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VISUAL REASONING MODEL AS AN ANALYSIS TOOL FOR DIFFERENT TASKS RELATED TO DESIGN ABILITIES

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ABSTRACT
It is generally regarded that visual reasoning ability is critical in design process. Earlier a visual reasoning model composed of eight primitive components was proposed based on the design ideation process of seeing-imagining-drawing. In this paper, we describe how the visual reasoning model could be used to identify characteristics in various tasks related to design ability such as missing view problem task, mental synthesis task, and conceptual design task. This could help in understanding design process characteristics in general as well as in devising supports to enhance design reasoning abilities adaptive to design student characteristics and situations.

Keywords: Visual reasoning model, Design reasoning, Design process, Design creativity

1 INTRODUCTION
To understand how designers think and how they conduct design, many researchers have tried to obtain important aspects and attributes of the design process. Recently, analysis methods have been developed by design researchers. Godlshmidt and Smolkov discussed how visual stimuli affect to the design process [1]. Nagai and Taura found the concept integration process can be associated with the extension of design space, which is related to design creativity [2]. In Bilda et al.'s study, design reasoning process could be conducted using internal representations in a concept design process [3]. Some design research efforts could identify various characteristics of design processes and they tried to figure out how the process characteristics affect to design abilities. In this paper, we explore the process characteristics related to design ability. We intend to apply a design reasoning model to identify distinctive task characteristics, which could be used to enhance design reasoning capabilities reflecting individual and situation specific needs. We analyze three tasks that are related to design abilities using a design reasoning model derived from visual reasoning processes. These tasks are the missing view problem, the mental synthesis task, and a conceptual design task. The missing view problem task is used as a typical visual reasoning task. The mental synthesis task [4] to make mentally creative combinations of the forms is central in design thinking [5]. Also a conceptual design task is used as a typical design task. Using a visual reasoning model, we analyzed several students design reasoning processes in these tasks so that process characteristics of the tasks could be identified.

2 VISUAL REASONING

2.1 Visual reasoning studies
A number of researchers have found that the visual reasoning capability and creative design are closely related [6, 7]. We regard visual reasoning as an underlying cognitive process in design process [8]. For scrutinizing the visual reasoning process, we devised a visual reasoning model [9] briefly described in the next section. We used typical visual reasoning task and conceptual design for confirmation of the visual reasoning model and we could observe how visual reasoning process is related in creative idea generation in design. The result suggested that the visual reasoning model could serve as a design reasoning model. Also, the visual reasoning model was used in identifying characteristics of different designers' sketching processes [10].

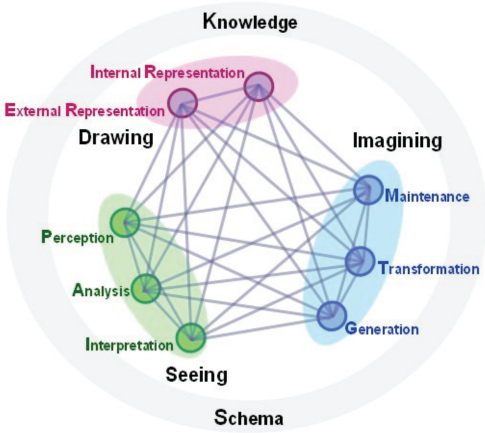

Figure 1. Visual reasoning model

2.2 Visual reasoning model

The design ideation process was described as an iterative process of *seeing, imagining, and drawing* by McKim in his book [11] published in 1972 and used in his visual thinking and design education at Stanford: the seeing process to understand problems, the imagining process to synthesize in mind, the drawing process to represent the synthesis results, and the seeing process to analyze the drawings and the problems so that the next iterations continued. Note that, later, this nature of design reasoning has also been discussed in Schon & Wiggins as the iterative process of seeing-moving-seeing [12]. This could be viewed as analysis, synthesis, and evaluation and moving includes both imagining and drawing of McKim. We defined visual reasoning as an iterative process composed of visual analysis, visual synthesis and modeling so that these three would account for seeing, imagining and drawing, respectively.

Then, by analyzing the visual reasoning process we identified underlying cognitive components of the three processes of seeing, imagining and drawing. There are two ways in reasoning, that is, in going beyond the information: one is to transform information according to rules and the other is to make inferences or judgments from the information [13]. In visual reasoning the given information can be regarded as visual information such as designer's sketch. To transform or infer about such information, observation and interpretation of visual information should occur. Also, retrieval of rules and usage of visual knowledge are necessary. At last, externalization is needed for confirmation of the results. Seeing is composed of *perception, analysis,* and *interpretation*. Imagining is composed of *generation, transformation,* and *maintenance*. Drawing is composed of *internal representation* and *external representation*. Also, knowledge and schema are engaged in design process composed of interactions of these components. The visual reasoning model is shown in Figure 1 and described below. More explanations about the visual reasoning model can be found in our previous publication [9].

Seeing. Seeing includes perceiving the visual information, identifying its associated meaning and purposes, and disassembling the data in order to understand its composition. It also includes interpreting the visual information in connection with our memory system. We classify these diverse aspects of the seeing process as perception (P), analysis (A), and interpretation (I).
Imagining. Imagining can be defined as synthesizing the visual information using perceptual and conceptual data to facilitate new representations. In the mental imagery field, Kosslyn [14] classified the imagery subjects as image generation, transformation, and maintenance. From a visual point of view, we refer to these imagery characteristics as the imagining process, specifically as generation (G), transformation (T), and maintenance (M).
Drawing. Drawing is defined as making a representation for evaluation and comparison. This representation is categorized into two groups: internal representation (IR) and external representation (ER).

2.3 Purpose of study

In this study, we intend to use the visual reasoning model as a process analysis tool to identify design process characteristics of tasks related to design abilities. Such analysis results could be used in enhancing design abilities in more suitable manners for design students individual needs and situations. For such purposes, we will discuss how the visual reasoning model is used in understanding and analyzing the reasoning processes in various tasks such as missing view problem task, mental synthesis task, and conceptual design task. Capabilities needed in those tasks are regarded to be related to design abilities [4, 5, 8]. In addition, we will describe the characteristics of the participants and the tasks as represented in the visual reasoning model.

3 CASE STUDY

Using a case study where protocol data are analyzed using the visual reasoning model, we explain characteristics of missing view problem, mental synthesis, and conceptual design tasks. For the protocol analysis we basically use the eight components of visual reasoning model. The specific coding schemes are explained in section 3.3. Four engineering senior students participated in this case study. They conducted the tasks on sketch tablet pad, and their all progresses were recorded by Camtasia program. In addition, the participants were asked to think aloud all their reasoning and their protocol data were recorded. The specific procedures about each task are introduced in the following sections.

3.1 Three tasks used

3.1.1 Missing view problem task

Missing view problem (MV), as a representative visual reasoning task was performed. In MV task, participants were required to visually construct a valid 3-D solid object by analyzing two 2-D orthographic projections and to form the missing view orthographic projection. They should find a solid satisfying the geometric constraints given by two orthographic views. Two missing view problems were given. The problems were presented in order of a degree of difficulty. Orthographic projections of top and front view were given so that both a pictorial and missing view should be sketched by participants. An example of missing view problem is shown in Figure 2.

3.1.2 Mental synthesis task

In mental synthesis task (MS), fifteen kinds of objects in Figure 3 were presented to the participants. The participants have only to be able to match the each name with the object. After they closed their eyes, the participants were given three objects among the fifteen kinds of objects. During two minutes with their eyes closed continually, the participants were asked to invent a meaningful product with the given three objects in a given category. After this stage, they were asked to sketch and describe their product during six minutes. In the first section, the given category is not changed; however, in the second section, the given category is changed after the participants sketch. Therefore, they should interpret their invention in a new category in the second section. In the first section the participants were asked to make a useful object in a utensil category using a handle, flat square, and half sphere. In the second section they were asked to make a transportation using sphere, cylinder and tube during two minutes with closed eyes, and they were asked to sketch what they imagined for two minutes, and then they have to describe it in a toys and games category for four minutes.

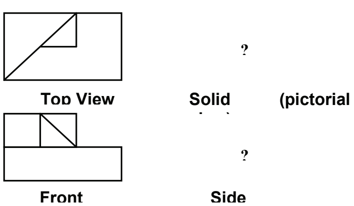

Figure 2. An example of missing view problem

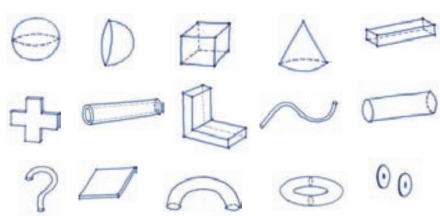

Figure 3. Objects used in mental synthesis task

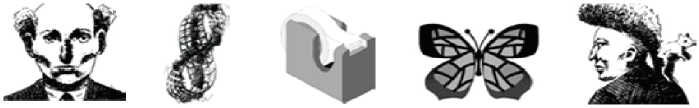

Figure 4. Visual stimuli given in the conceptual design task

3.1.3 Conceptual design task

In conceptual design task, the students were asked to design a wearable binocular. During first ten minutes, the students had to produce available ideas as many as possible for a wearable binocular using given five visual clues. Then, during next twenty minutes, they should choose one of the ideas which they generated, and elaborate it with sketching and making detailed descriptions. The five visual clues presented in Figure 4.

3.2 Visual reasoning model coding scheme

For the analysis of the each task, we analyzed protocols and sketches of the tasks. The participants' protocols and sketching processes were coded using the eight components of visual reasoning model. It is important to define and describe the content of the component for coding scheme. In this section we describe how the visual reasoning processes are coded according to the visual reasoning model in each task. We present a part of coding data from the each task in the tables which can show how the protocol is coded by the components. Note that two more components can be coded at the same duration. As McKim suggested that seeing-imagining-drawing processes facilitate and overlap each other when the design process goes on [11], we found some components of visual reasoning occur at the same time.

3.2.1 Coding in missing view problem task

We derived cognitive actions from protocol data and sketching process in MV task. We classified the cognitive actions occurred in MV task according to eight components of the visual reasoning model. Representative cognitive actions and corresponded components are presented in the bullet list. It is described how the components were used as codes in protocol data in Table 1. A part of protocol data of S3 in MS task is presented in Table 1. At first, S3 perceived (P) top view and analyzed it comparing front view (A). Then, S3 interpreted two projection views by finding the linked parts (I) and transformed 2D to 3D (T) through internal representation (IR). At last, S3 draw the solid (T/ER). When S3 just draw a line following the projection view without transformation 2D to 3D, we coded it as generation (G). This occurred between 01:03:13-01:10:07 and 01:22:06-1:25:02.

- Extracting of predicates to search for linking parts of two projection views through perception (P) and analysis (A)
- Generating alternative images of geometric entities (G)
- Transforming entities from 2D to 3D or from 3D to 2D (T) with visual schema
- Inspecting generated images of entities by comparing with given projections through perception (P) and analysis (A) using internal representation (IR)
- Transforming images of entities (T) with repetitive analysis about pictorial and projection (A)
- Externalizing images of entities through sketching (ER)
- Congruent transformation for confirmation (T)

Table 1. A part of protocol data of S3 in missing view problem task

Code			Time Duration		Script
P			00:21:03	00:29:14	At the first, seeing the top view…
A			00:29:15	00:33:09	the top view and the front view…
I	T	IR	00:33:10	00:39:09	As a whole, I guess there would be a big rectangular parallelepiped.
	T	ER	00:39:10	00:47:07	So let me draw it first.
	T	ER	00:47:08	00:51:04	(sketch the rectangular parallelepiped)
A			00:58:03	01:03:12	From the front view, I can see the big triangle.
	G	ER	01:03:13	01:10:07	So let me express it by dotted lines.
P			01:10:08	01:16:12	From the top view,
A			01:16:13	01:22:05	This is divided by this line.
	G	ER	01:22:06	01:25:02	So I draw this one certainly.
A			01:25:03	01:30:02	There is one more line here.
I	T	ER	01:30:03	01:35:06	I mark this line linking with a vertex of triangle.

Table 2. A part of protocol data of S3 in mental synthesis task

Code			Time Duration		Script
P	G	IR	00:18:02	00:25:13	The cylinder is…
A		IR	00:25:14	00:29:13	The most proper thing is… because there is no such a feature... in the bottom of the cylinder
I		IR	00:29:14	00:35:07	Tube is proper for that…
I			00:35:08	00:42:09	Because this is transportation, for convenience in transporting…
	G	IR	00:42:10	00:45:04	It would be better to add something like tires.
	T	IR	00:45:05	00:58:07	The tires must not be necessary. Like a cable car sticking the strings…
A			04:30:03	04:43:03	In the category of toy and game, it would be better to move actively
P			04:43:04	04:45:01	So this part for passengers
I	T	IR	04:45:02	04:53:06	will change into a shape which can rotate up and down and side to side.
I	T	ER	04:53:07	05:12:07	The tube shape will rotate freely.
I	T	ER	05:12:08	05:21:09	With rotating, the tube also will be illuminated.
	T	IR	05:21:10	05:34:01	This cylinder will support the tube.

3.2.2 Coding in mental synthesis task

We derived cognitive actions from protocol data and sketching process in MS task. We classified the cognitive actions occurred in MS task into eight components of the visual reasoning model. Representative cognitive actions and corresponded components are presented in the bullet list. It is described how the components were used as codes in protocol data in Table 2. A part of protocol data of S3 in MS task is presented in Table 2. S3 could generate a given object in his mind (G/IR), and inspected the object (P) and analyzed the characteristics of the object (A) with closed his eyes. Also, S3 tried to understand a given category's characteristics (I) and suggested tires (G). Then S3 changed them into a cable car (T). This whole process occurred with closed his eyes, and we can code it from his verbalization. It is presented between 00:18:02-00:58:07 in Table 2. When the changed category was given after S3's sketch, S3 tried to understand his own sketch from a different view point. That is the reason why much transformation occurred between 04:45:02-05:34:01.

- Generating given objects in mind (G, IR) with inspecting the objects (P) and extracting the features from the objects (A)
- Giving a new meaning to the objects such as name, material, color, and so on (I)
- Inventing a new object by changing the location of the objects or combining together (T)
- Internally representing with closed eyes during the first two minutes (IR)
- Sketching the invented object in mind after the two minutes (ER)
- Interpreting the invented object from a different point of view when the different category is given in the second section (I)
- Transforming its material, usage method, function and so on for the changed category (T)

3.2.3 Coding in conceptual design task

We derived cognitive actions from protocol data and sketching process in conceptual design task. We classified the cognitive actions occurred in conceptual design task into eight components of the visual reasoning model. Representative cognitive actions and corresponded components are presented in the bullet list. It is described how the components were used as codes in protocol data in Table 3. A part of protocol data of S3 in conceptual design task is presented in Table 3. S3 derived various concepts such as beauty, symmetry, and light from the butterfly visual stimulus (I). Then, S3 generated butterfly's flying in his mind (G/IR). From the representation, S3 derived freedom concept (I). This part is between 01:22:11-01:57:06. In latter half of the process, S3 generated circle which is a basic shape of lens (G), and transformed it into a butterfly shape (T/ER).

- Perceiving the given clues (P)
- Extracting predicates from the given clues (A)
- Giving a new meaning into the given clues (I)
- Generating as many objects as possible during first 10 minutes (G)
- Transforming concepts from the given clue for creative concept design (T)
- Combining the given clues (T)
- Analyzing and understanding problems from everyday life for successful design problem solving (A/T)
- Reflecting the problems from everyday life into the design (T)
- Explaining the function and detailing the structure (IR/ER)

Table 3. A part of protocol data of S3 in conceptual design task

Code			Time Duration		Script
P			01:22:11	01:24:12	The fourth clue, the butterfly... Um…
I		ER	01:24:13	01:28:13	It's beautiful…
I		ER	01:28:14	01:34:08	and symmetrical…
I		ER	01:34:09	01:42:06	light... Um...
	G	IR	01:42:07	01:47:08	and…something flying…then…
I		ER	01:47:09	01:57:06	freely... freedom.
	G	ER	12:25:08	12:32:14	The lens is a circular type like this…
A	G	ER	12:32:15	12:38:00	because this type is natural in seeing something through the lenses
	T	IR	12:38:01	12:45:12	For sticking this on the head, the butterfly shape string exists here.
	T	ER	12:45:13	12:55:11	the butterfly shape string like this…
P		ER	12:55:12	13:08:07	For more beautiful butterfly shape,
	T	ER	13:08:08	13:18:07	change wing shape of the butterfly like this way…

3.3 Evaluation of design creativity

Fluency, flexibility, originality, elaboration, and problem sensitivity have been identified as cognitive elements of design creativity [15]. Fluency, flexibility, originality, and elaboration are from Treffinger's creative learning model's cognitive side [16] and we add problem sensitivity. Each student's design creativity in conceptual design task was assessed using the criteria below.

- **Fluency.** Fluency is an ability to make multiple answers to the same given information in a limited time [17] and quantity of meaningful solutions [18]. In first ten minutes assignment of the conceptual design task, we can measure fluency by counting number of ideas participants produced.
- **Flexibility**. Flexibility is an adaptability to change instructions, freedom from inertia of thought and spontaneous shift of set [17]. That is the mode changing categories [18]. Flexibility can be evaluated by measuring conceptual distances between their ideas and between their ideas and clues.
- **Originality**. Originality is rarity in the population to which the individual belongs; its probability of occurrence is very low [17, 18]. We can evaluate originality by measuring solution's novelty in comparison with solution database and considering distinctiveness.
- **Elaboration**. Elaboration is the realization or transformation of an idea, which may become very general or simple or in contrary very fantastic or enriched into details [18]. Elaboration can be evaluated by considering how well the participants explain usage of their object and how detailed the objects are made.
- **Problem Sensitivity**. Problem sensitivity is an ability to find problems [18] and to aware needs for change or for new devices or methods [17]. They should think about the users or situations in which the product is used. By observing how well a designer identifies critical issues of a design problem, problem sensitivity can be evaluated.

4 RESULTS AND DISCUSSION

4.1 Performance of students in each task

4.1.1 Performance of students in missing view problem task

In this section the performances of the students are presented. In MV task, the average time duration was 5.93 minutes for problem 1, and 11.19 minutes for problem 2. From their protocol data, the average number of segments of problem 1 was 129 and problem 2 was 221. S2 and S3 had right solutions in both problem 1 and 2. S1 and S4 had right solution in problem 1 and they failed to find a right solution in problem 2. The examples of student's solutions in MV task are shown in Figure 5. The scores of students in MV task are presented in Figure 8.

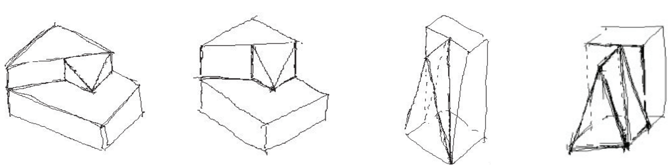

Figure 5. Examples of students' solutions in missing view problem task

4.1.2 Performance of students in mental synthesis task

In the MS task, the average time duration was 8.74 minutes in section 1, and 8.73 minutes in section 2. From their protocol data, the average number of segments of section 1 was 119 and section 2 was 139. As Finke et al.'s evaluation method [5], the expert designer evaluated the solutions of students in originality and practicality criterion. S2 and S3 had higher scores in originality and practicality. S1 and S4 had lower scores. The examples of student's solutions in MS task are shown in Figure 6. The scores of students in MS task are presented in Figure 8.

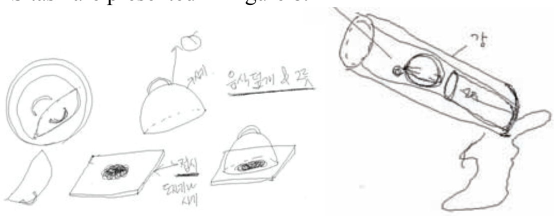

Figure 6. Examples of students' solutions in mental synthesis task

4.1.3 Performance of students in conceptual design task

In the conceptual design task, the average time duration was 25.68 minutes. From their protocol data, the average number of segments was 423. As we mentioned in section 3.4, the expert designer evaluated the solutions of students in fluency, flexibility, originality, elaboration and problem sensitivity criterion. Overall, S2 and S3 had high scores; S1 and S4 had low scores. The examples of student's solutions in conceptual design task are shown in Figure 7. The scores of students in conceptual design task are presented in Figure 8.

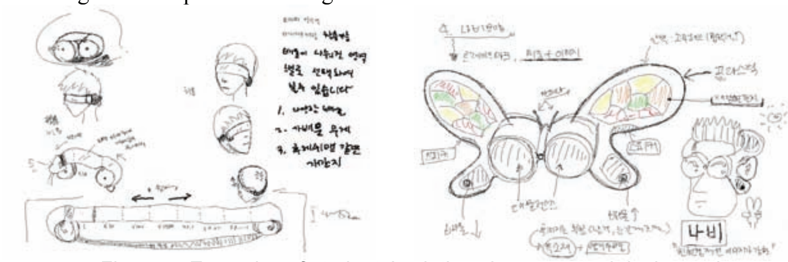

Figure 7. Examples of students' solutions in conceptual design task

4.2 Relation between performance and visual reasoning process

In this section we will scrutinize the relation between performances and visual reasoning processes. Especially, performances and visual reasoning processes between the lowest and the highest students will be compared. The scores of the performances of students are shown in Figure 8. As comparing the average scores of each task, S2 and S3 have high scores, and S1 and S4 have low scores. Previous statistical research shows that the scores of the three tasks had a significant correlation: a significant correlation was found between MV and design' scores ($r=.43$, $p<.01$) [19] and between MV and MS's scores ($r=.34$, $p<.01$). Also, in this study, students who obtained a high score in MV had high scores in MS and design task. We will compare visual reasoning processes between S2 and S4.

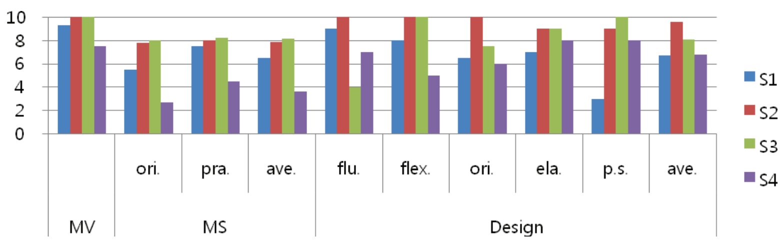

Figure 8. Scores of students in each task

4.2.1 Visual reasoning process in missing view problem

By observing the visual reasoning coding graphs, we compared S2 and S4's visual reasoning processes because S2 obtained high scores and S4 obtained low scores. From the visual reasoning model protocol analysis, the coding graphs can be derived. The horizontal line means time duration and the components of the model are presented in the vertical line. In case of S4, she failed to find a right solution in the missing view problem 2. The time duration of S4 (14.15 min.) shows how S4 struggled in the problem solving. It may be the reason why the coding graph shows much maintenance (M) compared to S2's. Also, she conducted little internal representation (IR) and just iterated trial and error through external representation (ER). On the other hand, S2 could find right solution through transformation (T) in internal representation. S2 and S4's visual reasoning processes in missing view problem 2 are presented in Figure 9.

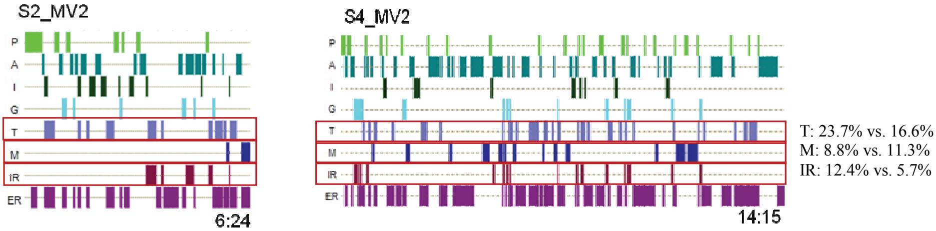

Figure 9. Visual reasoning model coding graphs of S2 and S4 in missing view problem task

4.2.2 Visual reasoning process in mental synthesis task

In MS task, S4's characteristic in visual reasoning process is much maintenance (M) compared to S2. S4 did not develop her own idea or detail it. On the other hand, S2 have much interpretation (I) and transformation (T) compared to S4. We guess interpretation and transformation play critical roles in design creativity. Because S2 could interpret the given object in various points of view, and then transform his own solution continuously, he achieved a high score in originality. Note that interpretation and transformation occurred repetitively in S2's visual reasoning coding graphs. Also, he made internal representation more than S4. Through internal representation, he confirmed its practicality. The visual reasoning processes of S2 and S4 in mental synthesis task are presented in Figure 10.

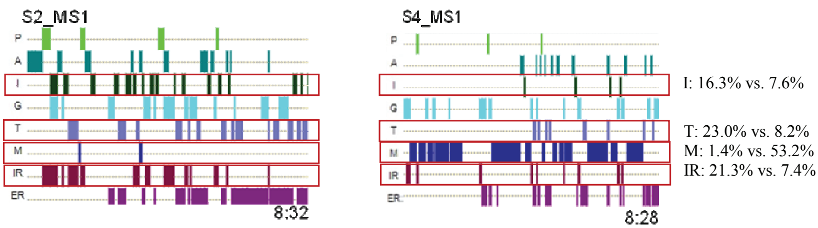

Figure 10. Visual reasoning model coding graphs of S2 and S4 in mental synthesis task

4.2.3 Visual reasoning process in conceptual design task

In conceptual design task, during the first 10 minutes, S4 suggested several ideas; however, those ideas were so simple because S4 could not derive meaningful concepts from the given visual stimuli instead she brought surface predicates from them. On the other hand, during that time, S2 derived deep meaning from the clues through much interpretation (I). In addition, S4 had much maintenance (M) whereas S2 had much transformation (T). Because S4 fixed the first idea with not much developing detailed structure and she maintained the idea, S4's solution could not be creative though she spent more time than S2. On the other hand, S2 interpreted the given clues as well as his own sketches so that he could transform his idea better. In other research, we also found the number of interpretation seems to be related to flexibility [9]. The visual reasoning processes of S2 and S4 in conceptual design process are presented in Figure 11.

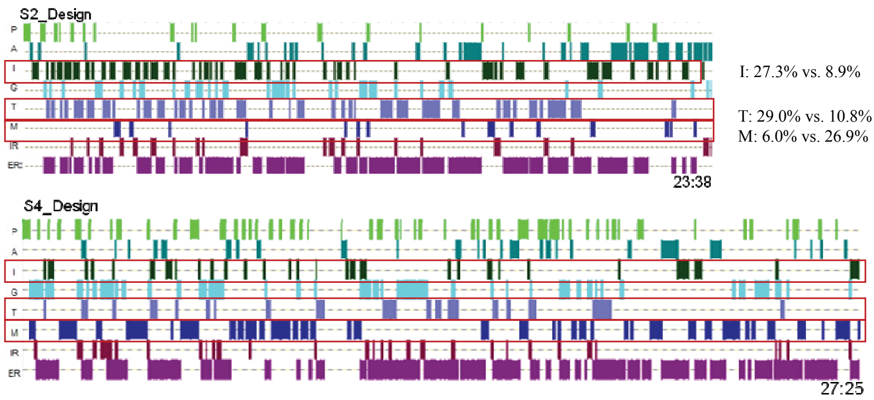

Figure 11. Visual reasoning model coding graphs of S2 and S4 in conceptual design task

4.3 Distinctive characteristics in three tasks

To observe the common process in each task, we compared percentage of amount of each component of visual reasoning model which is used in missing view problem, mental synthesis and design task. The percentage indicator is the ratio of the total time durations of each component to the total time durations of eight components. Because MV and MS tasks are composed of two problems, we used average percentage of each component as a percentage indicator. Analysis of variance (ANOVA) test was conducted for comparing percentage indicators of each component between the three tasks. As a result, there were statistically significant differences in perception (F=7.504, p=.012), analysis (F=8.667, p=.008), generation (F=14.121, p=.002), and internal representation (F=6.168, p=.021). Post Hoc Tests (Tukey HSD) was conducted and its results are presented in Table 4. The results show mean differences of percentage of component usage between MV, MS, and design task. Because the number of group was quite small, Kruskal-Wallis test [20] was also conducted to make sure the differences obtained from ANOVA test, and we obtained similar results. The differences were observed in perception (x^2=8.000, p=.018), analysis (x^2=6.731, p=.035), and generation (x^2=8.769, p=.012). Slight differences was also observed in interpretation (x^2=5.654, p=.059) and internal representation (x^2=5.654, p=.059). The specific discussion of the task characteristics will be in next sections.

To compare the characteristics of each task intuitively, we present the visual reasoning model diagrams. The time durations of components used are indicated by the areas of the corresponding circular disks in the diagrams. Through these diagrams, we can visually observe the characteristics of each task as described in next sections. The visual reasoning model diagrams of participating students in missing view problem, mental synthesis task, and conceptual design task are presented in Figure 12, 13, and 14, respectively. The visual reasoning model diagrams of three tasks in average size are presented in Figure 15. Note that we show the blinded part of the mental synthesis task separately in Figure 15.

Table 4. Percentage mean differences between MV, MS, and design task

	MV-Design		MV-MS		MS-Design	
	Mean Difference	Sig.	Mean Difference	Sig.	Mean Difference	Sig.
P	4.06	0.10	6.59*	0.01	-2.53	0.35
A	13.71*	0.02	15.26*	0.01	-1.55	0.92
I	-10.48	0.18	-11.23	0.15	0.75	0.99
G	-6.97*	0.02	-11.14*	0.00	4.17	0.18
T	2.53	0.89	7.64	0.37	-5.11	0.62
M	-7.85	0.66	-7.48	0.69	-0.37	1.00
IR	0.84	0.97	-9.68*	0.04	10.52*	0.03
ER	-13.13	0.15	3.90	0.82	-17.03	0.06

*. The mean difference is significant at the .05 level.

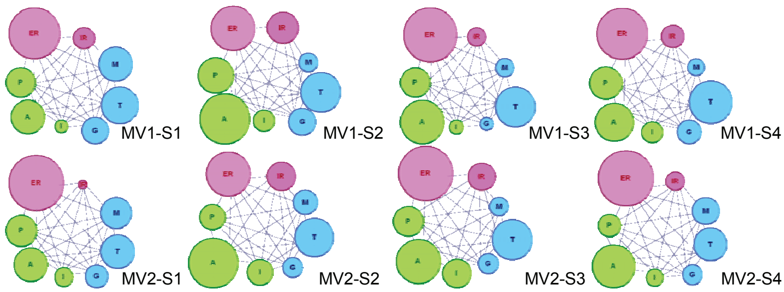

Figure 12 Visual reasoning model diagrams of students in missing view problem

4.3.1 Missing view problem task analysis

As you can see in Figure 12, the pattern of the visual reasoning model diagrams are very similar each other. It shows that the characteristics of visual reasoning process pattern in MV task are consistence on different students and different problems. In seeing process amount of analysis in seeing process is more than other components. It is because participants should analyze given top and front views for finding solutions and their own solutions for confirming it. In imagining process, there is more transformation than generation because students had to transform 2D to 3D repeatedly. Therefore, generation usages were less in MV than in MS (-6.97) and design task (-11.14) as shown in Table 4. Although there is more external representation than internal representation in drawing process, the students who did internal representation more than other students had usually higher performances. It is coincident to the results of Park and Kim's research [9]. It could be regarded that internal representation plays important role in the missing view problem.

4.3.2 Mental synthesis task analysis

In mental synthesis task, there are also consistent characteristics from a student to a student. Note that even though section 1 and 2 were different problems, the pattern of the visual reasoning has common aspects as you can see in Figure 13. That is more internal representation in MS task compared to MV (9.68) and design task (10.52) as shown in Table 4. Because the participants are required to compose an object with their eyes closed for two minutes, there are more internal representations of drawing process. Also, because they should produce a meaningful object with given three parts and explain it meaningfully in a given category, there are more interpretation of seeing process in mental synthesis than in missing view problem (11.23) although it is not statistically significant as shown in Table 4.

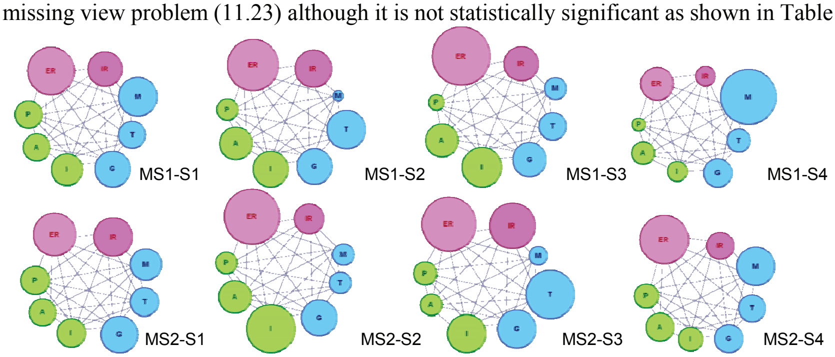

Figure 13. Visual reasoning model diagrams of students in mental synthesis task

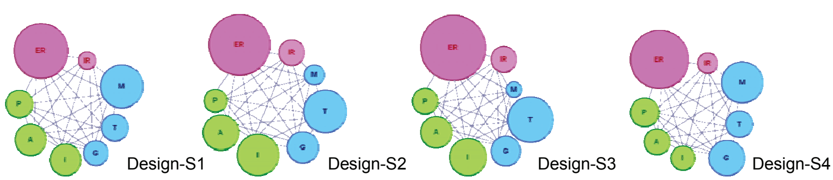

Figure 14. Visual reasoning model diagrams of students in conceptual design task

4.3.3 Conceptual design task analysis

In conceptual design task, the characteristics of visual reasoning pattern are different depend on the students. It might because design task has lower constraint compared to other tasks. In spite of that, we can observe common attributes in conceptual design tasks. Because the participants should analyze distinctiveness from the given clues and find new concepts from the clues, analysis and interpretation are necessary. As the student interpreted more visual clues or their own sketches, it is possible to obtain good results in design task. If the students used visual clues without transformation, more generation will be observed. In that case it is natural that the creativity score is low. That is the S1 and S4's case. They also had more maintenance which shows they did not develop their idea. On the other hand, students who used more interpretation and transformation obtained higher scores in creativity evaluation. Overall, we found that transformation and internal representation play important role in the missing view problem task and that interpretation and transformation are critical in the mental synthesis task and the conceptual design task.

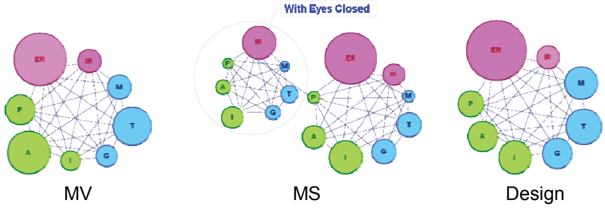

Figure 15. Visual reasoning model diagrams in each task

5 CONCLUSION

In this study, we analyzed different tasks, missing view problem, mental synthesis and conceptual design tasks using the visual reasoning model composed of interactions of seeing, imagining and drawing. By visual reasoning model analysis, we could compare different visual reasoning patterns among the student participants. While the participating students showed different reasoning processes, we identified characteristics of the three different tasks. Through the visual reasoning model diagrams, visual reasoning characteristics of the tasks can be compared easily as shown in Figure 15 where the blinded part of the mental synthesis task is shown separately to show the characteristics clearly. As shown in the statistical study and as supported by the visual reasoning model diagrams, analysis and transformation components are utilized more in the missing view problem. On the other hand, mental synthesis task involves more internal representation and interpretation components. These results could be used in providing guidance in enhancing design reasoning capabilities.

For those who are weak in transformation capabilities, missing view problem exercises could be given. Students who need more interpretation abilities could be guided to work more on mental synthesis and similar tasks. In this way, visual reasoning model could be used for analyzing the different tasks in design reasoning. Also, analysis of design processes using the visual reasoning model could be used in understanding individual designer's process characteristics. Design process characteristics could be presented by the way the visual reasoning model components are composed. For example, the creative idea generation moments match with heavy interaction among the components done in short time spans. By observing the visual reasoning pattern, the distinctive characteristics of a task can be identified. These results suggest that the visual reasoning model could serve as a good analysis tool in studying design processes and design abilities.

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