The Influence of Cognitive Factors on the Creative Abilities in Design

-Focused on the Sensory Modalities and Thinking Modes-

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Abstract: The primary purpose of this study was to investigate the influence of Cognitive Factors (CF) on the Creative Abilities (CAs) in design. We set up a model of Cognitive Design Process (CDP), which consists of four domains: Concepts, Experience, Five Senses (FS), and Thinking Modes (TM). Here, experience is first perceived by the five senses, and then recognized by intelligence. We regard design as a transforming process from concept to experience.

For this study, two major Sensory Modalities (Visual and Kinesthetic), four Thinking Modes (Brain Dominance Profile), and four Creative Abilities (Fluency, Flexibility, Originality, and Elaboration) were reviewed. We hypothesized that idea generation is influenced by different Sensory Modalities (Visual Sense vs. Kinesthetic Sense) and Thinking Modes, and that these have a close relationship with the attributes of CAs. Firstly, we have examined the cognitive thinking model in design. Then, we adapted the Test of Creative Abilities of Design Thinking (TCADT) for measuring CAs. We surveyed the CAs under CF in particular. Finally, we have investigated the influences of the different Sensory Modalities (Visual Sense vs. Kinesthetic Sense) on CAs.

It was found that a close relationship between Brain Dominance and CAs, and Sensory Modalities (SM) have different influence on these creative abilities. As a result, a tool for the Test of CAs and a framework for creative idea generation with the effective CF will be presented. These provide the basis for a new approach to creative idea generation in Experience Design.

Keywords: The 2006 Korea Design Research, Design History, Design Journal

1. Introduction

We employ four very different kinds of explanatory principles to the question of "why a thing is?", as a philosophical basis of design phenomena. The Four Causes (FC) that are responsible for the existence of

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an object are Material Cause, Formal Cause, Efficient Cause, and End Cause.[1] The Material Cause is the basic stuff out of which the thing is made. Their inherent qualitative properties are also transferred to the object in question. This has a close relationship to physical sketch modeling in the early phases of design. The Formal Cause is the pattern or essence in conformity with which these materials are assembled. This is the blueprint or the idea commonly held of what an object should be. The Formal Cause is the form, shape, idea, or concept of the completed whole as a result of design. The Efficient Cause is the agent or force immediately responsible for bringing this matter and that form together in the production of the thing. It constitutes the means and manner in which a thing actually comes into being. Lastly, the final cause is the end or purpose that something is supposed to serve. The End Cause is an entity's, object's, or system's purpose. In Aristotle's terms, it is the function a thing is intended to serve once completed. All the causes are necessary elements in any adequate amount for the existence and nature of the thing; Aristotle believed that the absence or modification of any one of them would result in a different thing.

As a complex of the Four Causes (FC), we consider that design is a cause of cultural generation. We noticed that the core object of design is the shifting from goods and services to experience, and experience is a key value differentiator. Now, Experience Design is a new discipline, which is emerging as a much-needed approach in business.

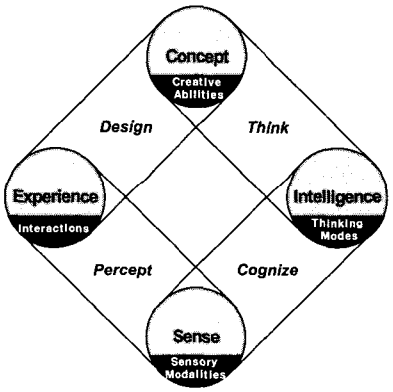

Fig. 1 Cognitive Interaction in Design

We focus on the Sensory Modalities (SM) in the germinal phase of design, which entails Mental Process (MP). We set up a model of cognitive interaction in design, which consists of four domains: Concepts, Experience, Five Senses (FS), and thinking modes (TM). We regard design as a transforming process from Concept to Experience. First, the experience is perceived by FS and then recognized by the Intelligence. Next, the Concept is coined by the intelligence. Finally, we change the concept into an object through design process (Fig. 1). This paper will examine the influences of Sensory Modalities (SM) on the Creative Abilities (CAs) in design, and the relationship between sensations of sketching tasks. These provide the basis for a new approach to a cognitive interaction in design.

[1] Velasquez, Manuel, 1999, Philosophy, Wadsworth Publishing, p.153-154.

2. Creative Abilities in Design

2.1 Designery Way of Thought

Design is a typical case of creative problem solving. For the problem that is being considered, we want to bring about a desired solution that is something new and valuable.[2] For that reason, design is a more open-ended problem solving activity that requires greater creativity, and the typical style of the designer's behavior underpins their creativity.[3] During the design development, design concepts will be developed from sketches on paper into simple massing models. Yet, it is in the earliest stages of design when fundamental forms are being established, that the ability to think and see in three dimensions (3D) is most important.[4] In general, designers design by sketching for idea generation.

Exploration on how thoughts by brain modes show different results is expected to bring important implications for design practice and design education. We have adopted Ned Hermann's Whole Brain Model in order to support collaborative thinking.[5] He described that the brain can be visualized as a circle divided into four quadrants. The four quadrants describe different processing modes that we all have access to. Hermann's model shows the left and right sides of reason (cerebral system), and the left and right sides of emotion (limbic system). These four are the "thinking" areas of the brain because they are associated with the neural cortex (area believed to be involved in thinking). The Whole Brain Model is involved in high-level cognitive functioning for design creation, and has four major modes of human brain-quadrants: A, B, C, and D.

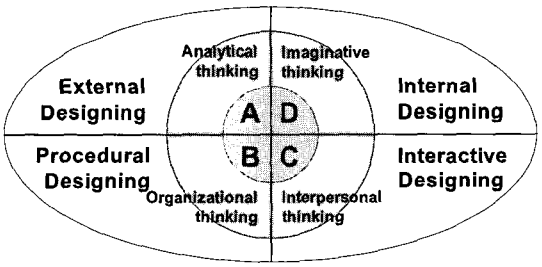

Fig. 2 Four modes of Brain Dominance in Design

Design can be regarded as a typical interdisciplinary activity, which involves all the four quadrants (Fig.2). External designing uses analytical thinking i.e., deciding through analyzing (quadrant A). Procedural designing uses organizational thinking of what is being designed, as well as practice and repetition to improve skills (quadrant B). Interactive designing uses interpersonal thinking such as discussions, and sensory experiences where we try, fail, and try again after considering verbal feedback and encouragement (quadrant C). Finally, internal designing uses imaginative thinking such as insight,

[2] During, D., 1999, Intuition in Design: A perspective on designers' creativity, *Asia Design Conference*, pp.2-3.

[3] Cross, N., 1982, Designery ways of knowing, *Design Studies*, 3(4), pp.221-227.

[4] Schilling, Terrance G. and Patricia M. Schilling, 1987, Intelligent Drawings. New York: McGraw Hill, 17, p. 236.

[5]Hermann-Nehdi, A., 2001, A Creativity and Strategic Thinking. Retrieved October 18, 2004, from http://www.hbdi.com/docs/Ann_CreativityandStrategicThinking.pdf, p.3.

visualization, synthesis, or a sudden holistic and intuitive understanding of a concept (quadrant D). By incorporating all of these modes into design strategies, effective designs can be created. When we consider the corporative design project, this model is helpful to set up a project team and to perform the project.

2.2 Attributes of Creative Abilities (CAs)

Creativity is reflected in the generation of novel, socially valued products. There are many definitions of creativity arising from various psychological studies. Creativity is best described as the human capacity to solve problems or to fashion products in a domain in such a way that it is initially novel, but ultimately acceptable in a culture. It is an effective resource that resides in all people.[6]

There are three components in Creative Behavior: Abilities, Skills, and Motivations. A high level of creative achievement can be expected consistently only from those who have creative abilities. The person who has a high level of Creative Abilities (CAs) and skills may become a creative achiever, if the creative motivation can be aroused. Similarly, the person who has CAs and motivation can become a creative achiever with the acquisition of the necessary creative skills.[7] Here, we consider Skills as a processing quality in Whole-brain mode, and Motivation and Skills activate the Creative Abilities. As a result, we are able to achieve creative accomplishments.

The relationship between creativity and problem solving is very close according to many investigators. Mumford et al. refers to creative thought as a form of problem solving.[8] Feldhusen and Treffinger combine creativity and problem solving into "a single complex concept," arguing that "CAs such as Fluency, Flexibility, and Originality...are indispensable components of realistic and complex problem solving behavior." [9] We draw four major CAs from former studies: Flexibilities, Fluency, Originality, and Elaboration. (Table 1)

Table 1: The Four Creative Abilities: Fluency, Flexibility, Originality and Elaboration[10]

Creative Abilities	Contents
Fluency	The number of interpretable, meaningful, and relevant responses to the stimuli
Flexibility	The variety of categories of relevant responses.
Originality	Responses which are unexpected, unusual, unique, or statistically rare.
Elaboration	The addition of pertinent details.

While fluency certainly increases the chance that original ideas will be produced, there is no

[6] Gardner H., 1993, The theory in practice, *Multiple Intelligence,* Basic Books: New York, p.14.

[7] Raina, M.K., 2000, E. Paul Torrance's Voyages of Discovering Creativity: *The Creative Passion.* Alex Publishing, pp.35-36, pp.157-158.

[8] Mumford, M. D., Connelly, M. S., Baughman, W. A., & Marks, M. A. (1994). Creative and problem solving: Cognition, adaptability, and wisdom. *Roeper Review*, 16, 241-246.

[9] Nikerson, R.S., 1999, "Enhancing Creativity" in *Handbook of Creativity* Robert J. Sternberg ed. Cambridge University Press: New York, p.394.

[10] Kim, K. H., 2002, Critique on the Torrance Tests of Creative Thinking: Figural Forms A and B. Retrieved October 18, 2004, from http://www.arches. ga.edu/~kyunghee/portfolio/review%20of%20ttct.htm

guarantee that this will occur. It is important to consider some of the special qualities of original alternatives and methods for increasing the chances that such ideas will occur.[11] A core of the CAs is Originality which is supported by the Flexibility. Elaboration can be quite expensive, not only financially, but in regard to other qualities that have to be sacrificed. Even though the high elaborator sacrifices fluency, flexibility, and originality on the Tests of Creativity Thinking, it has important meaning for design.[12]

For the Test of Creativity in Design, we adapted a measuring tool, the Test of Creative Abilities of Design Thinking (TCADT)[13], from our previous studies. It consists of both 2-Dimensional and 3-Dimensional Tasks. 2-Dimensional TCADT has two types of tests: figural and verbal tests. 3-Dimensional TCADT consists of modeling Tasks. Each TCADT is arranged with specific stimuli, time limits, and scores respectively. We developed the manual of scoring and criteria for rating the results of the TCADT (2-D & 3-D)

3. Cognitive Approach in Design

3.1 Sensory Modalities

Cognition, or mental activity, involves the acquisition, storage, transformation, and use of knowledge. Based on experience, an idea or concept is empirical if it is derived ultimately from the five senses, to which introspection is sometimes added.[14] Cognitive approach is often contrasted with several other current psychological approaches.[15] We regard design as a typical cognitive approach with human Sensory Modalities (SMs). People think using internal representations of their five senses: Visual, Auditory, Kinesthetic, Olfactory and Gustatory. Of these, Visual, Auditory and Kinesthetic are the ones most often used. Examples of each include the following:[16] We are aware of the physical plane through our five senses. We see, hear, feel, taste, and smell things in our environment. When we process this information we represent it back to the external world using these same senses.[17]

The success of the visual process requires that some form of object identification based on size, shape, color, and experience take place; that movement of objects be detected; and that recognition of objects be possible in the full range of lighting conditions normally experienced by the individual in its habitat.[18] Although not all products can or should be touched, the quality of tactility cannot be avoided. The roughness and smoothness still evoke the "feel" of the solid material form through vision. Haptic

[11] Torrance, E. P., & Safter, H.T., 1999, Making The Creative Leap Beyond, Creative Education Foundation Press, p.87.

[12] Torrance, E. P., & Safter, H.T., 1999, Making The Creative Leap Beyond, Creative Education Foundation Press, p.108.

[13] Woo, H.R., 2005, Creative Abilities in Design: Relationships between Brain Dominances and Creative Abilities of Design Thinking, The Korean Journal of Thinking & Problem Solving, pp.101-113.

[14] Honderich, Ted ed, 1995, The Oxford Companion to Philosophy, Oxford University Press, New York, p.261.

[15] Matlin, Margaret W., 1998, Cognition, Harcourt Brace & Co., Orlando, p.2.

[16] http://www.saladltd.co.uk/salad%20pages/Nlp%20tips/nlp_tip_6.htm

[17] http://www.hypnosisworld.com/nlpmain.html

[18] Bear, Mark B., etc, Neuroscience, 2001 Lippincott Williams & Wilkins, p.281.

experience is therefore bi-directional, its reciprocality stemming from the possibility of our touching an object or a surface, while simultaneously producing effects of the object touching us.[19]

3.2 Cognitive Interaction in Design

Design work starts with a mental construct rather than a physical one. We regard that design process is a Visual/Tactile Thinking Process (VTTP). A Cognitive Map (CM) is a mental device that codes and simplifies the way our spatial environment is arranged. We use imagery for a wide variety of different cognitive activities. Imagery is the mental representation of stimuli, which are not physically present. Mental imagery is immensely helpful when we want to solve spatial problems or work on a task that requires creativity.[20]

As shown in Fig. 3, there are three types of images: graphic/physical, perceptual, and Mental Images (MIs). When we start idea sketching, we just draw an image on the paper, which is a two-dimensional (2-D) graphic image. We model an image with clay, which is a three-dimensional (3-D) physical image. As pointed out by Paul Laseau, depending on our experience, interests, and what we are trying to do, we will see certain things take and/or leave something in the sketch, which is a perceptual image. Next, we form a Mental Images (MI) to further reference and give them orientation from this perceptual one. When this Mental Image (MI) is transferred to paper or space once more through motor processes, it goes through yet other changes for the design development.[21] Many theorists-such as Stephen Kosslyn, Roger Shepard, and Ronald Finke-argued that information about a MI is stored in an analog code. An analog code is a representation that closely resembles the physical object. According to the analog-code approach, mental imagery is a close relative of perception.[22]

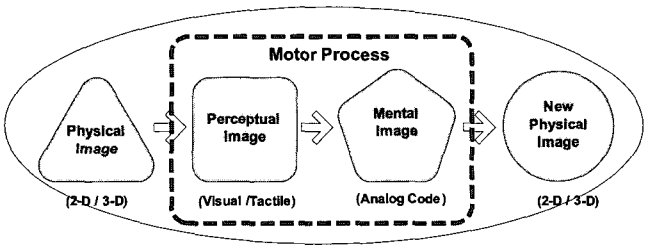

Fig. 3 Visual & Tactile Thinking Process

During the conceptual design phase in product development, sketching enables designers to concentrate on essentials and leave out distracting details thus allowing right-brain activities such as intuitive and creative thinking, and idea synthesis.[23] Moreover, we should not pass over these Visual/Tactile Thinking Processes (VTTP) for surveying the Creative Abilities (CAs) in design. Therefore,

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[19] http://www.ggy.bris.ac.uk/postgraduates/ggmp/haptics/touches.htm

[20] Matlin, Margaret W., 1998, Cognition, Harcourt Brace & Co., Orlando, p.183.

[21] Laseau, P., 2000, Graphic Thinking for Architects & Designers. John Willey & Sons, 8.

[22] Matlin, Margaret W., Cognition, 1998, Harcourt Brace & Co., Orlando, pp.184-185.

[23] Lumsdane, E., Lumsdane, M., & Shelnutt J. W., 1999, Creative Problem Solving and Engineering Design. McGrawHill, pp.30-73.

research on the VTTP is expected to facilitate idea generation for design practice.

4. Method

The primary purpose of this study was to investigate the influence of Cognitive Factors (CF) on the Creative Abilities (CAs) in design. In order to measure the CAs under different sensory systems, we adapted the Test of Creative Abilities of Design Thinking (TCADT). The TCADT is a tool for measuring creative thinking for assessing four Mental Characteristics: fluency, flexibility, originality and elaboration. Then, we examined the relationships between CAs and Sensory Modalities (SMs).

We formed the following hypotheses to address the questions posed in the Introduction as research issues.

Hypothesis 1: There are close relationships between the Representation Modes (RMs) in the tasks of the CAs. The CAs are measured by the TCADT (2-D and 3-D). This is based on the belief that four major attributes of the CAs interact with Sensory System and Thinking Modes (TM).

Hypothesis 2: Different Sensory Modalities (SMs) exist in 3-Dimensional Modeling. We reviewed that design is a typical cognitive approach with human SMs.

Hypothesis 3: There are significant relationships between preferred Representational Modes (RMs). From the above discussion, we refined that design is a cognitive interaction, which influences the preferred RM.

4.1 Subjects and Tasks

72 subjects participated in the experiments. All subjects were undergraduate students of Industrial Design major, in 'A' university in Seoul. (Freshman: 38.8%, Sophomore: 61.1%; Female: 66.6%, Male: 33.3%; Average Age: 21.4 years old) Subjects were requested to generate their ideas of creative form using the material.

4.2 Experimental Design

With the different Sensory Modalities (Visual and/or Kinesthetic), we set up three experiments; 2-Dimensional Drawing and Writing, 3-Dimensional Modeling with Naked Eye [3-D(NE)], and 3-Dimensional Modeling with Eye Bandage [3-D(EB)]. For the three dimensional tasks, we adapted modeling clay and aluminum wire, which have plasticity. (Table 2)

Table 2: Experimental Design

Experiments	Sensory Modalities	Representation Modes	Materials	TCADT
A	Visual Only	Drawing/Writing	Pen & Paper	2-D (DW)
B	Visual + Kinesthetic	Modeling	Clay & Wire	3-D (NE)
C	Kinesthetic (eye bandage)	Modeling	Clay & Wire	3-D (EB)

4.3 Procedure

We designed the experiments and its procedures to verify the hypotheses. The followings are the experimental processes.

a) All of the subjects were asked to fill a form, which consisted of titles and their sensation for tasks on idea

generation. The focus of this experiment was to examine the relation between Sensory Modalities (SM) and Design Tasks (2-D/3-D).

b) Investigation: We set up the experiments to examine the Creative Abilities (CAs).

• The Test of Creative Abilities (CAs) of Design Thinking (TCADT)

We reviewed major tools for the Tests of Creative Thinking (TCT), and developed the TCADT into 2-D and 3-D types for testing the CAs under the experimental design. The Procedures for scoring and rating under the criteria of the TCADTs were prepared for measuring the CAs. In order to measure the Influence of the Different Sensory Modalities (Visual vs. Kinesthetic Senses) on the CAs in Design, we set up two experimental situations: Visual Kinesthetic (Naked Eye: NE) and Kinesthetic (Eye Bandage: EB). (Fig. 4)

• During 2-dimensional Experiments, the preferred Representation Modes (RMs) between Drawing and Writing were recorded.

• Subjects recorded their sensation with 5 senses after finishing their tasks of the experiment 3-D(NE) and 3-D(EB) respectively.

• The Brain Dominance Mode as Thinking Characteristics was surveyed.[24]

c) Period: March 2nd ~30th 2005.

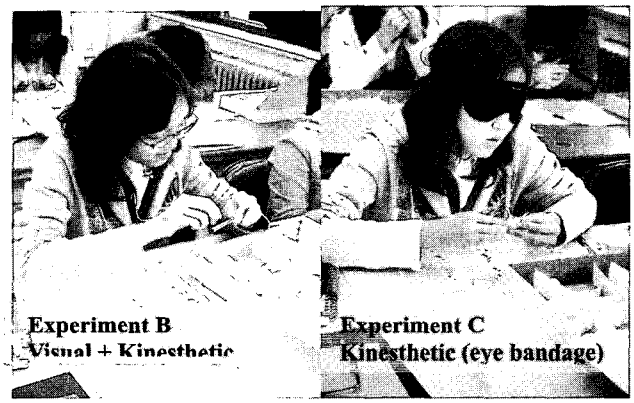

Fig. 4 Experiment Scenes

Table 3 Correlation between Sensory Modalities (2-D Drawing and Writing : 3-D Clay Modeling)

Experiment A / Experiment B		2-D Drawing & Writing			
		Fluency	**Flexibility**	**Originality**	**Elaboration**
3-D Modeling	**Fluency**	0.11978 0.3163	0.12484 0.2961	0.06979 0.5602	0.03373 0.7785
	Flexibility	-0.21029 0.0762	-0.17959 0.1312	-0.10414 0.3840	-0.03180 0.7909
	Originality	0.27470 0.0195	0.05636 0.6382	0.28447** 0.0154	0.05369 0.6542
	Elaboration	0.02107 0.8605	0.18373 0.1224	-0.07878 0.5107	0.17079 0.1515

(Pearson Correlation Coefficients Prob > |r| under H0: Rho=0 / N = 72)

[24] Lumsdane, E., Lumsdane, M., & Shelnutt J. W., 1999, Creative Problem Solving and Engineering Design. McGrawHill, p.53.

5. Results and Discussions

We examined Hypothesis 1 as shown in Table 3. The output of Correlation Analysis shows that Originality in 2-D experiment and Originality in 3-D experiments has some close relationship with a correlation coefficient of 0.28447 ($p<0.0154$). This means that Originality as a property of Creative Abilities (CAs) shows little influence under the different condition of experiments (2-D or 3-D). (Table 3)

Regardless of the Sensory Modalities (Visual and/or Kinesthetic), Originality is a common element of CAs. This means Originality has no differences in the result of tasks, which is performed among three different Sensory Modalities; Visual, Visual + Kinesthetic, and Kinesthetic only. A person who has a specific preferred Rep-Mode (Writing) shows more CAs in general.

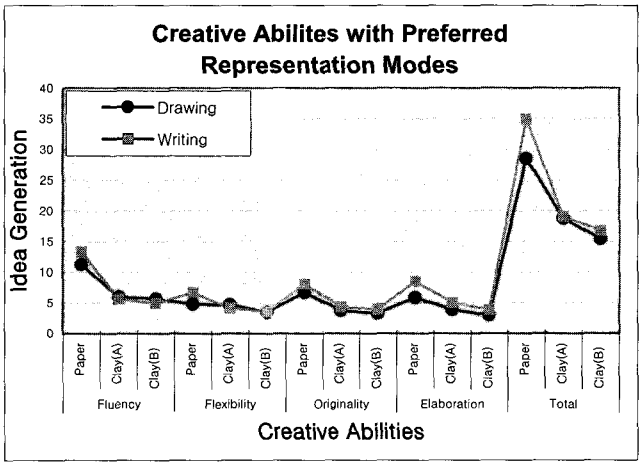

Fig. 5 Creative Abilities (CAs) with Preferred Representation Modes

In 2-dimensional experiment for the preferred Representation Modes (RMs) between two groups (Drawing and Writing), most of the pooled t-test are appropriate. The pooled p-values of Fluency, Flexibility, Originality, Elaboration are 0.0181, <.0001, 0.0185, <.0001, and the t-values are -2.43, -4.60, -2.42, -4.35 respectively. One would reject the null hypothesis of equal means and conclude that the true average records for the two groups are not equal. This means that the preferred RMs have overall influenced to all of the CAs in 2-dimensional experiments. (Fig. 5) Besides, in 3-dimensional experiments for the preferred RMs between two group (Drawing and Writing), most of the pooled t-test are appropriate. The pooled p-value of Elaboration is 0.0076, and the t-value is -2.77. One would reject the null hypothesis of equal means and conclude that the true average records for the two groups are not equal. This means that the preferred RMs have only influenced the Elaboration in 3-dimensional experiments.

The output of Correlation Analysis shows that two of CAs (Elaboration and Originality) in two 3-D experiments have closer relationship with a correlation coefficient of 0.62615($p<.0001$), 0.56207($p<.0001$), respectively than Flexibility. This means that two CAs (Elaboration and Originality) show relatively low influence under the different conditions of experiments (Naked Eye and Eye Bandage). (Table 4)

Through the experiment 3-D (NE) and 3-D(EB), subjects show the sensation of five senses as in Fig. 6. They show the most high frequencies in vision, then touch, taste, smell and hearing, respectively in the

experiment 3-D (NE). Also, this is almost same in the experiment 3-D (EB). Vision is higher in experience 3-D (NE) than 3-D (EB), while touch and taste are higher than in the experience 3-D (EB) than 3-D (NE). These results mean that we have different experiences of the task depending on what kind of sensory modality we use. (Fig. 6)

Table 4 Correlation between Sensory Modalities (3-D Clay Modeling with Naked Eye : 3-D Clay Modeling with Eye Bandage)

Experiment C \ Experiment B		3-D Modeling (Naked Eye: NE)			
		Fluency	**Flexibility**	**Originality**	**Elaboration**
3-D Modeling (Eye Bandage: EB)	**Fluency**	0.14815 0.2143	0.20773 0.0800	0.03255 0.7861	0.00568 0.9622
	Flexibility	0.08544 0.4755	0.26040** 0.0272	0.22035 0.0629	0.21161 0.0744
	Originality	0.00526 0.9651	-0.07801 0.5148	0.56207** <.0001	0.02634 0.8261
	Elaboration	0.04675 0.6966	0.17302 0.1461	0.07559 0.5280	0.62615** <.0001

(Pearson Correlation Coefficients Prob > |r| under H0: Rho=0 / N = 72)

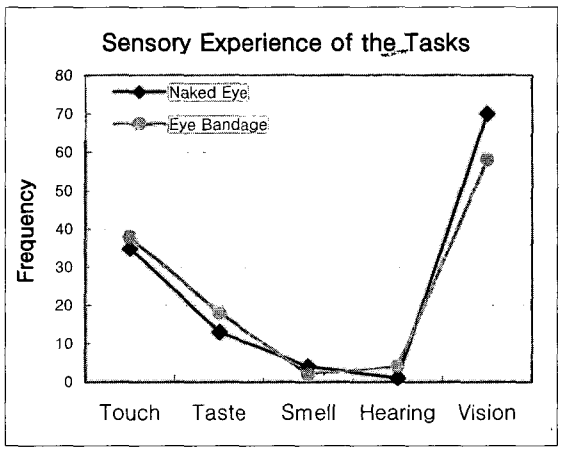

Fig. 6 Preferred Senses of 3-D Modeling

6. Conclusions

We examined cognitive Interaction in design, which has four components; Senses, Intelligences, Concepts, and Experience. On this basis, we developed a Cognitive Design Map (CDM), which has four layers; four Causes (FC), four Thinking Modes (TMs), five Senses (FSs), and four CAs. With the Cognitive Map (CM), we can effectively approach the Experience Design Methods. For the measurement the CAs, we have developed a testing system (TCADT), which consists of 2-D and 3-D types for testing CAs.

In this study, it is my intention to see how interactions with the material and the senses, the three-dimensional spatiality, and the syntheses of the senses are played on through the Tactile-Kinaesthetic

encounter.[25] We studied the Sensory Modalities (SM) based on sketching with paper and pencil, and sketch modeling in the early design phase. The relative size of cortex devoted to each body part is correlated with the density of sensory input received from that part. Size on the map is also related to the importance of the sensory input from that part of the body. The importance of touch information from our hands and fingers is obvious.[26] From our review and discussion of cognitive interaction in design, we found the multi-layered cognitive design complex, which is a case of cultural generation and is based on human experience. The four layers interact with each other from start to end in design process with this Cognitive Design Map (CDM). We can approach the experience-oriented design, and apply this map to other problem-solving fields as well. (Fig. 7)

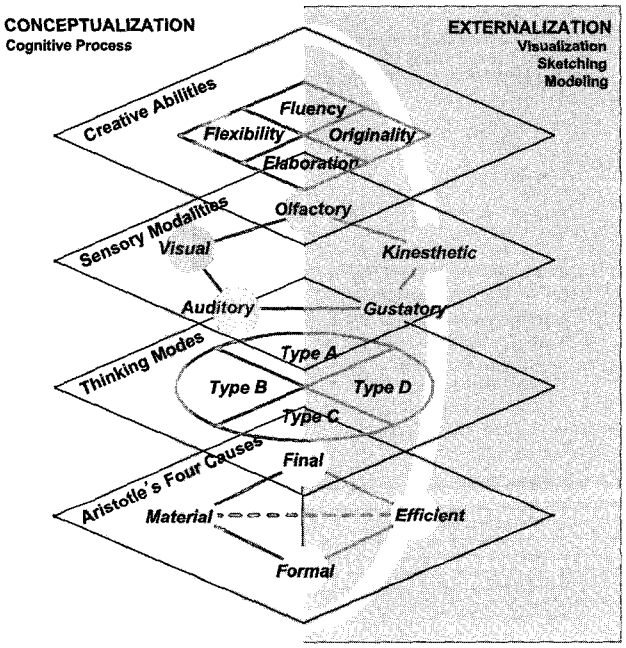

Fig. 7 Cognitive Design Map (CDM)

We have confirmed that 2-D Drawing has a close relationship with 3-D modeling in a specific CA (Originality). There are close relationships between experiment (B) and experiment (C) in 3-D modeling tasks although the differences of Sensory Modalities (Visual + Kinesthetic vs. Blind + Kinesthetic). Elaboration and Originality have closer relationships than others. As a result, Originality is the only one component which has no influence under a specific Sensory Modality with a Representation Mode.

This study does not offer a complete testing of two dimensions (2-D vs. 3-D), and these results are helpful to measure and evaluate the CAs in design. For future studies, we need to expand the subjects more generally, and find ways to reduce the errors of assessing the result of tests. It is also necessary to do more studies on Cognitive Design. We need to expand our studies on the interaction of the four domains in the Cognitive Design Map (CDM).

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[25] http://www.ggy.bris.ac.uk/postgraduates/ggmp/haptics/touches.htm

[26] Bear, Mark B., etc, Neuroscience, 2001, Lippincott Williams & Wilkins, p.415.

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