Jour. Korean Earth Science Society, v. 25, no. 8, p. 674–683, December 2004

Rethinking the High Ability Students to Foster Their Scientific Research Skill: Through an Experimental Designing Test

Myeong-Kyeong Shin[1,*], Jong-Wook Park[1], Hyun-Chul Jung[2], and Nam-Young Heo[2]

[1]Cheongju National University of Education, 361-711, Korea
[2]Korean Educational Development Institute, 137-791, Korea

과학적 연구능력을 통해 본 영재학생에 대한 재고: 실험설계검사를 통하여

신명경[1,*] · 박종욱[1] · 정현철[2] · 허남영[2]

[1]청주교육대학교 과학영재교육원, 361-712 충북 청주시 흥덕구 수곡동
[2]한국교육개발원, 137-791 서울 서초구 우면동1137-791

Abstract: There is more than one way to conduct scientific research. In addressing the concern for educating the gifted in science towards achieving objectives of fostering their research skill, its elements need be explored and discussed by first admitting that various methodologies and features coexist in the name of scientific research. This study explores the various features of research skills presented as scientific process skills focusing on the student's experimental designing. Of course, there are several other domains included facets of research skills, such as problem finding, scientific knowledge, and self-efficacy. A Diet Cola Test (DCT) (Fowler, 1990) for digging into science process skills as an element of research skills was administered to 705 students from 3rd to 10th grade, who enrolled the gifted education centers in Korea. Data was interpreted and analyzed based on the focus of Science educational perspectives and research methods related to creative thinking and problem-based learning. But I eschew establishing and generalizing fixed constituents of research skill from this research.

Keywords: gifted education, scientific creativity, research skill

요 약: 과학연구를 하는 방법은 매우 다양하다. 과학영재아들로 하여금 본연의 과학연구능력을 계발하고 구현하도록 하는 목적을 달성한다는 것은 이미 알려진 영재교육의 목표이다. 여기서 과학연구능력이라고 할 때 과학연구의 요소는 무엇인가 살펴볼 필요가 생기며 하나의 과학연구가 존재하기 보다는 다양한 연구방법이 공존한다는 입장이 더 설득력이 있다. 본 연구는 연구능력의 다양한 측면과 특성을 알아보는 탐색연구이며 더 세부적으로 들어가서 과학과정 능력 중 실험설계능력에 초점을 맞추었다. 물론 연구능력이라고 할 때에는 문제 발견, 과학지식, 자아통찰 등 다양한 영역이 포함된다. 본 연구에서는 실험설계능력을 보기 위해 1990년 Fowler가 개발한 Diet Cola Test를 국내의 학생들이 사용할 수 있도록 번안하여 사용하였다. 전국 과학영재교육 프로그램에 참여하는 학생 중 총 705명의 초등학교 3학년에서 고등학교 1학년 학생들이 연구대상이 되었으며 과학교육분야에서의 문제중심학습과 창의적 사고력이라는 부분에 초점을 맞추어 연구자료를 해석하였다.

주요어: 영재교육, 과학적 창의력, 연구능력

*Corresponding author: mysehee@hanmail.net
Tel: 82-43-299-0625
Fax: 82-43-299-0627

Background to the Study

This paper will depict how the gifted in science design their own experiments to solve a given science related problem. It is popularly assumed that the gifted are good in making something very creatively. Designing experiments will not be an exception. Creativity has been characterized by several properties such as sensitivity to problems, identification of difficulties, search for solutions, formulation of hypothesis and their experimental examination (Torrance, 1962). These properties have been used as fundamental ideas for the development of several natural science curricula for high school students. Divergent thinking, which is common to these ideas, is manifested in high school curricula activities like scientific master-papers, or open discussion of any studied subject matter. To find out whether these activities, or any other natural science curriculum, contribute to the development of science creativity, a relevant test is needed. Such a test should be able to, not only to evaluate curricula, but also to identify highly creative students, to measure the development of scientific creativity in student populations and to suggest the direction that special programmers for science creativity could take.

General creativity measurements have been usually based on verbal responses to verbal and nonverbal stimuli, concerning all kinds of creativity (Taylor and Getzels, 1975). Different perceptions of the meaning of creativity have led to a correspondingly wide variety of techniques to assess creativity. The Diet Cola Test used in the study was one of such trial but it focuses on scientific process skills with an emphasis on designing experiments.

Theoretical Perspectives and Research Questions

Research can be used as a method to work with the gifted especially in science. The method is characterized as self-regulated projects, targeted to a interdisciplinary subject, problem based, discerning known and unknown variables, taking a great use of what they already know, and using and nurturing students' sciencing skills including problem finding, problem solving, problem reevaluation, and scientific reporting. Such elements of research can be termed as research skill. Looking into each facet of research skill leads us to easily detect an implicit overarching theme of "in creative way", which is refined to be scientific creativity.

Before considering how research skill is revealed in the gifted, I need to clarify what scientific creativity is meant as commonly possessed. The concept of creativity has proven over the years to be an elusive one to define. As early as 1960, Rapucci (quoted by Welsch 1981) counted between 50 and 60 definitions in the literature on creativity. Twenty years later, an extensive review forced Welsch (1981) to conclude that the literature contains that the task of arriving at an integrated and agreed definition is virtually impossible.

Nevertheless it is possible to find some common features and to combine these into a model of scientific creativity. For example, many researchers combine two or more aspects of the creative process, creative product, creative person and creative environment in defining general creativity. As proposed by Hu and Adey (2002), scientific creativity is structured with three dimensions: 1st dimension is trait consisting of fluency, flexibility and originality; 2nd is process of thinking and imagination; 3rd is product of technical product, science knowledge, science phenomena and science problem. Their model is quite different from general creativity. Also similar trials of defining and facilitating scientific creativity have targeted gifted students (Jung, 2002; Park, 2004). Park (2004) documented that the domain-general creativity test could not cover domain-specific scientific creativity test based on the neuropsychologoical approaches to 147 middle school students. Recalling the best known test of general creativity, it would be the Torrance Test of Creativity Thinking (Torrance, 1990) which is a paper-pencil test which taps divergent thinking abilities (Hu and Adey, 2002). Torrance (1990) considered fluency, flexibility, and original thinking as central features of general creativity. Fluency means the number of original ideas produced, and flexibility is the ability to 'change tack', not to be bound by an established approach after that approach is found no longer to work efficiently. Originality is interpreted statistically: an answer which is rare, which occurs only occasionally in a given population, is considered original. Fluency, flexibility, and originality thus form one dimension of the model, one which can be described as being a personality trait, the characteristics of the creative person. Although divergent thinking is no longer considered to be synonymous with creative ability, it is nevertheless an important component of creative potential. For divergent thinking just leads to potentially creative ideas but there's much more to creativity than being unusual or original, as we will see.

Regarding the development of creativity, there is no general agreement. Findley and Lumsden (1988) documented that from the age of 7 to early adolescence there seems to be a continual decline in creativity caused by greater attention to peer pressure and social conventions. But Chein (1982) concluded that the creative thinking abilities of gifted students increase with age. Lubart (1994) has suggested that creativity is related to knowledge and experience. Amabile (1987), Sternberg and Lubart (1991) and Fledhusen (1995) all report that domain-specific knowledge and skills are a necessary component of creativity. Creative thinking is also moderately related to academic achievement although there seems to be no linear relationship between knowledge and creativity (Simonton, 1983). With the increase of age, scientific knowledge, experiences, and skills increase so according to the above researchers, scientific creativity should increase but it should be have linear relationship with age (Hu and Adey, 2002).

In summary, scientific creativity is defined as a kind of intellectual trait or ability producing or potentially producing a certain product that is original and has social or personal value, designed with a certain purpose in mind, using given information. Scientific creativity is different from other creativity since it is concerned with creative science experiments, creative scientific problem finding and solving, and creative science activity. The structure of scientific creativity itself does not include non-intellectual factors, although non-intellectual factors may influence scientific creativity. Also it depends on scientific knowledge and skills. Creativity and analytical intelligence are two different factors of a singular function originating from mental ability. Finally scientific creativity should be combination of static structure and developmental structure. The adolescent and the mature scientist have the same basic mental structure of scientific creativity but that of the latter is more developed (Hu and Adey, 2002).

The research questions which we tried to answer in this study are as follows:

1) How are the gifted students' experiment designs evaluated in terms of given checklist items of 14?

2) How are the experiment designs affected by student factors: their gender, grade, intensive program contents, local area, the number of years spent in the gifted education programs?

Methodology

Subjects

Students in the study attended the Korean gifted education institutes for students talented in science. Admission to the institutes is competitive. Students applying to the institutes ranked in the top 5% of Korean students in regular schools in terms of achievement test similar to ITBS (Iowa Test of Basic Skill). All students participated in the test were 3rd to 10th graders: 22 in 3rd, 10 in 4th, 118 in 5th, 155 in 6th, 115 in 7th , 201 in 8th, 66 in 9th, and 17 in 10th. A total of 705 student subjects have applied for the creative research based invention festival which was organized by the Korean Education Development Institute. The ratio of student gender is male students of 459 and

Table 1. Checklist for evaluation of experiment design

Item number	Checklist item for evaluating experiment design
1	Including more than three steps in designing an experiment.
2	Considering safety rules in designing an experiment
3	*Describing questions or problems.*
4	Predicting results and formulating hypotheses
5	Preparing lists of experiment devices and materials
6	Defining terms or jargons used in an experiment.
7	*Including observation plan.*
8	Including measuring plan.
9	Including data collection plan.
10	Including plan of interpreting data
11	Including plan of inferring and creating conclusions based on the data collected
12	Defining variables
13	Controlling variables
14	Including plan of reiterating experiments

female, 235. It can be assumed that they have more interest and positive attitude in creative research based-inventing activity among the tutees of the gifted education centers.

Instrument

Before administering the experimental design test, we collected the demographic data of students including their gender, age, grades, field of intensive works, locality and the time that they started to participate the gifted education programs.

The instrument to test students' experimenting skill was the Diet Cola Test developed by Fowler (1990). In this study, we used form B. The DCT is to test a skill of designing an experiment.

Student subjects were asked of the following question: "Are earthworms attracted to light?" followed by a direction saying "How would you do a fair test for this question?".

Scoring was done by the checklist of 14 items and 0 or 1 or 2 were awarded for each item incorporated into the design. Four graduate students in science education major worked as scorers and the agreement rate was employed to establish an interrater reliability. It was 0.74 by scoring 101 DCT answering sheets out of 705 samples.

Checklist Items

To score students' responses, the checklist was prepared as Table 1. These checklist items are translated and modified from the original work of Fowler (1990) in order to be used properly for this study by considering the level of understanding of students.

In this study, the items can be divided into two categories which are not suggested in the original study of Fowler's. One category is regarding actions related to complicated thinking and imagination, and the other is to general skill and techniques. Again the first category is seen as more frequently shown in the regular science textbooks as basic skills. One category consists of item 1, 5, 7, 8, 9, 12, and 13. The other includes item 2, 3, 4, 6, 10, 11, and 14. Formulating hypothesis, defining problems and inferring conclusions based on the data may well ask more students' divergent and creative thinking than preparing lists of experiment devices and materials.

Research Findings and Discussions

Descriptive Analysis of Student Designing of Experiments

The scores in the table are the average of four scorers' points. Each of 14 items ranged from 0 to 4 based on counting the frequency of each item. Also the total score of 14 items reached only around 18 at most in the current data pool. It means that 14 components of evaluating designing

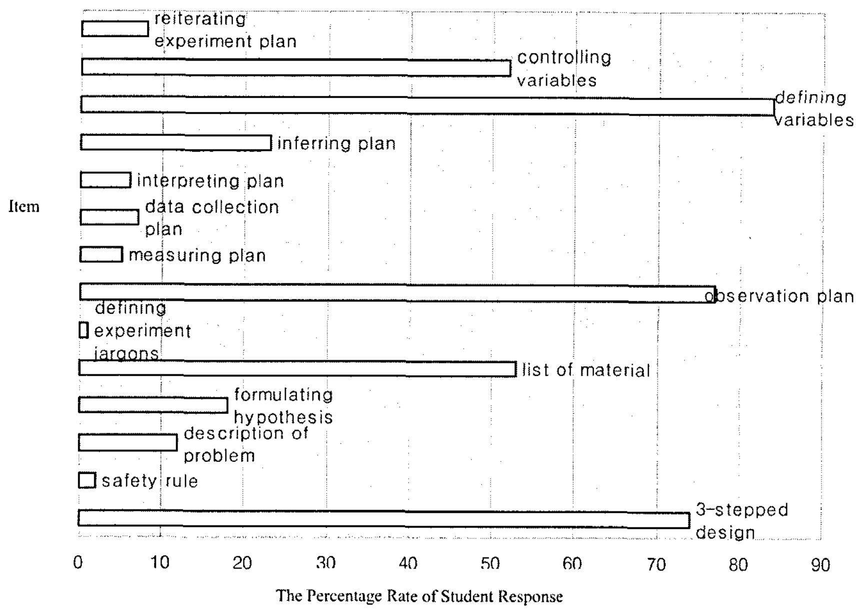

Fig. 1. Student experiment design evaluation according to each of 14 items.

experiments were not successfully presented in students' designs. An example of an experiment design scored of 9.:

"Experiment 1) Materials: three lanterns of three kinds each, soil, several earthworms, 4 of same sized box, 4 black plastic sheets, fixing device for lanterns./Cautions: 1. Cover the box with black plastic sheets. 2. Put all of four boxes in cool and dark place. 3. Don't sill the soil in the box. 4. Put same number of earthworms in each box. 5. Prepare big boxes."

The overall trend of each item was shown in Table 2. On average, 5 of 14 items were considered in students' designing. That is, item 12, 7, 1, 5, and 13 in a descending order of response rate were identified as meaningfully accounted by being appeared in more than 50% of student subjects' designs. Figure 1 indicated the overall scores of students of each item of the checklist which intended to evaluate the experiment designing. The rank of the accounted items was visually depicted from this figure.

What are the five most frequent items which students considered in designing their own experiments? They are 1) Defining variables, 2) Observation plan, 3) 3-stepped design, 4) List of experiment material and 5) Controlling Variables. These five items are relatively classified to be "easy steps" It is quite disappointing results for they are not much connected with students' own creating and imaginations. Especially when considering they are gifted students having above average level of abilities and creativities. Also those five items are most frequently appeared in the school textbook, especially in cook-book styled experiment activity sections. Consequently, students in the gifted program could not go far beyond the existing regular school curriculum focusing on superficial features of scientific research and totally outdated version of science process skill.

Comparisons According to Student Variables: Gender, Grade Level, Localities, Involving Periods and Fields of Intensive Work

With major regards to checklist items described in the above session, we run ANOVA with each item score and several student variables: student gender, grade level of elementary and secondary, localities of five different places where students live, how long students have been involved in the gifted edu-

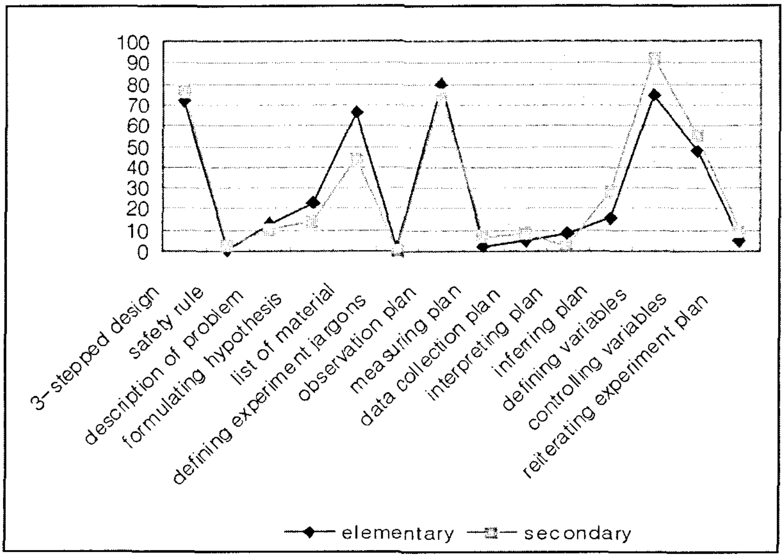

Fig. 2. Comparison of experimental design scores in 14 items between student grade level.

cation program and fields of intensive work of 'science program only' and 'science and math program' which students participated. And significant items resulting in the alpha level of $p<0.05$ will be exclusively presented.

Firstly, there are no significant differences in designing experiments according to student grades for 8 items shown in Fig. 2: elementary (n = 305) and secondary (n = 399). The items are item 4[p = 0.002], 5[p = 0.000], 10[p = 0.000], 11[p = 0.001], 12 [p = 0.000] and 14 [p = 0.033]. Interestingly item 4, 5, and 10 showed elementary students' superiority to secondary students and item 11, 12, and 14 showed secondary students'. While item 5 and 10 are classified as less complicated thinking level, item 4 regarding predicting results and formulating hypothesis is hardly seen in cook-book style experiment guide in science textbooks. Nevertheless the items 11, 12, and 14 to indicate secondary students' superiority were classified as higher level of process skills involving student creativity and thinking skills. It was not as expected for attaining more knowledge and learning experiences at school science was assumed to help students to design experiments better as students spend more time in school. This result leads us to impose two possible interpretations: 1) students' works in designing experiments are not related to their experiences and knowledge; 2) or students' designing experiments can be improved and nurtured by practicing designs and stimulating their research building abilities.

In the reports of student grade vs. student designing experiments, it failed to show that secondary students made their experimental designs more sophistically and more similar to scientific research. Somehow the amount of time in involving with the gifted education center will affect the quality of their designs. The assumption of this hypothesis is that the gifted education program will concentrate on giving students experiences of doing research in real. The comparison results between student designs and their spending time in the gifted education is shown in Fig. 3. The students were divided into three groups according to the time they spend in the gifted education program: less than 1 year of 254 students, less than 2 years of 254 students, and more than 2 years of 111 students. Similar to the results of student grade, there are no significant differences between their spending time amounts in overall. Item 5, 7, and 12 showed significant differences between groups. Those items were categorized as the first group of not sophisticated skills of

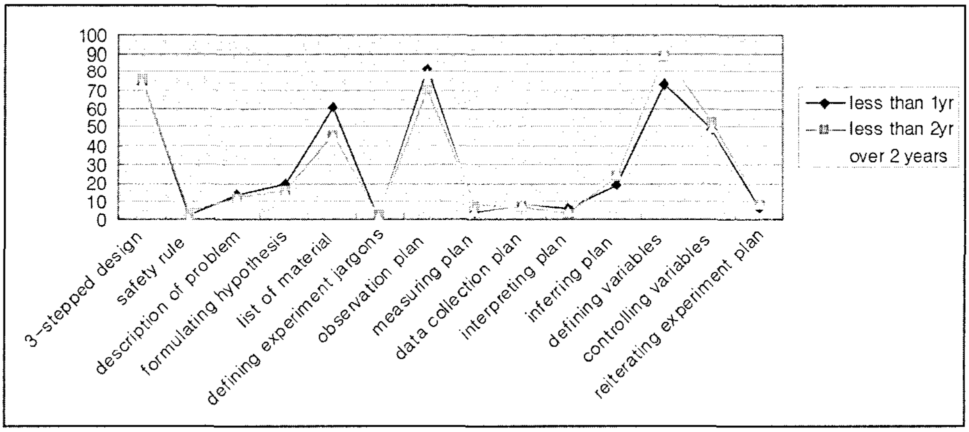

Fig. 3. Comparison of student designs according to the time of students' spending in the gifted education program.

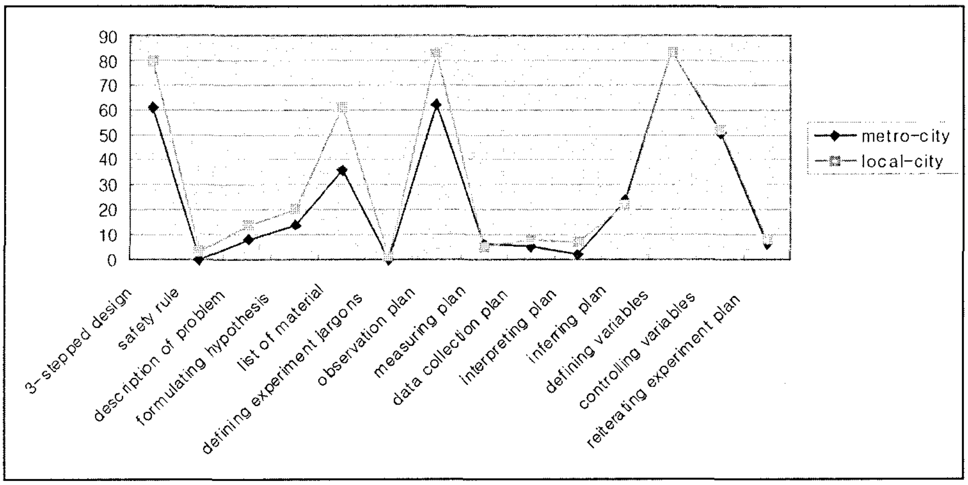

Fig. 4. Results of student localities and designing experiments (Metro-City (n=215), Local-City (n=470)).

research. Item 5 and 7 even showed the group of less than 1 year worked out better than the group of over 1 year. According to overall tendency, the total points of all 14 items rather indicated the less than 2 year groups designed better than over 2 year group. It implicates that the gifted education program does not work on students' research skill exemplified with designing experiments which means no differentiation from the regular school curriculum.

Next variable is student localities. Interestingly, there were significant differences statistically in six items and the total point of 14 items (see Fig. 4): item 1, 2, 3, 5, 7, 10 and a total score of 14 items. My expectation was the metropolitan city group of students will work better than the middle sized city group. The results however showed the opposite. However it is too bold to conclude that local middle sized cities provide better program and learning environment for the gifted students. For an in-depth interpretation of this result, it is necessary to examine detail curriculum of their gifted education programs.

Another student variable is students' intensive work. About 54 percent of student subjects participated in science program and the rest of them in science and math program: 381 students in science program and 320 in science and math program. In overall, there was no significant difference between

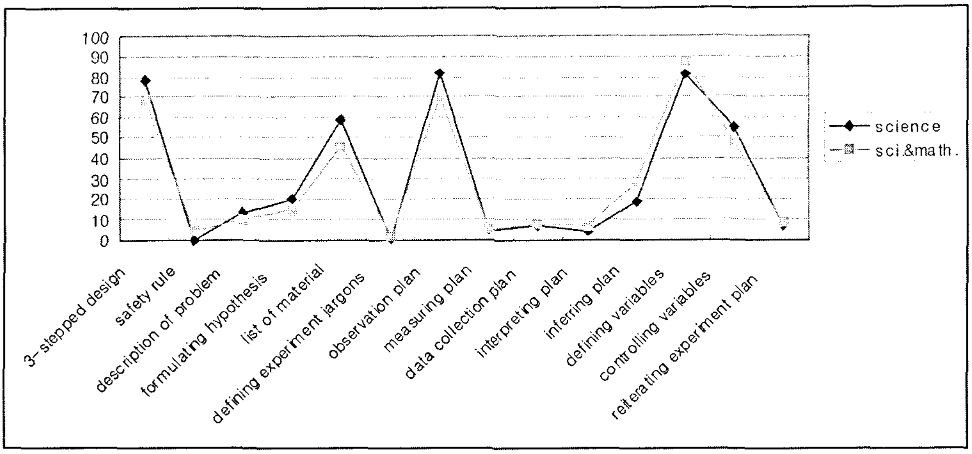

Fig. 5. Student program and designing experiments: science vs. science & math.

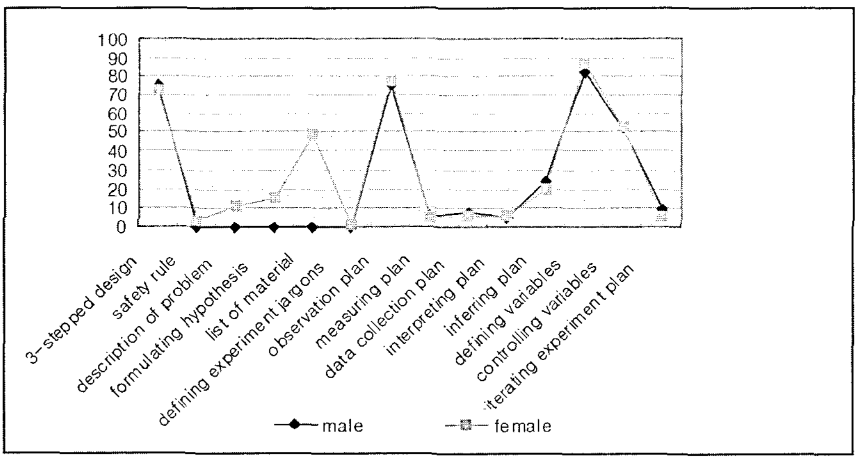

Fig. 6. Student gender and designing experiments.

both groups (see Fig. 5). Item 1, 2, 5, 7 and 11 reported significant differences. Except item 2, the rest of items indicated that students in the science program did better than the science and math programs. It can let us presume that science program might have more field work or experiment oriented activities than in science and math program. It can be granted that integrating math and science will appear more in-class work pretty much focusing on pen and pencil works.

There were 459 male and 235 female students involved in this study. The overall data did not show distinctive gender differences. In other words, there was no difference according to student gender but the total score of 14 items was higher in female group than male group: A total score of female group was 4.33 and 4.14 for male group. Nevertheless, item 5 of "including list of experiment materials" succeeded in showing that female students' mean score (0.61) was significantly higher than male's (0.59) (see Fig. 6). Also similar visual tendencies were found in domains of description of problems and formulating hypothesis. Female students used to be better organizers, and fond keeping something in order and journaling. Such trait of female students might result in their plotting higher than males in 'list of materials for the experiment'. It can be interpreted in the same way that female students wrote more lines regarding the problems and what the results would be.

Rather male students are weak in keeping records in this study. However recording and documenting is quite important elements in scientific process. Especially describing the problems and its experimental situation and predicting the experiment results needs to be emphasized in the gifted education program for the current study showed overall lower percentage of both male and female student responses in those areas.

Epilogue: Implications and Further Research Suggestions

The results of this study were not successful in finding significant differences between grades, gender, and experiences of intensive fields such as a science cluster or a science-mathematics combined cluster of the gifted students except a few sub-categories. Adams and Callahan (1995) worked on the DCT test with 180 students in 4th to 8th grade. They found no significant differences between male and female students.

Also they insisted, based on their data analysis, that DCT is not related to specific science content or to science achievement but may instead address alternative science process skills. The convergent and discriminant validity of the DCT to identify students with high ability in science was established by Adams and Callahan (1995). They used three kinds of tests: the Iowa test of basic skills, the group embedded figures test to examine field-dependence/independence, and the test of basic process skills. The DCT and the basic skill tests did not correlate significantly. It was rather disappointing in case of testing field-dependence/independence test and process skills, too. It failed to prove itself to be sufficient to suggest use for making decisions about the specific aptitude of specific individuals as an identification instrument.

It can help to interpret the results in this study. Possessing and recalling sufficient amount of scientific knowledge does not guarantee their quality experimental design. It means that learning science concepts quite often is not related to doing better scientific research. Therefore the gifted education programs should make distinguished efforts on nurturing each facet of students' creative research skills respectively. It is supported by why scientific creativity has three dimensions. The gifted education program with focusing on attaining concepts will not automatically be transferred to make prodigies to acquire real-life research skill.

In practical level, a certain portion of "finding and elaborating problem" and "design experiment to find the way to reach the answer" may as well be included in the gifted program. It does not mean that the gifted education program should let out 'all kinds of lecture'. Rather it suggests that students attain scientific knowledge through lecture after students have needs of a certain knowledge for its use in solving and perceiving their own problems.

In the level of the gifted education program, they investigate the traits and characteristics of their students in detail. For example, they might grasp of what abilities and traits their students are weak in and strong in. For supporting such investigation, there should be surely numerous studies to understand what is the scientific inquiry in terms of history of science. Therefore the better shaped gifted education program needs to be established based on the research of what is the essence of scientific creativity and how these essences are connected to student behavioral and cognitive aspect of "real knowing" under the assumption of that real knowing scientific knowledge means "doing science", that is "creating and producing".

The limitation of using the DCT was also found. The Cronbach's alpha was achieved as 0.62 when establishing the internal reliability among the checklist items. The value is hardly considered to be acceptable level. It implicated that the checklists needs to be reconsidered in terms of its consistency among items and that it is necessary restructuring the checklists through merging similar items and adding other factors or deleting some of existing items. The future study will focus on proposing several types of checklist items and refining critical features or elements of experimental designs of students' own developing. Also correlation of other facets of science process skills including problem finding will be explored. Finally how to nurture students' innate scientific research skill will be probed in later studies.

References

Adams, C.M., and Callahan, C.M., 1995, The reliability and validity of a performance task for evaluating science process skills. Gifted Quarterly, 39 (1), 14-20.

Amabile, T.M., 1987, The motivation to be creative. In S.G. Isaken (ed.) Frontiers of creativity Research: Beyond the Basics (Buffalo, NY: Bearly) pp. 223-254.

Billington, H.L., 1997, Poster presentations and peer assessment: novel forms of evaluation and assess. Journal of Biological Education, 31 (3), 218-220.

Chein, M.F., 1982, Creative thinking abilities of gifted children in Taiwan (Chinese). Bulletin of Education Psychology, 15, 97-110.

Cohen, I.B., 2000, The impact of science on society. Science Teacher, 67(5), 25-27.

Feldhusen, J.F., 1995, Creativity: A knowledge base, metacognitive skill, and personality factor. Journal of Creative Behavior, 29, 255-268.

Finlay, C.S., and Lumsden, C.J., 1988, The creative mind: toward an evolutionary theory of discovery and Innovation. Journal of Social and Biological Structures, 11, 3-55.

Fowler, M., 1990, The diet cola test. Science Scope, 13 (3), 32-34.

Friedlander, M., 1983, A natural science creativity test as a prediction of creative thinking in science. The Creative Child and Adult Quarterly, 8 (4), 211-215.

Gallagher, S.A., William, S.J., and Rosenthal, H., 1992, The effects of problem-based learning on problem Solving. Gifted Child Quarterly, 36 (4), 195-200.

Hu, W., and Adey, P., 2002, A scientific creativity test for secondary school students. International Journal of Science Education, 24 (4), 389-403.

Jung, H.C. et al., 2002, Development of programs to enhance the scientific creativity-based on theory and examples, Journal of Korean Earth Science Society, 23(4), 334-348.

Lubart, T.I., 1994, Creativity. In R.J. Sternberg(ed.)Thinking and Problem Solving (London: Academic Press), pp. 289-332.

Lunetta, V., and Tamir, P., 1989, Matching lab activities with teaching goals. The Science Teacher, 46 (5), 22-24.

Molitor, L.L., 1976, Development of a test of science process skills. Journal of Research in Science Teaching, 13 (5), 405-412.

Ochanji, M., 2000, Rethinking the role of the science teacher. The Science Teacher, 67 (5), 24.

Park, K.H., 2004, Development of the scientific creativity test and analysis of gifted in science students' brain functions, Unpublished Ph.D. Thesis.: The Korea National University of Education.

Simonton, D.K., 1983, Formal education, eminence and dogmatism: the curvilinear relationship. Journal of Creative Behavior, 17, 149-162.

Sternberg, R.J., and Lubart, T.I., 1991, An investment theory of creativity and its development. Human Development. 34, 1-31.

Stevens, R.J., and Slavin, R.E., 1995, The cooperative elementary school: effects on students' achievement and Attitudes. American Educational Research Journal, 32 (2), 321-351.

Taylor, I.A., and Getzels, J.W., 1975, Perspectives in creativity. Aldine Publishing Company, Chicago.

Torrance, E.P., 1962, Guiding creative talent. Englwood Cliffs, New Jersey: Prentice-Hall.

Torrance, E.P., 1990, Torrance test of creative thinking, Beaconville, IL: Scholastic Testing Services.

Welsch, P. K., 1981, The nurturance of creative behavior in educational environments: A comprehensive curriculum approach. Dissertation Abstracts International, 41 (9), 3870A (University Microfilms No. 81-06456).

2004년 7월 20일 원고 접수
2004년 10월 21일 수정원고 접수
2004년 11월 13일 원고 채택