct answers, the more fluent the person is.
② Flexibility refers to generation of many different categories of responses and ideas overcoming the fixedness. The more the number of different categories of correct answers, the more flexible the person is.
③ Originality refers to generation of responses and ideas different from other persons It means rarity and uniqueness of answers.
④ Elaboration refers to extension of a simple design to a more complex or intricate design. However, elaboration is not measured by MCPSAT.

Mathematical creativity, divergent products, can be measured in three different ways: first, fluency only is used as measuring factor (*cf.* Foster 1970; Bauer 1971; Maxwell 1974). Second, flexibility only is used (*cf.* Krutetskii 1976). Third, fluency and originality are used (*cf.* Mainville 1972). Fourth, fluency, flexibility and originality are used (*cf.* Evans 1964; Zosa 1978; Balka 1974; Kim et. al 1997; Song 1998; Lee & Hwang 2003; Hwang 2005). Among the four different ways, the first is the easiest way. Especially when there are some thousands students writing the exam and need to be scored within some days, practical efficiency is one of the necessity. In addition, several studies showed high correlation coefficients between the fluency and flexibility in math creative problem solving (Kim, Kim, Bang, Song & Hwang 1997; Balka 1974) ranging from 0.97 and 0.92. And the correlation coefficients were significant at the .001 level. Fluency and originality also showed high correlation with coefficients of 0.70 (Kim and others 1997) and 0.57 (Balka 1974). The correlation coefficients were statistically significant. Therefore, only fluency was used to measure creativity in this study, since originality is more difficulty to score with high reliability without intensive training.

1.2. Mathematical Thinking Ability

Mathematical thinking ability measured in the MCPSAT is composed of 5 sub-abilities as follows:

① Intuitive insight refers to figuring out the relationship and structure of given information and conditions, find out the critical cues of problem solving.
② Organization of knowledge refers to collecting and manipulating the necessary information for solving problems.
③ Reasoning refers to systematic reasoning in terms of inductive thinking and deductive thinking.
④ Generalization and application refers to generalizing and applying the mathematical relationships.
⑤ Reflective thinking refers to a kind of meta-cognitive processes on his/her own problem solving process and its relevancy with the problem

Examples of 3 types of problems among the 10 problems were presented in the followings.

Problem 2 (Number and Operations, Reflective thinking): 75 can be expressed as a sum of two continuous natural numbers as 75 = 37 + 38. 75 can also be expressed as a sum of three continuous natural numbers as 75 = 24 + 25 + 26. Find as many new equations that make 75 by adding continuous natural numbers as possible.

Equation: ______________
Equation: ______________
Equation: ______________
Equation: ______________
Equation: ______________

Problem 4 (Pattern and Function, Generalization and application): In the following diagram, the sum of two numbers at the left side is written on the next right side box. Using the same pattern, please answer the following problems.

4	6	10	16	26
4 + 6 = 10 6 + 10 = 16 10 + 16 = 26				
10	0	10	10	20
0	7	7	14	21
5	5	10	15	25
3	6	9	15	24
10	20	30	50	80
20	40	60	100	160

Complete the following table.

(1)	6		9		
(2)	6				15

(3) Let ◎ be any even numbers, with 40 < ◎ < 50. Find all natural numbers that can be ◆.

◆		18		◎

Problem 6 (Geometry, Generalization and application): There are 9 sticks of different lengths from 1cm, 2cm, 3cm, 4cm, 5cm, 6cm, 7cm, 8cm, to 9cm. Several sticks can be selected to make a square.

(1) How long is the length (cm) of one side of the biggest square?
(2) What is the area (cm^2) of the smallest square?
(3) How many different ways of making square whose length of one side is 9cm are there?
(4) How many squares of different sizes can you make?

Because of time limit, all sub-abilities and contents in taxonomy matrix of mathematics could not be included in the tests. In addition, mathematical concepts the Grade 5 students learned through regular curriculum are limited, so that math contents of 10 problems could not be diverse either. Time needed for implementation of the test was 90 minutes.

2. METHOD

2.1. Design

The study was carried out (a) to examine reliability, validity, difficulty, relevance and discrimination power of creative problem solving ability test; and (b) to investigate whether differences in mathematical problem solving ability exist between students applied for gifted education centers and classes and between male and female students. In this study, internal validity and difficulty were assessed based on Rasch's 1-parameter item-response model.

2.2. Subjects

The subjects of this study were 2,029 Grade 5 students who applied for entrance examinations to the Gifted Education Centers and Classes of 7 Metropolitan Cities and

Provincial Offices of Education.

2.3. Instrumentation

Ten problems were used for evaluation of mathematical creative problem solving ability. Taxonomy of 10 problems is presented in Table 1. Ten problems were developed through four times of workshops among 1 professional in gifted education, 2 mathematicians, 3 professionals in math education and 10 math teachers in 2005. Activities of workshops includes analysis of math problems developed and used for identification of the gifted in 2004, deciding the direction of problem development in 2005, detailed planning of problem development, review of newly developed problems to secure more of ill-defined, unstructured and non-entrenched problems, and several times of revision of inappropriate problems and selection of the best 10 problems.

Table 1. Mathematical Creative Problem Solving Ability Test

Item Number	Contents	Mathematical Thinking	Score
1	Number and Operation	Intuitive insight	15
2	Number and Operation	Reflective thinking	15
3	Number and Operation	Deductive thinking	15
4	Pattern and Function	Generalization and application	20
5	Equation	Deductive thinking	20
6	Geometry	Generalization and application	20
7	Equation	Organization of information	20
8	Pattern and Function	Deductive thinking	25
9	Pattern and Function	Deductive thinking	25
10	Pattern and Function	Inductive thinking	25
Total			200

The type of problems to be developed was decided based on the analyses of the previous response data of gifted students on open math problem in terms of their validity. In the previous study, some test items were found inappropriate for identification of the gifted. In other words, students of highly capable and creative could not provide new and unique solutions to such test items; meanwhile students of relatively lower ability could provide solutions (Lee & Hwang 2003; Hwang 2005). Such items showed following characteristics.

First, test items do not allow partial answers and partial scores. On such test items, students showed extreme scores of either zero or full marks. Distribution of data was concentrated at each end of the scores resulting in U shape of data distribution.

Second, entrenched test items for certain group of students, who prepared and practiced for math competition were inappropriate for identification of the gifted. Those who experienced scored very high, and those who did not experience scored low generally. Distribution of data on such test item is also U shaped and mismatched between students' overall math ability and score on the test item.

Third, complex problems which require many problem solving steps did not show high discrimination validity since those experienced with similar problems can solve, meanwhile those inexperienced with similar problems could not provide solutions within such a short exam time.

Fourth, test items whose concepts to be learned at the higher grades were found to be inappropriate for identification of the gifted. Therefore, such types of problems were excluded as much as possible in the process of problem development. Problems of less defined, less structured and non-entrenched, from students' perspective, were sought as much as possible in the development of test items.

2.4. Test Administration and Scoring

Ten problems were administered to those who sat for paper-pencil test at the 2nd screening stage in the process of identification of the gifted at the gifted education centers and gifted education classes in 7 metropolitan cities and provincial offices of education in January 2005. Prior to conducting the test, the subjects were instructed by administrators for 5 minutes on how to complete their answer sheets. They were given 90 minutes to present various types of original and unique answers. Best math teachers who have had experience of teaching the mathematically gifted from each Metropolitan cities and provinces were designated for scoring and they were trained on the nature of the problem and possible answers for each test item. A reference table for scoring students' responses was developed by selecting and classifying all relevant responses of students to each item Teachers consulted the research team when they were faced with very unique responses and when they were not sure how to score.

2.5. Data analysis

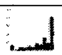
In order to evaluate item-internal consistency reliability and discrimination, Cronbach α was calculated using SPSS 10.0K. Internal validity and difficulty were calculated using BIGSTEPS (Livacre & Wright 1994, 2003) based on Rasch's 1-parameter item-response model.

3. RESULTS

3.1. Analysis of Students' Responses on the MCPSAT

Means and SD, Internal validity, difficulty levels, discrimination validity and distribution of scores of each of 10 problems were shown in Table 2. Test item 1, 5, and 9 showed medium level of difficulty and their Infit and Outfit indices were higher than 1.2. Therefore these items were not appropriate for analysis model. However, there was no test item whose Infit and Outfit indices were higher than 1.5, the test items could be seen as appropriate for analyses according to the Rach's 1-paprameter item-response model.

Table 2. Mean, SD, Internal Validity, Difficulties, Discrimination and Distribution of Applicants' Responses at MCPSAT in Grade 5

Number	Mean	SD	Internal Validity		Difficulties	Discriminations	Distribution
			Infit	Outfit			
1	10.61	5.14	1.24	1.21	-0.35	0.4552	
2	7.17	5.74	0.88	0.96	0.05	0.4922	
3	6.08	6.55	0.88	0.84	0.32	0.3720	
4	14.22	6.81	1.14	1.18	0.02	0.3765	
5	10.66	7.51	1.00	1.25	0.20	0.4948	
6	6.36	5.63	0.70	0.75	0.01	0.5046	
7	13.57	5.81	1.01	0.99	-0.43	0.5451	
8	18.87	7.29	1.19	1.17	-0.19	0.5616	
9	5.15	6.91	1.24	1.17	0.01	0.4553	
10	5.84	6.91	0.84	1.00	0.36	0.4757	
Total	98.53	32.86	1.01	1.05	0.00		

3.2. Goodness of MCPSA Test

In order to examine the goodness of the MCPSA test for identification of the mathematically gifted, statistical analyses were carried out in terms of item-internal consistency reliability, internal validity by item relevance index, difficulty level, and discrimination validity.

Item-internal Consistency Reliability.

To evaluate the reliability of the test, Cronbach α was calculated, which indicates item-internal consistency reliability. Cronbach α was 0.68 suggesting that the test composed of 10 problems is fairly reliable.

Internal Validity by Item Relevance Index.

The internal validity of each test item was calculated using BIGSTEPS, a computer program designed to measure parameter values and conduct item analysis based on Rasch's 1-parameter item-response model. The analysis model used in this study was the Partial Credit Model. Every item relevance index was less than 1.2. The results showed that the internal validity of the test items were high enough to be good items.

Table 3. Internal Validity of the MCPSAT by Item Relevance Indexes

Item	1	2	3	4	5	6	7	8	9	10	Total
Infit	1.24	.88	.88	1.14	1.00	.70	1.01	1.19	1.24	.84	1.01
Outfit	1.21	.96	.84	1.18	1.25	.75	.99	1.17	1.17	1.00	1.05

Difficulty.

Item difficulty refers to the degree of difficulty of each test item. In this study, item difficulty was calculated based on Rasch's 1-parameter item response model. The item difficulty of 0.0 means "average." A higher positive number indicates the test item is more difficult. On a "difficulty" scale, the differences in difficulty between items are evenly distributed as far as the logit score does not exceed 0.36. All the item reliability indices were higher than 0.68. The fact implies that the problems were well distributed in terms of difficulty level and highly appropriate for discrimination of the mathematical creative problem solving ability of applicants.

Table 4. Difficulty level of the MCPSAT Items

Item	1	2	3	4	5	6	7	8	9	10	Total
Difficulties	-.35	.05	.32	.02	.20	.01	-.43	-.19	.01	.36	.00

Discrimination validity.

The discrimination power of each open-ended item was examined by calculating point-biserial correlation coefficients. Point-biserial correlation represents the correlation between the score of a single item and the total score of the remaining items. An item with negative value is not suitable for discrimination between high- and low-ability students. Items with point-biserial correlation of less than 0 are interpreted as of low discrimination validity because they allow students to get good marks easily based on their previous knowledge. Among the 10 problems, there was no item whose point-biserial correlation coefficient was less than 0. All items can be interpreted as good items in discrimination between high and low ability students on the basis of mathematical creative problem solving ability.

Table 5. Discrimination validity of the MCPSAT Items

Item	1	2	3	4	5	6	7	8	9	10
Discriminations	.5002	.5447	.5233	.5620	.4925	.4684	.5848	.5905	.5247	.3249

3.3. Group Differences in MCPSA

In order to examine the gender differences in Math Creative Problem Solving Ability, responses of male and female students were analyzed. Means and standard deviations of scores of male and female students of each test item and t-test results are presented in Table 6.

Table 6. Differences in MCPSA between male and female students

Item Number	Gender	N	Mean	SD	t	p
1	Male	1243	11.1529	4.90776	6.015	.000**
	Female	786	9.7570	5.37090		
2	Male	1243	7.7530	5.80349	5.805	.000**
	Female	786	6.2455	5.52696		
3	Male	1243	6.3644	6.56087	2.426	.015*
	Female	786	5.6412	6.51239		
4	Male	1243	14.1698	6.77979	-.375	.707
	Female	786	14.2863	6.86323		
5	Male	1243	11.3186	7.32311	4.983	.000**
	Female	786	9.6247	7.67146		
6	Male	1243	6.5406	5.71919	1.840	.066
	Female	786	6.0687	5.48330		
7	Male	1243	13.9107	5.69580	3.383	.001**
	Female	786	13.0178	5.94216		
8	Male	1243	19.3484	7.05957	3.729	.000**
	Female	786	18.1132	7.58803		
9	Male	1243	5.7168	7.32687	4.653	.000**
	Female	786	4.2583	6.10321		
10	Male	1243	6.2518	7.01472	3.351	.001**
	Female	786	5.1997	6.68429		
Total	Male	1243	102.5270	33.15177	6.968	.000**
	Female	786	92.2125	31.39178		

There were significant differences in most of the test items of MCPSA between male and female students except in item 4 and item 6. The results confirmed the findings of other studies (Haylock 1984; Skaalvik & Rankin 1994) which showed males were more creative in math problem solving, except in two items.

In order to analyze the differences between applicants for Gifted Education Centers and for Gifted Education Classes, t-test was carried out and it was found that there were significant differences in most of the items of MCPSAT between applicants for two different institutions except in the test item 10.

Table 7 provides the means and standard deviations on the MCPSAT of students in each group. The result of *t*-test (see Table 7) showed significant differences between the applicants for the two gifted educational institutions in the performance scores on MCPSAT. Applicants for the Gifted Education Centers showed significantly higher scores on most of the test items except in item 10.

Table 7. Differences in MCPSA between applicants for gifted educational centers and classes

Item Number	Group	N	Mean	SD	t	p
1	Centers	1497	10.8958	5.02439	4.190	.000**
	Classes	532	9.8139	5.36301		
2	Centers	1497	7.5478	5.72374	5.012	.000**
	Classes	532	6.1034	5.67071		
3	Centers	1497	6.5364	6.60215	5.250	.000**
	Classes	532	4.8120	6.23326		
4	Centers	1497	14.7802	6.56511	6.332	.000**
	Classes	532	12.6241	7.23155		
5	Centers	1497	10.9713	7.54460	3.117	.002**
	Classes	532	9.7932	7.32450		
6	Centers	1497	6.6834	5.70017	4.387	.000**
	Classes	532	5.4417	5.33637		
7	Centers	1497	13.9733	5.61111	5.351	.000**
	Classes	532	12.4154	6.18929		
8	Centers	1497	19.4816	6.91863	6.401	.000**
	Classes	532	17.1485	8.01191		
9	Centers	1497	5.4870	7.15573	3.674	.000**
	Classes	532	4.2086	6.09032		
10	Centers	1497	5.8370	6.81685	-.079	.937
	Classes	532	5.8647	7.15740		
Total	Centers	1497	102.1937	31.62227	8.571	.000**
	Classes	532	88.2256	34.09511		

Note. Centers=Gifted Education Centers; Classes=Gifted Education Classes

The results confirmed that more capable students apply to the gifted education centers, which provide program for the talented in mathematics at the level of school district; meanwhile the less talented students apply to the gifted education classes.

4. CONCLUSIONS

The test developed in this study was analyzed by Rasch's 1-parameter item-response model with the data of 2,029 Grade 5 applicants for the gifted education program in Korea. As a result of item analyses, it showed the test was fairly reliable since the Cronbach α as an index of internal validity was 0.68. The Item Relevance Indices for Internal Validity of the MCPSAT were high since most of the indices were lower than 1.2 except few items and ranged between 0.70 and 1.24. Item difficulty levels of 10 problems were well distributed from easy to difficult ranging from -0.43 to 0.35. Discrimination power of test items was found to be high enough since the indices is generally higher than .30 ranging from .33 to .59. Overall, the MCPSAT is found to be reliable and valid for identification of the mathematically gifted.

The finding of the study confirmed the gender differences found in previous studies, revealing that the male students are more creative in math problem solving than female students at the MCPSAT. However, no significant difference was found on the component of Generalization and application ability (t = -0.375, p = 0.707). It was also found that the applicants to two different gifted educational institutions were significantly different in their MCPSA, being the applicants to Gifted Education Centers higher than those for Gifted Education Classes in MCPSA. However, no statistically significant difference was found on the component of inductive thinking ability (t = -0.079, p = 0.937).

Based on these results, it was concluded that the direction of test item development, which is to exclude the test items which may lead extremely skewed or U shaped distribution of data and to included problems which are less defined, less structured and non-entrenched were correct. It was also confirmed that scoring creativity in math problem solving on the basis of fluency is reasonable and quite efficient. However, by requiring students to produce as many responses as possible within the limited time period to measure fluency, students' ability to produce original solution could not be maximally executed. Therefore, further study about this is needed. It is necessary to carry out more in-depth study on the relationship between fluency and originality in the future studies.

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