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COGNITIVE CHARACTERISTICS AND DESIGN CREATIVITY: AN EXPERIMENTAL STUDY

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ABSTRACT
The objective of this research is to identify the relations between various cognitive characteristics and design creativity so that such relations could be exploited as a guide for design education. In this paper, an experimental study toward these goals is presented where various cognitive characteristics and abilities were evaluated for three groups of students whose exposure and education in design varies. Based on the experiment, constructive perception ability that combines perception and conception and basic ability in visual reasoning composed of visual analysis, synthesis and representation in iterative nature are equally related with creative design ability. However, the correlation between constructive perception and visual reasoning has not been identified in spite of some common aspects of the two.

Keywords: Design Creativity, Personal Creativity Modes, Visual Reasoning, Constructive Perception

1. INTRODUCTION
When an individual person or a group, in design or in other professional tasks, seeks a solution to a new problem, iterations of the following technical and cognitive processes are performed to derive ultimate solutions as depicted in Figure 1. First, careful **analysis** is made regarding the nature of the problem and the problem solving environment including the entity's capability. Second, partial solutions are gradually **synthesized**. Using proper **representations** of the partial solutions and the given problem, the solutions are **reanalyzed and evaluated** considering the problem context and an improved solution is synthesized. This entire problem solving process must be performed in a creative manner to obtain innovative solutions to new problems.

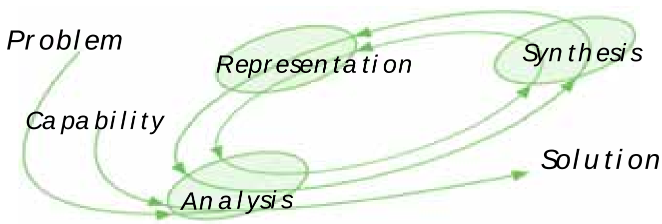


Figure 1: Problem Solving Process.

Thus this kind of **reasoning** capability, based on basic personal skills and professional knowledge, is the most essential asset for the professional competitiveness of an individual in the area of engineering product design where new products need to be created in response to customers ever-changing demand for improved functionality and performance within technical and economical limitations. The design ideation process can be viewed as composed of the interactions of the following three processes as shown in Figure 2; **imaging** process to synthesize in mind, the **drawing** process to represent the synthesis results, and the **seeing** process to analyze the drawings [6]. The nature of design reasoning as the iterative process of seeing-moving-seeing has also been discussed in

[10]. This process is heavily related with sketch as the medium for this reasoning. The essential relation for sketch and design has been studied extensively [9]. For example, recent studies related the amount of sketch activities and design team performance [11, 20].

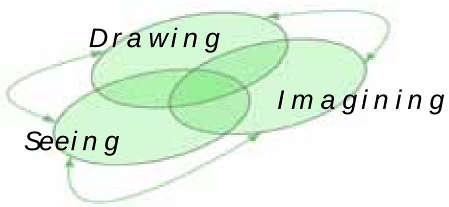


Figure 2: Design Ideation Process [6].

Among many cognitive research efforts on design creativity, the role of constructive perception [13], combined ability in perception and conception, and personal creativity modes and design roles based on Jungian cognitive theory [18] are relevant for our research. Sketch and visual and spatial reasoning capabilities of designers are believed to be related with design ability. Also divergent thinking ability is regarded an asset for creativity. These rather basic cognitive characteristics are to be examined regarding their relations to design creativity and their mutual correlations.

The objective of this research is to identify the relations between various cognitive characteristics and design creativity so that such relations could be exploited as a guide for design education. In this paper, an experimental study toward these goals is presented where various cognitive characteristics and abilities were evaluated for three groups of students whose exposure and education in design varies.

2. TESTS FOR COGNITIVE CHARACTERISTICS RELATED TO DESIGN CREATIVITY

2.1 Personal Creativity Mode Test

Based on Jungian creativity theory, Professor Wilde of Stanford University developed a *personal creativity mode test* (PCMT). This test is to be referred to as *Wilde test* as well in this paper. Wilde test has been used at Stanford in composing design teams in project-based design courses. The personal creative modes are intrinsically related with the personal cognitive preference [19]. Based on the cognitive theory of Jung, personal cognitive preferences can be identified based on four aspects, perceiving/judging preference, factual/ conceptual perception, thinking/feeling judgment, and introverted/ extroverted cognitive motivation. With these cognitive preferences, eight different modes of creativity can be identified as shown in Table 1. By further partitioning each mode into two and including two central ones, a total of 18 design team roles have been determined and associated with the personal cognitive preference modes as shown in Figure 3 [18].

In Wilde test, personal preference information on four areas of Introverted/Extroverted (I/E), iNtuitive/Sensing (N/S), Feeling/Thinking (F/T), and Perceptive/Judging (P/J) is evaluated. Also from the four area scores, Gough Creative Index (GCI) can be obtained. GCI is a creativity index derived empirically from personal cognitive preference information of well known creative people [2, 17].

At Stanford, Wilde test has been used in composing design teams so that the design team roles are distributed as evenly as possible for all the teams. As a way to verify the utility of this team composition method, they used the design team performances in a typical design competition as reflected in the quantity and the quality of the awards Stanford design teams received [18]. Wilde test has also been used at Sungkyunkwan University in its freshmen level design courses where student teams were formed based on the Wilde test so that the entire class teams can be composed as even as possible from the distribution of the modes. Some initial results support the usefulness of such team composition methods [3, 4]. For small projects for which the teams were composed randomly ignoring the personal creativity modes, those teams with more modes covered by the team members collectively performed better than those teams with less modes covered.

Table 1: The eight personal creative modes [19].

	PERCEPTUAL MODES		RESPONSIVE MODES	
	Conceptual (Intuitive)	Factual (Sensing)	Objective (Thinking)	Subjective (Feeling)
EXTRAVERTED MODES	*Synthesizing*	*Experiential*	*Organizing*	*Teamwork*
NTROVERTED MODES	*Transforming*	*Knowledge-based*	*Analyzing*	*Evaluating*

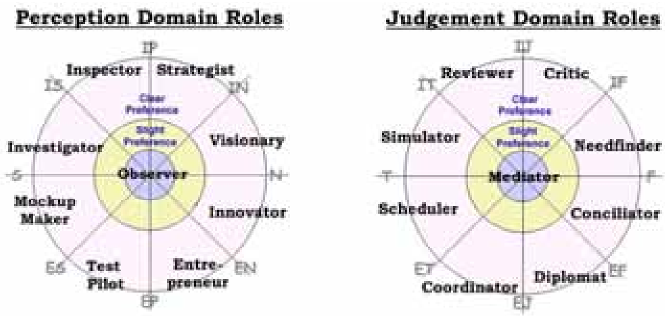


Figure 3: Team Roles [18].

2.2 Constructive Perception

Recent experimental psychology research results show that constructive perception capability is closely related with design creativity. This was initially revealed by the study of cognitive process of an architect that perceptual discoveries of sketch and generation of ideas and interpretations form design expertise of the architect [12]. Later, it was identified by an experiment where the ability to generate many interpretations from ambiguous sketches was evaluated for four different groups of professional designers, design students, non-design students and non-design adults [13]. Figure 4 shows the ambiguous sketches used in the experiment. Constructive perception is the ability to link reorganization of perceived information to conceptual process of finding meaningful interpretation. In a more recent work, Suwa and Tversky identified correlation of constructive perception ability with perceptual ability of reorganizing parts of drawings and associative fluency, but not with general spatial perception ability of mental rotation [14].

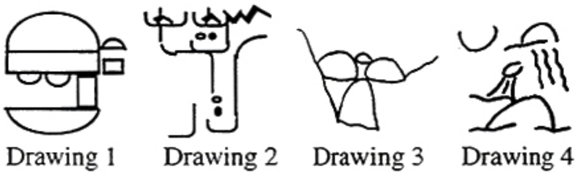


Figure 4: Ambiguous Sketches Used for Constructive Perception [13].

2.3 Visual Reasoning

The ability of a designer to visualize and reason about geometric aspects of physical objects and processes is crucial to the success of their professional activities. The essential relation between design creativity and visual reasoning has been argued by many design educators [6] and creativity researchers. Udall argued that the capability to see and to integrate objects in various viewpoints is a decisive factor for design creativity [16]. Here, by visual reasoning, the iterative reasoning process composed of visual analysis, representation and visual synthesis is collectively referred to. Constructive perception could also be deeply related to visual reasoning.

As a way to test the student's capability in visual reasoning before they receive any form of education on the matter, we conducted a simple test composed of relating orthographic projections and pictorial projections of polyhedral solid objects. For example, so-called missing view problems have been given to the students without much explanation on how to solve the problems but with a very general introduction on perspective projection and orthographic projections. The missing view problem requires visually constructing a valid 3-D solid object by visually analyzing two 2-D orthographic projections, and forms the foundations of visual reasoning processes. See Figure 5 for an example of missing view problem. Note that due to the incompleteness of the constraints given with two orthographic views, there are multiple solid objects satisfying these geometric constraints. Thus, the solution process requires visual synthesis with partial clues and corresponding internal and external representation of the synthesis result in order to go through the next reasoning step starting with visual analysis. As this kind of ability varies greatly from student to student, an intelligent tutoring system where a self-paced adaptive learning of visual reasoning is enabled would be desirable [5].

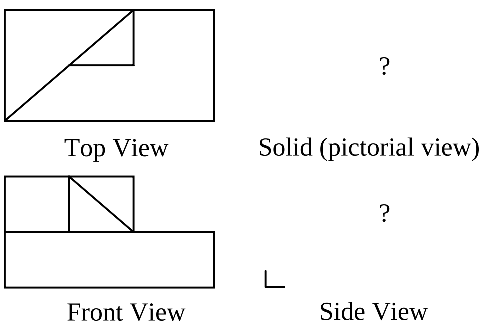
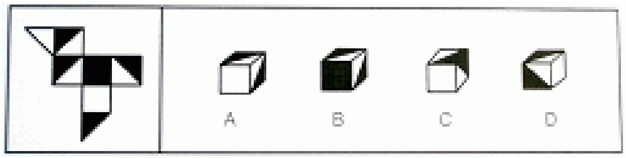


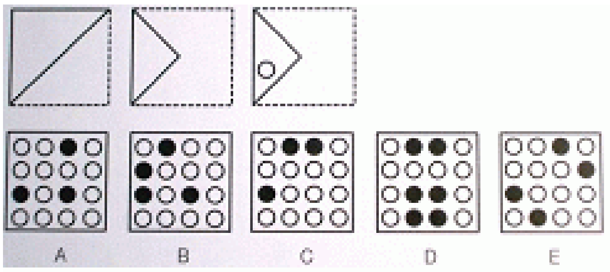
Figure 5: A Missing View Problem as an Example of Visual Reasoning Test.

2.4 Spatial Perception

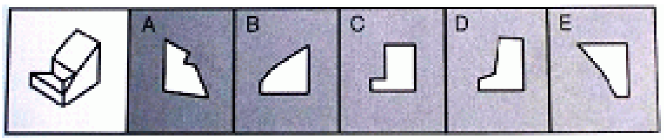
Spatial ability is generally regarded closely related with design ability. As [14] attempted to identify the relation between spatial perception ability and constructive perception, a few spatial ability tests were included so that the relations with other cognitive characteristics tests could be studied. Specifically, unfolded view test, paper folding test and penetration test were selected from a spatial ability training book made for dental school entrance eligibility test [8]. Figure 6 shows examples of these three tests respectively. Note that these tests are all multiple choice types.



Unfolded View Test



Paper Folding Test



Penetration Test

Figure 6: Spatial Perception Tests [8].

2. 5 Idea Generation Test

This test evaluates idea generation capability in textual and visual manners. The test was conducted for 30 minutes with 10 minutes for textual one and 20 minutes for visual one under the same subject. The evaluation was done on the quantities for both textual and visual idea generation tests.

In the textual idea generation test, associated words are to be listed in the form of nouns, verbs, and adjectives under the same subject. The noun portion will describe the whole and the parts as well as materials and elements of the subject object. The verb portion will describe the functions and the usages. The adjectives portion will cover issues on form, color and other characteristics. This kind of attribute listing is a great technique for ensuring all possible aspects of a problem have been examined [7]. Attribute listing is breaking the problem down into smaller and smaller bits and seeing what you discover. Attribute listing is good to be utilized in understanding the properties of the design subject before engaging in the design development.

In the visual idea generation test, a morphological chart is to be developed where many alternative concepts are sketched for the functions or elements the designer is to develop under the same design subject as used in the textual idea generation where basic understanding of the properties of the subject has been acquired. Figure 7 shows examples of student results on idea generation tests.

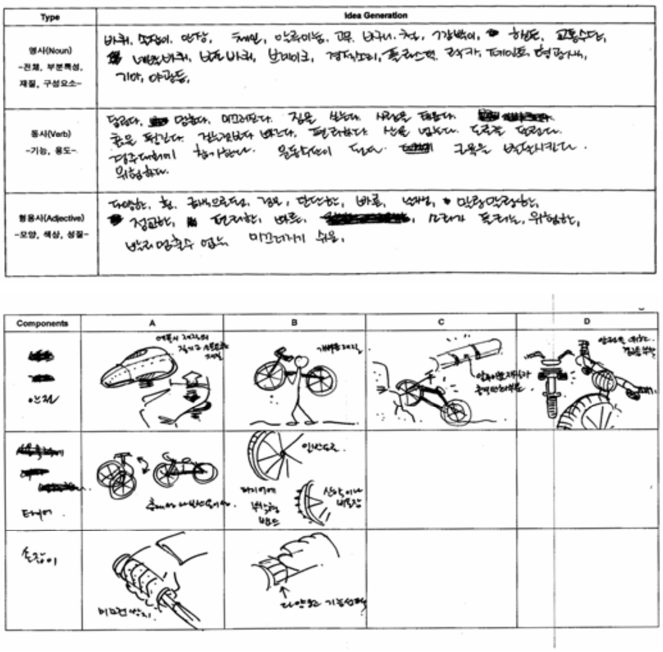


Figure 7: Example Student Results of Textual and Visual Idea Generation Tests.

2. 6 Design Task Test

The purpose of the design task test is to evaluate design problem solving capabilities of test students for a design task under a common design goal with time limitation and specific design constraints. Most other tests conducted in this experiment, e.g., constructive perception test and visual reasoning test, take about 20 minutes so that test students most intrinsic capabilities and characteristics can be evaluated without the effect of learning and the differences of level of efforts by the test students. Thus, a design capability test that can be done using about 20 minutes needs to be devised. The following design test was the one used for this experiment.

<u>Experiment Design Test</u>

1. Design Time Limit: 25 Minutes.
2. Design Goal: - Wearable Binocular
3. Constraints
   a. Both eyes should be used.
   b. The product should be wearable using head or face of a user.
   c. Manual adjustment is allowed for controlling lens and focus.
   d. As no supporting information is available in the design test situation, the following visual clues are provided. Two of five clues could be used. It should be noted which clue has been used for two design results respectively.
4. Design development is to be done in the following 3 steps:
   a. Idea development (Thumbnail Sketch): provide simple sketches and notes for design ideation.
   b. Design proposal: provide design proposal effectively using design sketches. The drawing of a face and head depicted in pictorial manner will be helpful.
   c. Design description: provide explanations of the design proposal including design concept, manufacturing, materials, use activities, and functions.

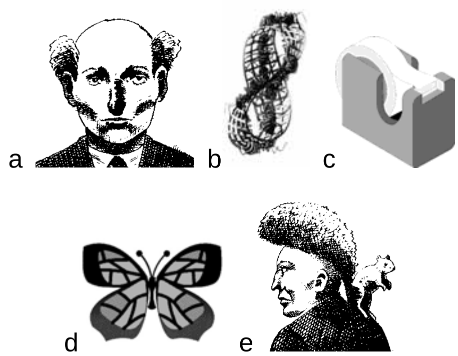


Figure 8: Visual Clues Given for Design Task Test.

The five visual clues are shown in Figure 8, and they are drawings that could enable design reasoning in direct and/or indirect manners and allow rooms for associations with some ambiguities. Note that design results would be very different between the cases with and without such visual clues. It would be possible that some test students would find great difficulties in getting started in the design task if clues are not given. Considering this, the test provided visual clues as if the very initial design stages of relevant information gathering of the design problem have been conducted.

The five visual clues could provide the following implications respectively:

a. attachment using the shape of head, to hang, to support,
b. analysis and application of structural characteristics of a mobius strip, to twist, to divide and meet,
c. use of different materials and combination methods, to stick, to roll, to pull,
d. use of symmetric shape, use of the shape of a butterfly, to hook, to bend,
e. a hat-like attachment, to wear, to put on,

Student design proposals have been graded based on the originality and on the usefulness using the following evaluation criteria:

· Originality: concept originality, design form originality, transformation of the clues given (5 points maximum).

· Usefulness: functions, design form realization, use activities, design effectiveness and thoroughness of design techniques used (5 points maximum).

Two student design solutions are given as examples of good design results. The first example student result, shown in Figure 9, has the following positive evaluations: For the originality part, a bold new functional concept is proposed in that not only visual magnification but also sound magnification is proposed. Also, another technological suggestion is provided so that digital zoom lens could allow that both eyes will have proper zoomed views by using a single zoom lens. The clue has been enhanced so that the putting-on-the-head notion has been aggressively expanded into a new fashionable head gear form. For the usefulness part, the design proposal provides the combined binocular and earphone mechanism in a realizable manner considering the ergonomic issues. The second example, shown in Figure 10, suggests a combination of another radically new function that sports cheering gears can be combined with the binocular used by sports game watchers. Also, the clue of rolling concept has been actively applied to store internally cheering ribbons in a roll attached to the binocular. The design obtained good usefulness evaluation in that the design description properly explains the situation where a sports game spectator can use the binocular and the cheering gears. Also, the design provides appropriate attachment mechanism of the device to human bodies and admits the usual cheering situation as used in sports game scenes.

Student Result 1

Used Clue: e

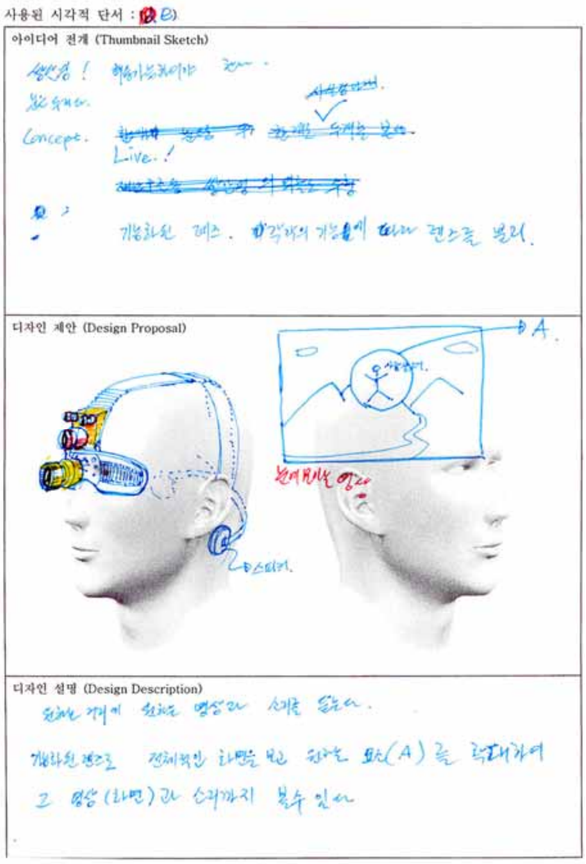


Figure 9: Example Student Result 1 for Design Task Test.

3. EXPERIMENT

As a way to study the relations among different cognitive characteristics and design creativity, an experiment was conducted for three different kinds of groups of individuals in their design experiences using the following seven tests: Personal Creativity Mode Test, Constructive Perception, Visual Reasoning, Spatial Perception, Idea Generation Tests (textual and visual), and Design Task Test as described in the previous section.

3.1 Participants

From three different groups of (1) engineering undergraduate students (junior level), (2) industrial design graduate students, and (3) psychology and consumer sciences undergraduate students (junior level), a total of 38 students participated in the experiment. The group 1 of engineering students is composed of 8 mechanical engineering majors and 3 industrial engineering majors of Sungkyunkwan University. The group 2 of industrial design graduate students is composed of 10 students of Seoul National University of Technology. The third group is composed of 2 consumer sciences majors and 15 psychology majors of Sungkyunkwan University.

Student Result 2

Used Clue: c

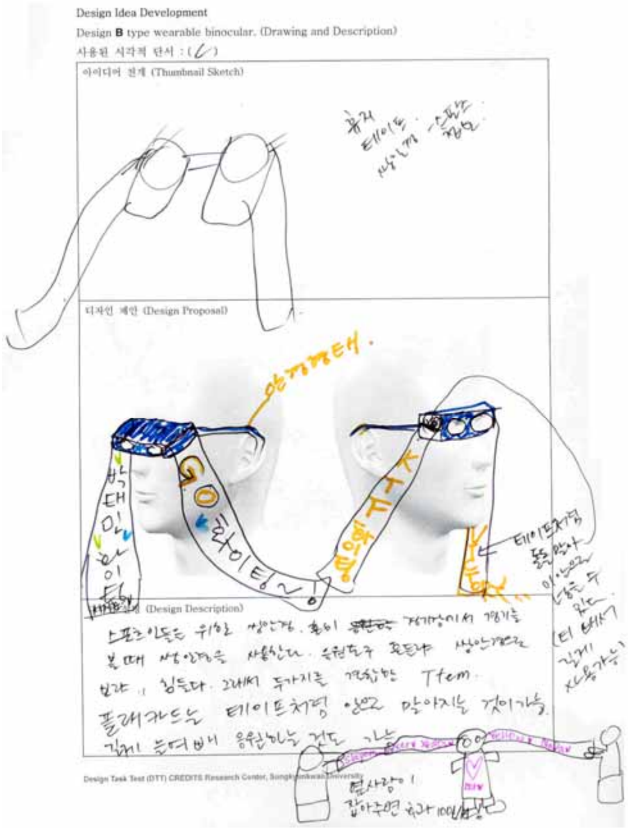


Figure 10: Example Student Result 2 for Design Task Test.

3.2 Procedures

Personal Creativity Mode Test (PMT) was conducted by individual using the website, where personal cognitive preferences on Intuition/Sensory measure and Introverted/Extroverted measure in perception mode and on Subjective/Objective measure and Introverted/Extroverted measure in judgment mode are computed. The result of individual test is presented in a graphical manner devised by Wilde as well as Gough Creative Index (GCI) and primary and secondary team roles derived from the measures. Typically PCMT takes about 20 minutes.

Constructive perception test (CPT) was done following the way Suwa and Tversky did in their experiment [13]. Each person generated as many as possible interpretations of four ambiguous sketches of [13] using four minutes per drawing. The number of different interpretations was counted. The total test time for constructive perception was for 16 minutes with some pause between the drawings.

For visual reasoning test (VRT), four different missing view problems were given in an increasing order of difficulties during 25 minute time duration. For the easiest, a pictorial drawing was given while one orthographic projection view was missing. For the others, two orthographic projections were given so that both pictorial drawing and a missing view should be sketched by the test student.

For spatial perception test (SPT), 10 unfolded view tests were given for 5 minutes; 15 paper folding tests, 10 minutes; 15 penetration tests, 10 minutes. In evaluating, wrong answers were counted negative as these were multiple choice problems.

Idea generation test (IGT) was given for the subject of a bicycle with 10 minutes for textual idea generation and 20 minutes for visual idea generation. A subject familiar to all the test groups was chosen so that the divergent idea generation ability can be measures excluding the chances that test students idea generation is hampered by the technical burden of the subject. The number of ideas was counted respectively for textual and visual parts.

The design task test (DTT) was devised and given to assess design creativity in an experiment setting as described in detail in the previous section, so that similar amount of metal activity is used as in other cognitive ability tests conducted in this experiment. We understand that the general validity of the given design task test as a design creativity measure could be questionable. However, tests for cognitive abilities should be compared with any design test. For the time duration the test students can devote, the given design task of wearable binocular is regarded appropriate.

4. RESULTS

4.1 Differences among the Groups

Analysis of variation (ANOVA) was done to identify the difference among the three groups. Based on the ANOVA result, meaningful differences among the groups were identified for SPT($F(2, 35)=7.21$, $p=.002$), CPT($F(2, 35)=8.06$, $p=.001$), and VRT($F(2, 35)=6.96$, $p=.003$). For spatial perception test, group 1 of engineering students and group 3 of psychology students have differences ($F(1, 36)$ design graduate students and group1 of engineering students ($F(1, 36)=9.24$, $p<.01$) and group)=13.67, $p<.001$). For constructive perception, group 2 of industrial 2 of industrial design graduate students and group3 of psychology students ($F(1, 36)=14.53$, $p<.001$) have differences. For visual reasoning, group 2 of industrial design graduate students and group3 of psychology students ($F(1, 36)=14.30$, $p<.001$) have significant differences. For spatial perception, constructive perception and visual reasoning, the average differences are shown in Table 2. Figures 11, 12, 13 and 14 show the average score differences among the groups. For Gough creativity index, idea generation test (textual and visual) and design task test, meaningful group differences were not found using ANOVA. For design task test, though ANOVA indicates no significant differences, the performances order of group2 of design graduate students, group 1 of engineering students and then group 3 of psychology students is clearly observable in Figure 14.

Table 2: Average Score Differences among the Groups.

	Average difference between groups		
Test	Group 1 - Group 2	Group 1 - Group 3	Group 2 - Group 3
Spatial Perception	35.46	73.83**	38.37
Constructive Perception	-18.73*	4.57	23.29**
Visual Reasoning	-17.82	16.71	34.52**

* Significant at the level .01(two-tailed)
** Significant at the level .001(two-tailed)

Note that the performance order of design graduate students, engineering undergraduate students and psychology undergraduate students appears commonly in constructive perception, visual reasoning and design task test, as shown in the figures. Thus this experiment in a way confirmed the result of [13] for constructive perception, considering experiences and education of these three groups of students. At the same time, it can be equally argued that visual reasoning could be regarded as a meaningful measure for design creativity as well. Also note that the design task test proved to be appropriate as the result of the group difference observed. For design task test, the originality part and the usefulness part show the same group difference pattern. Note that, however, the performance order for spatial perception is different from that for constructive perception, visual reasoning and design task.

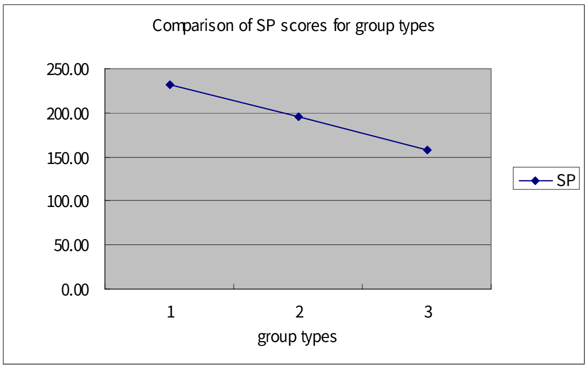


Figure 11: Group Difference in Spatial Perception Test.

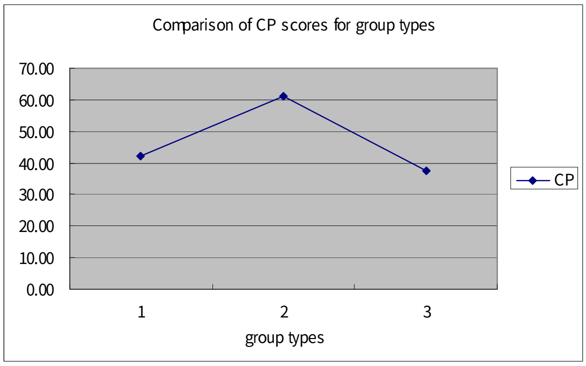


Figure 12: Group Difference in Constructive Perception Test.

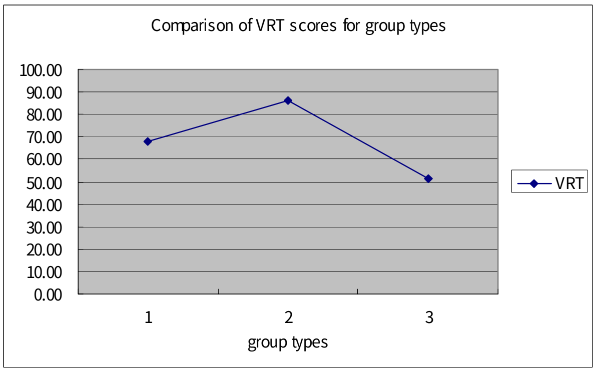


Figure 13: Group Difference in Visual Reasoning Test.

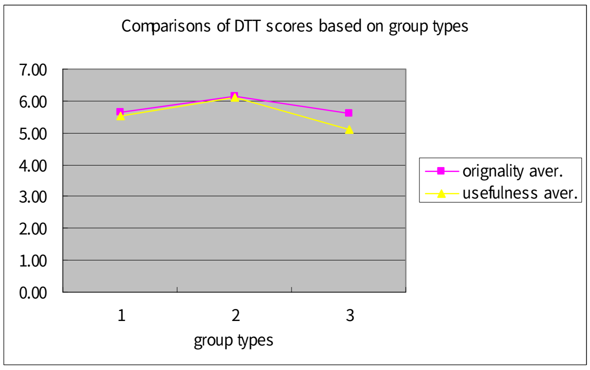


Figure 14: Group Difference in Design Task Test.

4.2 Correlations of the Different Cognitive Characteristics

To identify the relations among all the cognitive characteristics tested in this experiment, a correlation analysis was conducted over the entire 38 test students. For personal creativity mode, Gough creative index was used, and the design task test was included using both the originality and the usefulness separately and collectively. Correlation coefficients for all these test score are shown in Table 3.

Table 3: Correlation Coefficients for Different Test Scores.

	GCI	SPT	CPT	IGT_t	IGT_v	VRT	DTT	DTT ori	DTT util
GCI		0.035	-0.019	**0.353 ***	0.119	-0.075	0.168	0.041	0.248
SPT			0.091	-0.002	0.196	**0.655****	0.178	0.081	0.216
CPT				0.088	0.134	0.209	0.065	-0.004	0.105
IGT_t					**0.632****	-0.048	0.243	0.298	0.148
IGT_v						0.180	0.212	0.199	0.171
VRT							**0.426****	**0.368***	**0.390***
DTT								**0.877****	**0.901****
DTT ori									**0.591****

* Significant at the level .05(two-tailed)
** Significant at the level .01(two-tailed)

As shown in Table 3, positive correlations have been found between Gough creativity index and textual idea generation test (r=.353, p<.05), between spatial perception test and visual reasoning test (r=.655, p<.01), and between visual reasoning test and design task test (r=.426, p<.01). That is, the personal cognitive preferences of those who made creative outcomes (particularly in architecture area as Gough's study used architects as the exemplary creative people) are related with the ability to generate many ideas in verbal manner. This indicates that why some creativity tests such as Torrance Test of Creative Thinking (TTCT) [15] based on the divergent thinking creativity theory of [1] are utilized. The correlation between spatial perception test and visual reasoning test can be explained that these two have many common characteristics as apparently both involves geometric issues specially in 3D space. Design task test is positively correlated with visual reasoning test as analyzed in the correlation analysis as well as in the group differences. Note that spatial perception is not correlated with design task test. From this, it can be argued that visual reasoning ability is much beyond (at least different than) just spatial ability and accounts for some ability needed in design creativity.

5. SUMMARY AND DISCUSSION

An experimental study has been presented where various design creativity related, cognitive characteristics and abilities were evaluated for three groups of students whose exposure and education in design varies, that is, junior-level engineering students, industrial design graduate students and junior-level psychology students. Six kinds of tests were conducted: (1) personal creativity mode test by Wilde based on Jungian cognitive theory, (2) constructive perception test by Suwa and Tversky where the ability to generate many interpretations from ambiguous drawings are evaluated, (3) visual reasoning test which evaluate iterative reasoning composed of visual analysis, synthesis and representation, (4) spatial perception test, (5) idea generation test, and (6) a simple design task test.

Analysis of variation reveals the group differences in constructive perception and visual reasoning in that design graduate students are better than engineering juniors and engineering juniors are better than psychology juniors. On the other hand, the performance order of engineering juniors, design graduate students, and psychology juniors, is identified in spatial perception test. Though not statistically proven, the design task test performance order matches that of constructive perception and visual reasoning. From this result and the result of [13], it can be argued that both constructive perception and visual reasoning are related with design creativity.

Correlation analysis done for the entire 38 student participants indicates that visual reasoning capability is closely correlated with spatial perception ability and design ability of the given design task test. Also those with high Gough creativity index, which is derived from the personal creativity modes, are good in generating ideas in textual mode, confirming a common and naïve view of creativity in terms of divergent thinking ability.

Note that despite some seemingly common aspects of constructive perception and visual reasoning, no correlation has been found for these two abilities. As the group differences show the same pattern for these two abilities and design task over the three groups, meaningful interpretations for the experiment results are desired. First, the current constructive perception test is done using drawings which are strictly 2 dimensional, while missing view test used for visual reasoning evidently involves 3 dimensional visual reasoning. Second, while constructive perception test involves the nature of a speed test, that is, seeing something quick and getting the response quick, the missing view test on the other hand is more structured in that though different view points are allowed and utilized, but a certain view point needs to be maintained while proceeding to a solution. In other words, the amount of reasoning needed for constructive perception test and visual reasoning test is quite different. The iterative nature of design reasoning may not be identified in the constructive perception test, while it is critical in the missing view test. Certainly, both tests can be regarded related to design creativity equally through such brief experiments. But at the same time, design creativity has so many elements in it that neither can serve decisive characteristic role. Obviously, much more experimental research efforts would be needed.

Now that both constructive perception and visual reasoning are desired cognitive abilities for design creativity, what kind of personal creativity modes are associated with these could be an interesting question. Unfortunately in this experiment, any correlation between personal creativity modes and constructive perception and between personal creativity modes and visual reasoning were not found.

Rather less significant correlation results are the positive correlations between textual idea generation and visual idea generation and between the originality and the usefulness parts of design task test. These seem to be rather obvious relations. But if these were not found, the credibility of the experiment itself would have been questionable.

6. ACKNOWLEDGEMENT

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