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EXERCISES FOR COGNITIVE ELEMENTS OF DESIGN CREATIVITY

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ABSTRACT
This paper discusses the development of a set of exercises to address the cognitive elements of creativity; fluency, flexibility, originality, elaboration and problem sensitivity. To foster the design creativity, an exercise program for the cognitive elements of creativity has been proposed and it is composed of five activities including making stories, negation, filling black box, sensitization and diverse classification. Each activity of the exercise program has been devised so that one or two cognitive elements are strongly addressed. In this way, this program could be used in helping students considering their individual needs and contexts. Preliminary experimental results indicate that the proposed creativity cognitive element exercise program could be useful in design creativity education.

Keywords: Design creativity, Creativity cognitive element exercise program, Fluency, Flexibility, Originality, Elaboration, Problem sensitivity

1 INTRODUCTION
Creativity has been considered as a major driver for knowledge creation and social and economic advancement through the development of a knowledge society. Creativity has received a high degree of attention from scholars, professionals and policy makers alike in recent years. Yet, despite the significant overall interest in the topic, so far relatively little attention has been paid on how creativity and innovation can be enhanced within and by academe.
Design creativity is closely related to ideas [1]. Creative products, whether tangible or intangible, can be regarded as the embodiment of 'good ideas'. Although every good idea may not be considered as 'creative', all creative outcome can be traced back to good ideas. Therefore, the design creativity has been often defined in terms of the capacity to produce new or original ideas by many pioneering researchers [2, 3, 4]. Methods with the aim of enhancing design creativity have pursued the promotion and maximization of the generation of ideas [5, 6, 7]. Brainstorming is one example of such a family of methods.
Many design researchers have recently showed much higher interest in design creativity, and conducted a great deal of studies. Several notable researches on design cognition to investigate the significant factors or conditions associated with designers' creativity have been conducted through the analytical approaches [8, 9, 10, 11]. In addition, research to develop the methods assessing the creativity of generated ideas was conducted by introducing new metrics [12]. Sarkar and Chakrabarti also studied the creativity measures by obtaining common definition of the creativity [13]. Jin and Chusilp have recently proposed the cognitive activity model of conceptual design to describe the generation of creative ideas in various design contexts [14]. Taura and Nagai have proposed the systematic methods to study design creativity based on design insight, which could be composed of perspective, criteria and motive [15]. Lubart and Caroff studied the critical factors – intellectual, personality-motivational and environmental – to yield an individual's creative potential, and their research could be used to examine designer's creativity and guide creativity training [16]. The convergence approach was studied to understand the cognitive processes underlying design creativity [17]. The research to correlate a sketch to design creativity was also conducted [18].
Some researchers have dealt with the design creativity in conjunction with design knowledge. Ward studied the paradoxical role of knowledge to enhance creativity or originality of newly generated ideas [19]. To appropriately understand design knowledge having complexity and multiplicity, the advanced computational modeling approaches have been introduced [20, 21, 22], and the ontology theory were adopted to formally represent design concepts [23].

However, design creativity cannot simply be defined by only the capability to produce new or original ideas. It is necessary to further decompose the design creativity into its cognitive elements which are highly related to design thinking ability. In addition, there exists no systematic exercise program to foster design creativity by its cognitive elements.
Therefore, it is important to establish a concrete concept of design creativity and to find a distinct cognitive process for design problem solving in education of design creativity. At the Creative Design Institute (CDI), research work toward design creativity education has been conducted so that various underlying cognitive elements and processes of design creativity were identified. These design creativity elements and processes can then be enhanced through training methods reflecting individual learner's cognitive personal characteristics. Figure 1 demonstrates the overall research framework on design creativity education which the CDI has been conducting.

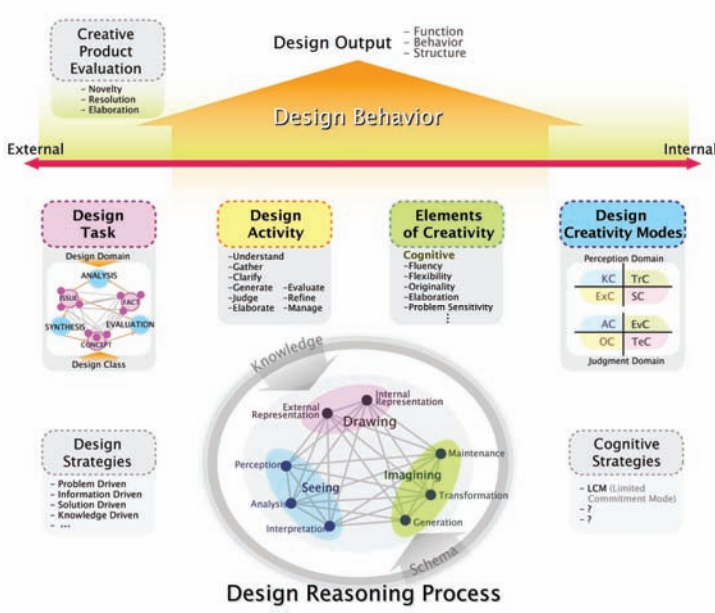


Figure. 1 Design reasoning learning framework

Visual reasoning capability has been identified as a critical element of design creativity [24], and a design reasoning process model was obtained from visual reasoning model to investigate the cognitive interaction among elementary steps, as can be seen in Figure 1 [25, 26]. This design reasoning process model has been used to study design creativity education and to develop its enhancement program. A study on the characteristic patterns of designers based on their design creativity modes, given in right-above of Figure 1, was also conducted by investigating the design activities, which are shown in central part of Figure 1 [27]. In addition, a study on the relations among design creativity modes, perceived creativity and design team interactions was carried out [28].
In this paper, the cognitive elements of design creativity will be identified, and the new exercise program for design creativity elements will be proposed. A conceptual design task to evaluate the design creativity was developed. In addition, the effectiveness of the proposed exercise program was validated with experiments. The cognitive elements of design creativity will be identified in the section 2 and the detailed descriptions on the proposed creativity cognitive element exercise program will be followed in the section 3. In section 4, the experiments to investigate the effectiveness of the creativity exercise program will be given, and their results and discussions will also be addressed. Finally, the conclusions will be given in section 5.

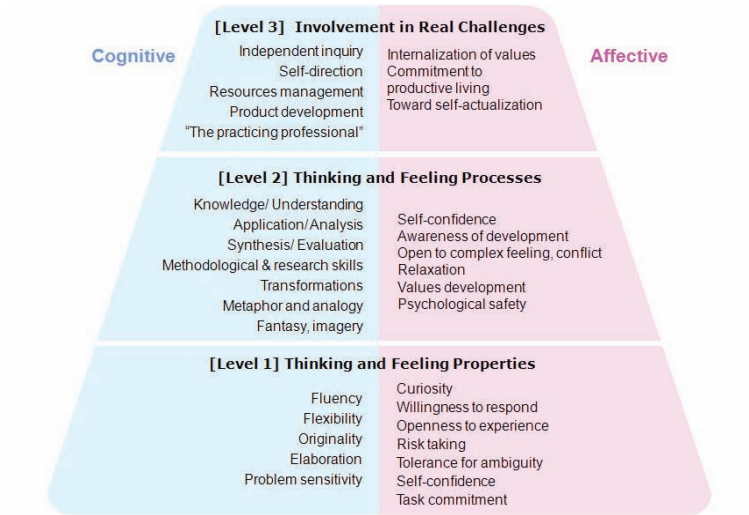


Figure. 2 Modified creative learning model [29]

2 COGNITIVE ELEMENTS OF DESIGN CREATIVITY

The cognitive elements of design creativity have been defined based on Treffinger's creative learning model [29]. The Treffinger's model encompassed the cognitive and affective aspects, and the cognitive aspects at the level of divergent functions were considered for the cognitive elements of design creativity. Those cognitive aspects are fluency, flexibility, originality, elaboration, and cognition and memory. We replaced cognition and memory with problem sensitivity, and identified five cognitive elements of design creativity such as fluency, flexibility, originality, elaboration and problem sensitivity. Figure 2 shows the modified creative learning model adapted from Treffinger's one. As can be seen in Figure 2, the identified five elements of the creativity serve as the basis for the cognitive side of the entire creative learning model. These five creativity elements coincide with those claimed by Kraft [30], and the definitions of each cognitive elements of creativity are as follows:

- **Fluency:** Ability to make **multiple answers** to the same given information in a limited time [31] and **quantity** of meaningful solutions [32]
- **Flexibility:** Adaptability to **change instructions**, freedom from inertia of thought and spontaneous shift of set [31]. That is the mode **changing categories** [32]
- **Originality: Rarity** in the population to which the individual belongs; its probability of occurrence is very low [31, 32]
- **Elaboration:** The **realization** or **transformation** of an idea, which may become very general or simple or in contrary very fantastic or enriched into details [32]
- **Problem Sensitivity :** The ability to **find problems** [32] and to **aware needs** for change or for new devices or methods [31]

3 DESIGN CREATIVITY COGNITIVE ELEMENT EXERCISE PROGRAM

The exercise program was developed to enhance the above five elements of the creativity. This program includes 'making stories', 'sensitization', 'negation', 'filling black box' and 'diverse classification'.

3.1 Making Stories

The 'making stories' exercise asks the students to produce different stories using three different pictures by changing the order of them. Therefore, this activity aims to improve the flexibility. The elaboration can also be developed through this activity by implying cause and effect of given pictures and specifying them. In addition, the originality can be enhanced through the activity to make unique and novel stories. The snapshot of the 'making stories' exercise is given in Figure 3.

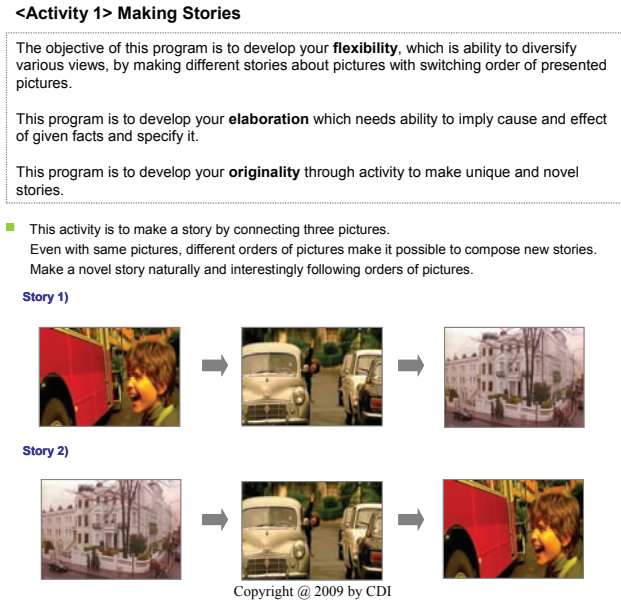


Figure. 3 Snapshot of activity of 'Making Stories' Exercise

3.2 Negation

In the 'negation' exercise, the students are asked to compulsively and purposely negate the given objects. In this activity, the students are supposed to negate a chair and a shopping basket and make new ideas about them. As a result, the fixed views or ideas on the objects can be broken, and the students can find the different and potential aspects of the objects. In this way, this activity can help to make new objects and transform original objects. This program aims to develop flexibility and originality. The snapshot of the 'negation' exercise is given in Figure 4.

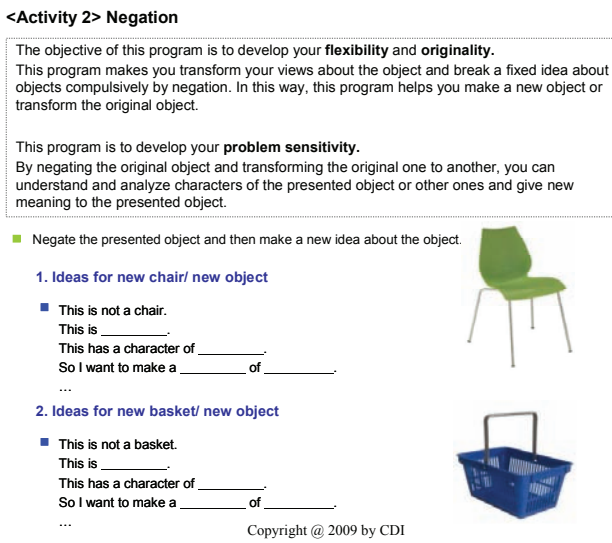


Figure. 4 Snapshot of activity of 'Negation' Exercise

3.3 Filling Black Box

The objective of 'filling black box' exercise is to mainly develop fluency by logically addressing the connections between the given input and output concepts as many times as possible within a limited time. This activity can also develop elaboration by explaining the logical relations of input and output concepts. The originality can additionally be enhanced by discovering distinctive connections between given input and output concepts. The snapshot of the 'filling black box' exercise is given in Figure 5.

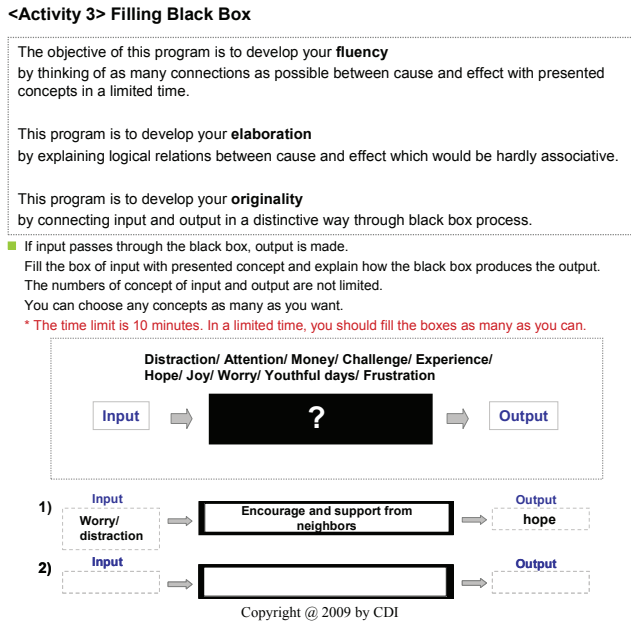


Figure. 5 Snapshot of activity of 'Filling Black Box' Exercise

3.4 Sensitization

In the 'sensitization' exercise, the students are asked to express their feelings on the given physical objects and abstract concepts according to five different senses. In this activity, the problem sensitivity can mainly be developed to dig out potential characteristics of the given objects or concepts. In addition, this activity aims to develop the flexibility by describing concrete feelings on abstract concepts from the view of five senses. The snapshot of the 'sensitization' exercise is given in Figure 6.

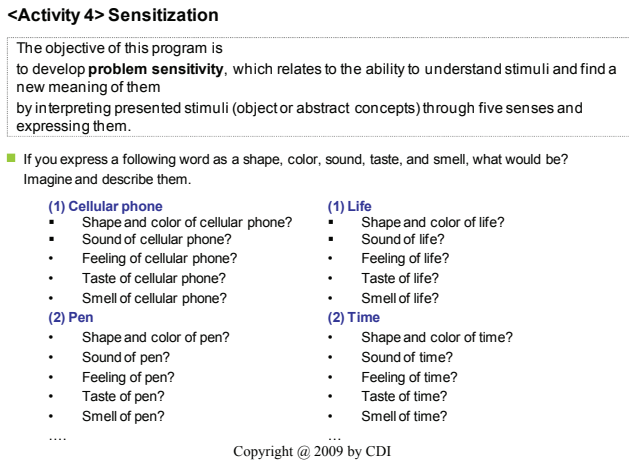


Figure. 6 Snapshot of activity of 'Sensitization' Exercise

3.5 Diverse Classification

The final activity is the 'diverse classification' exercise. In this activity, the students are asked to classify the given objects in several different ways. Therefore, flexibility can be developed by considering diverse criteria to group given objects in a different fashion. In addition, this activity aims to develop problem sensitivity to understand the multiple characteristics of given objects. The snapshot of the 'diverse classification' exercise is given in Figure 7.

Figure. 7 Snapshot of activity of 'Diverse Classification' Exercise

4 VALIDATION OF DESIGN CREATIVITY ELEMENT EXERCISE PROGRAM

We grouped the five programs of the design creativity element exercises that are given in the previous section into two activity sets: activity set A and activity set B. Activity set A was composed of making stories, negation, and filling black box. It is expected that the activity set A improves the participants' fluency, originality and elaboration. On the other hand, activity set B contained sensitization and diverse classification, and is expected to mainly enhance the participants' problem sensitivity and flexibility. Figure 8 represents the map between the design creativity cognitive elements and each exercise. From the map given in Figure 8, we could set up the following assumptions on the creativity cognitive element exercise program.

- Assumption 1: The fluency, originality or elaboration of those who attended the activity set A will be enhanced.
- Assumption 2: The problem sensitivity of those who attended the activity set B will be enhanced.

Elements / Activities	Fluency	Flexibility	Originality	Elaboration	Problem Sensitivity
Making Stories		High	Low	Medium	
Negation		High	Medium		Low
Filling Black Box	High		Low	Low	
Sensitization		Medium			High
Diverse Classification		High			Medium

Figure. 8 Relation map between creativity components and each training program

For the confirmation of our assumptions, we conducted the experiments investigating the effectiveness of design creativity cognitive element exercise program. The experiments were carried out based on pre and post tests according to the following steps:

- Step 1. Conduct pre-test for 50 students of the creative engineering design course of the Sungkyunkwan University for measuring the abilities in the five elements of design creativity.
- Step 2. Classify the 50 students into three identical groups based on the results of the pre-test. Apply activity set A to group 1, activity set B to group 2 and no activity to group 3. (Group 1 and 2: experimental groups, Group 3: control group)
- Step 3. A week after, each group conducts post-test, which is a design task to produce conceptual designs of a portable reading device.

4.1 Pre Test

The results of the pre-test were used to identify three identical groups. The pre-test was composed of two tests: (1) constructive perception test and (2) mental synthesis test. The detailed descriptions on each test are given in the following sections.

4.1.1 Constructive Perception Test

The constructive perception test was performed according to the method proposed by Suwa and Tversky [33]. The students were asked to generate and write down as many interpretations as possible of the ambiguous picture cards. Four minutes were given to each ambiguous picture for generating various interpretations, and total 16 minutes were given to each student to consider four kinds of pictures in this test. Ambiguous pictures used in the test are presented in Figure 9.

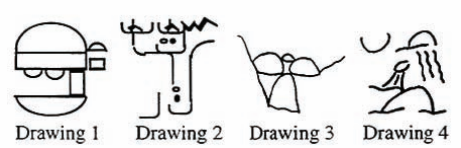


Figure. 9 Ambiguous pictures used in the constructive perception test [33]

4.1.2 Mental Synthesis Test

In the mental synthesis test, the students were required to memorize 15 object parts in Figure 10, and then generate a meaningful product with three objects in a given category while closing their eyes for two minutes [34]. Then, they were asked to sketch and describe their product invented in their mind for six minutes. The first section was to make a transportation vehicle using cylinder, half-sphere, and cross. The second section was to make furniture using tube, sphere, and ring for two minutes with their eyes closed, and they were asked to sketch what they imagined for two minutes. Then, they had to make a reasonable explanation of it in terms of a weapon category for four minutes.

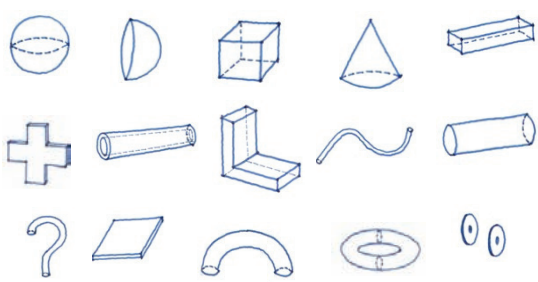


Figure. 10 Set of object parts in mental synthesis test [34]

4.1.3 Pre-Test Evaluations

The evaluations on the pre-test results were conducted in terms of the five elements of the design creativity: fluency, flexibility, originality, elaboration and problem sensitivity. The fluency and flexibility of the participating students were evaluated in the constructive perception test. Other elements including originality, elaboration and problem sensitivity were evaluated in the mental synthesis test. Table 1 shows the descriptions on the evaluation guidelines for test results in terms of the five elements of design creativity.

Table 1 Evaluation guidelines for the five design creativity elements

Creativity Elements	Evaluation Guidelines
Fluency	Count the number of ideas generated. The more the ideas, the higher the fluency scores.
Flexibility	Count the category of ideas generated. The more the categories, the higher the flexibility score. Categories can be counted by grouping several ideas based on their similarity.
Originality	Evaluate the novelty of ideas generated. The rarer the ideas, the higher the originality score.
Elaboration	Evaluate the detailedness and degree of development of ideas. Consider the detailedness and completeness of developed ideas with sketches and descriptions.
Problem Sensitivity	Evaluate the appropriateness and fidelity of ideas to given problem Consider how well the students reflect the intention of given problem in their ideas.

4.2 Post Test

4.2.1 Conceptual Design Task

The post-test is a conceptual design task to design the portable reading device. In the design task, during first 10 minutes, the students had to produce as many ideas as possible for a portable reading device with five given clues: an accordion, a tape, a hinge, a toilet pump and a steel wire hanger. Then, during next 20 minutes, they were to choose one of the ideas which they generated, and elaborate on it with sketches and detailed descriptions. The snapshot of the post-test is illustrated in Figure. 11.

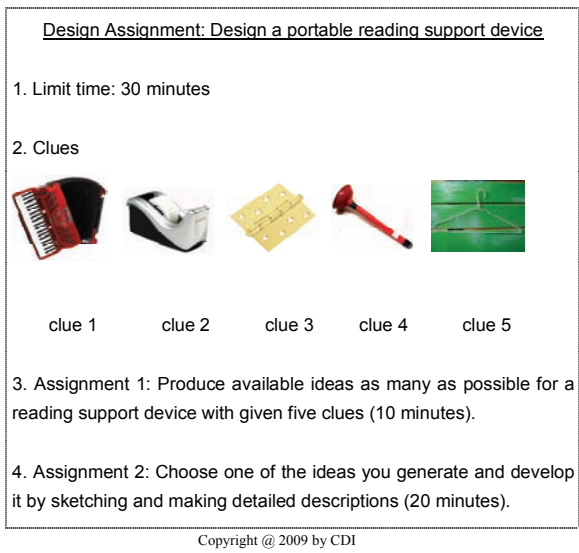


Figure. 11 Snapshot of post-test – conceptual design task for a portable reading device

4.2.2 Post-Test Evaluations

The results of post-test were also evaluated based on the guidelines given in Table #. Fluency was evaluated by counting the number of ideas with which the students came up in assignment 1. In the case of the measurement of flexibility, the categories of generated ideas were counted in assignment 1. The originality measure was done by considering the rarity of the ideas in comparison with all other generated ideas and their distinctiveness. In the case of the elaboration measurement, the detailedness of the developed conceptual design given in assignment 2 was evaluated. Besides, the detailedness of the usage of the conceptual design that was required to be addressed in assignment 2 was considered. The problem sensitivity could be evaluated by considering how well the students reflected the issues of users or situations in which the portable reading device was used. If they identified the critical issues of the given design problem, their problem sensitivity scores could be high.

4.3 Experiments

As described in section of 4.1, all 50 students who were taking the creativity engineering design course took the pre-test, and then they were grouped into three identical groups: group 1, group 2 and group 3. When assigning the students into three identical groups, each group was formed in order for the average scores of five creativity elements of each group to be uniform. In addition, the distributions of gender and grade were uniform for each group. The group 1 was composed of 17 students and the group 2 had 16 students, respectively. 17 students were assigned to group 3 as a control.

The students of group 1 conducted the activity set A, and those in group 2 did the activity set B. Neither activity set was applied to group 3. A week after the group 1 and group 2 did the activities of design creativity element exercise program; all three groups conducted the post-test, the conceptual design task of a portable reading device.

4.4 Results and Discussions

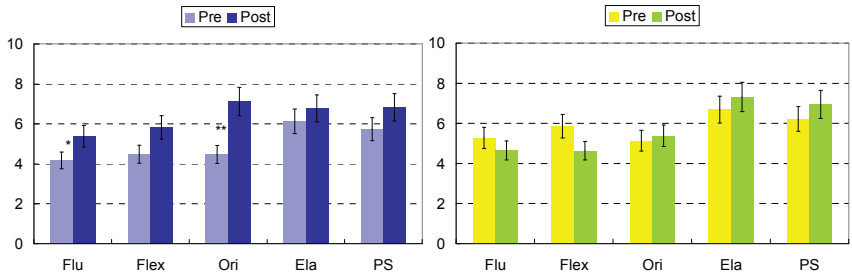
The evaluations on each creativity component in the post-test were conducted by two evaluators. The correlations between two evaluators are given in Table 2. The double asterisk (**) in Table 2 denotes that those correlation coefficients are statistically significant. As can be seen in Table 2, the inter-rater correlation coefficients for each creativity element measure are larger than 0.5, which represents medium and strong correlation between two evaluators. Therefore, the evaluation results from two evaluators can be used for further analysis.

Table 2 Correlations between two evaluators for the evaluations of post-test

	Fluency	Flexibility	Originality	Elaboration	Problem sensitivity
Correlations	.944**	.559**	.608**	.602**	.644**

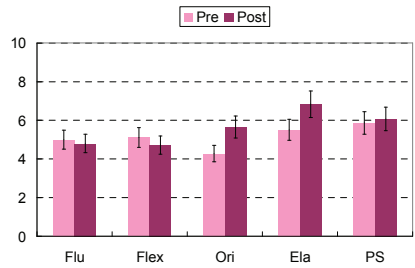
The differences of creativity component scores between pre-test and post-test were analyzed statistically, and the results of t-test are shown in Figure 12. As can be seen in Figure 12, the statistically significant results are observed in group 1. In group 1, the scores of fluency and originality in the post-test are higher than those in the pre-test to a statistically significant degree. It is believed that the activity set A was effective to enhance students' fluency and originality, since the assumptions given in the section of 4.1 coincide with the results for these two measures. However, no statistically significant results were found in the case of elaboration, although activity set A also aimed to enhance students' elaboration ability.

Although statistically significant results were only found in the cases of fluency and originality in the analysis of group 1, the tendency of increases in the scores of flexibility, elaboration and problem sensitivity between pre and post tests are observed. This observation could also demonstrate the overall effectiveness of the activity set A. However, no such consistent results in the cases of group 2 and group 3 were found.



(a) Group 1

(b) Group 2



(c) Group 3

Figure. 12 T-test results of design creativity element scores between pre and post tests (: p<0.05, **: p<0.01)*

If we recall assumption 2 given in the section of 4.1, activity set B was designed to improve the students' problem sensitivity, but no statistically significant results were found. However, the tendency of the enhancement in problem sensitivity can be found in Figure 12(b). To ensure the effectiveness of activity set B, it may be necessary to revise its program.

It is also possible to revise the pre test and post test. In the pre test, the results of the constructive perception test and mental synthesis test were used for the uniform distributions among groups. However, it was not easy to measure creativity elements such as problem sensitivity from the mental synthesis test. Therefore, it may be necessary to develop another pre test, which is similar to post test to compare the scores between pre and post tests and improve the effectiveness of the design creativity element exercise program.

5 CONCLUSIONS

In this study, the cognitive elements of design creativity were identified and a new exercise program for cognitive elements of design creativity was proposed. This program could be used in helping students considering their individual needs and contexts. Five cognitive elements of design creativity were identified: fluency, flexibility, originality, elaboration and problem sensitivity. The proposed exercise program for cognitive elements of design creativity was composed of five different activities such as making stories, negation, filling black box, sensitization and diverse classification.

In making stories, the students were required to produce several different stories by changing order of three different pictures. The aim of this activity was to improve flexibility, originality and elaboration. The negation asked students to compulsively negate the given objects and contrive their alternate purpose or usage. Accordingly, the students' flexibility, originality and problem sensitivity could be enhanced. In filling black box, the students were supposed to logically connect given input and output concepts in as many possible ways within a limited time, and as a result, the fluency could be improved. The sensitization asked students to express their feelings on the given physical objects and abstract concepts according to five different senses. With this activity, the problem sensitivity could be enhanced primarily and flexibility secondarily. In diverse classification, the students were asked to classify the given objects in several different ways. Therefore, flexibility was developed and problem sensitivity developed secondarily.

The validation experiments were conducted to investigate the effectiveness of the exercise program for design creativity cognitive elements. The results show that the proposed program was partially effective to enhance the students' design creativity cognitive elements, especially fluency and originality. It may be necessary to revise the activities of the exercise program to improve its effectiveness. A more rigorous approach is desired to examine what cognitive elements could be effectively addressed in each activity. In addition, as a pre test, the conceptual design task similar to the post test could be introduced for the effective evaluation of cognitive elements of design creativity as it is difficult to measure some cognitive elements such as problem sensitivity in the mental synthesis test. These research efforts would be helpful for design creativity education by considering individual's needs and contexts.

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