Design Activity by Determinization Level

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Abstract: The objective of this study is to examine the effect of the determinization level of the design task on the dynamics of design activity as well as on design problems, process, and solutions. With design tasks at two different determinization levels, we conducted protocol analysis based on the Triad categories and Determinization categories, and administered comparative questionnaires about design problems, process, and solutions. In regards to the Triad categories, designers identified the problems of the existing solutions and created solutions in the earlier stage of the design process when solving the low determinization level design task. About the Determinization categories, designers increased the determinization level more when solving the high determinization level design task. In the case of the low determinization level design task, the problem was easier and more interesting, and the solution was more appropriate, beautiful, creative, useful, and better. In addition, the process of the low determinization level task was easier, more interesting and creative. Designers were better at concept generation and redefining the design problem when solving the low determinization level task. On the other hand, in the case of the high determinization level design task, the process was more concrete and planned, and the solution displayed higher usability.

Keywords: Comparative Questionnaires, Design Activity, Determinization Categories, Determinization Level, Protocol Analysis, Triad Categories

1. Introduction

Rational problem-solving (Simon, 1996) which is connected to rationality, and reflection-in-action (Schön, 1983), relating to professionalism, are the two representative paradigms to describe design activity (Dorst & Dijkhuis, 1995; Joseph, 1996; Dorst, 1997; Cross, 1999; Coyne, 2005). In order to establish a model for describing the simultaneity of the two paradigms, in our previous study (Kwak & Kim, 2006;

Kwak & Kim, 2008), the subject matter of design was newly defined as a quasi-determinate goal area, and the triad problem-solving model of design with a controllable determinization level was established based on the quasi-determinate goal area. The term of quasi-determinate was defined as determinate as a determinized boundary but indeterminate within the boundary, and determinize was defined as to transform the indeterminate state into the quasi-determinate state. As the property of the subject matter of design is quasi-determinate, designers can control the subject matter of design by determinization level which indicates how concretely a designer defines the determinized boundary of the subject matter of design. There are several studies which support the concept of a controllable determinization level (Oxman, 1986; Göker, 1997; Liu, 2000; Findeli, 2001; Stempfle & Badke-Schaub, 2002; Coyne, 2005).

However, there are only a few empirical studies which discover the effect of the determinzation level. Fricke (1999) gave designers two differently precise design problems and analyzed the tactical approaches while designers were analyzing goals and searching for solutions. He suggested successful methodical approaches on the basis of the analysis results of the effect of the characteristics of the designer and the completeness of the assignment on the design approaches. Even though Fricke's study analyzed designers' design activity with differently determinized problems, his suggestions for successful methodological approaches were limited to the design tactics which were mostly drawn from designers' characteristics and lacked of the reflection of the effect of the completeness of the design problems.

In this study, we conducted protocol analysis and comparative questionnaires in order to examine the effect of the determinization level. This study identifies the dynamics of design activity based on the triad problem-solving model of design with a controllable determinization level and investigates the effect of the determinization level of the design task on the dynamics of design activity as well as on design problems, process, and solutions.

2. The Determinization Level of the Goal Area

In our previous study (Kwak & Kim, 2006; Kwak & Kim, 2008), we developed the triad problem-solving model of design with a controllable determinization level. The proposed model is a goal-oriented model that distinguishes a goal from a solution and transforms the binominal relationship between a problem and a solution into a triadic relationship among a problem, a solution, and a goal. The property of the goal area is quasi-determinate, and designers can control the goal area by determinization level.

The determinization level of the goal area as shown in Fig.1 is defined as the degree in which a designer determinizes the boundary of the goal area. The more concretely does a designer define the determinized boundary of the goal area, the higher the determinization level is. The determinization level of the goal area is controllable, and it determines the proportion between discovery and invention in the triad problem-solving model of design. According to different proportions between discovery and invention, the determinization level can be divided into the invention-focused, in which the portion of invention is larger than that of discovery, the discovery-focused, in which the portion of discovery is larger than that of

invention, and the balanced. We expect that the determinization level affects the level of creativity of the solution which is closely related to invention, and the level of efficiency of the process which is closely connected to discovery. For the case of ambiguous and inefficient problem-solving process, the discovery-focused determinization level is recommended by increasing the determinization level. At the discovery-focused determinization level, that is to say, when the determinization level is heightened as shown in the addition control in Fig. 1, the portion of discovery increases, and that of invention decreases. We expect that with a high determinization level, the level of efficiency increases due to the more systematic and logical approach by discovery, while the level of creativity of the solution decreases. Alternatively, for the case of insufficient creativity, the invention-focused determinization level is suggested by decreasing the determinization level. At the invention-focused determinization level, that is to say, when the determinization level is lowered as shown in the subtraction control in Fig. 1, the portion of invention increases, and that of discovery decreases. We anticipate that with a low determinization level, the level of creativity of the solution increases, while the level of efficiency of the process decreases (Dorst & Dijkhuis, 1995).

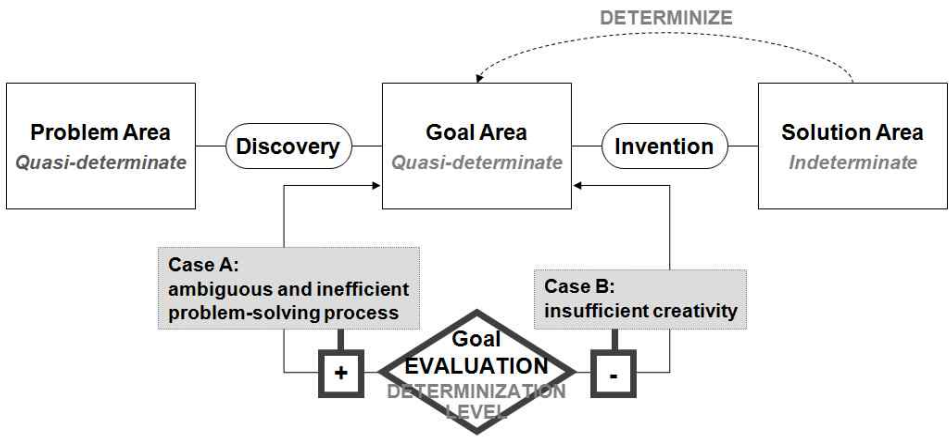

Figure 1. The Determinization Level of the Goal Area

3. Study Design

In order to examine the effect of determinization level, a protocol analysis was conducted with design tasks at two different determinization levels, and design problems, process, and solutions were compared by determinization level of the design task.

To investigate the effect of the determinization level of the design task on the dynamics of design activity and on design problems, process, and solutions, research questions were defined as follows:

1. In the design process, how are the patterns of the components of the established model affected by the determinization level of the design task?

2. In the design process, how are the patterns of a designer's determinizing process affected by the determinization level of the design task?

3. How does the determinization level of the design task affect the designers' assessment of the

problem, process and solution?

To investigate the answers about the research questions, an experiment was designed with the following variables. The experiment used a 2 within groups factorial design. The within groups factors were determinization levels of the design tasks (high or low), and participants solved both high and low determinization levels of the design tasks. With these independent variables, designers' thought processes were analyzed by protocol analysis on the basis of the coding schemes of the triad problem-solving model of design with a controllable determinization level. The design problem, the problem-solving process of design, and the design solution were evaluated by comparative questionnaires. The protocol analysis results and the questionnaires results were compared according to the determinization level of the design task.

3.1 Design Tasks

The pilot test was conducted with the 6 design tasks which consisted of the two design problems (trashcan, earphones) by three determinization levels (low, middle, high). Through the pilot test, among the 6 design tasks, trashcan design problems at two different determinization levels were selected (Kwak, 2008).

Design Task 1 [Low Determinization Level]: Design a new trashcan which satisfies user's need by solving the problems of the current trashcans.

Design Task 2 [High Determinization Level]: Design a trashcan which satisfies the following conditions: (1) In order to treat garbage from food, the trashcan should be designed such that the garbage is relatively not visible and prevent the leakage of any garbage stench; (2) When dumping garbage, the garbage should not stick to the trashcan; (3) Reducing unpleasantness to the most when touching trashcan.

3.2 Participants

In order to examine the effect of the determinization level on design activity of designers, eight university students who were majoring in industrial design were recruited for the study.

3.3 Experimental Setup

The experimental setup was constructed with reference to the Delft protocols workshop (Cross et al., 1996). The experiments were conducted in a design room equipped with video and audio recording facilities, and supplied with table and chairs, drawing pad, pens and pencils, and a ruler. Neither the existing products nor materials to get information were provided in order to control these variables. Two experimenters were present in the room separated by a partition: one experimenter guided the experiment, and the other experimenter controlled the video recording and kept a summary of the procedures.

With the experimental setup, the procedures were composed referring to the Delft protocol workshop. After the short introduction about the experiment, a think aloud training exercise was executed in order for the designer to become accustomed to thinking aloud. Then, the experimenter read the instructions about the experiment, and the designers signed in the consent form. The designers were then given the design

tasks, and the session began.

Each design task was performed for 60 minutes. After all the design tasks were completed, we conducted interviews for the retrospective verbal accounts, and asked participants to assess the design problems, their process and solutions by comparative questionnaires for comparing design task 1 and 2.

3.4 Measures of the Comparative Questionnaires

On the comparative questionnaires, participants evaluated the design problem, the problem-solving process of design, and the design solution on 15 different items. The evaluation items for the design problem were: difficult-easy, boring-interesting. The evaluation items for the problem-solving process of design were as follows: (1) How well were the design concepts generated in the problem-solving process? : badly generated-well generated, (2) How creative was the problem-solving process? : not creative-very creative, (3) In the problem-solving process, how much was the design solution developed in details? How concretely was the design solution developed? : abstractly-concretely, (4) Was the designer's problem-solving process free-flowing or determined/planned? : free-flowing-determined/planned, (5) How easy was the problem-solving process? : difficult-easy, (6) How interesting was the problem-solving process? : boring-interesting, (7) How much did the designer redefine the design problem? : not at all-very much. The evaluation criteria for the design solutions were constructed based on several criteria presented in the previous studies (Baxter, 1995; Dorst, 1997; Jo, 1997; Owen, 2005; Kim et al., 2006). They were total judgment (better/worse), appropriateness, creativity, aesthetics, functional utility, and usability.

3.5. Coding Categories

We developed triad problem-solving model categories (Triad categories) and Determinization categories to identify the dynamics of design activity (See Table 1). The Triad categories are determined by the definitions and the attributes of each Triad category, and they are Problem(P), Goal(G), and Solution(S). The Determinization categories describe the control of the determinization level of the triad problem-solving model of design, which is divided into [+], [0], and [-]. The Determinization category is determined by the differences between the determinization level of the Triad category in the (n)th order and that in the (n+1)th order. The detailed coding scheme of Triad and Determinization categories can be found in (Kwak, 2008).

Table 1. Coding Categories

Categories		
Triad PSM	P	Problem
	G	Goal
	S	Solution
Det. Level	[+]	increase of the determinization level
	[0]	halt determinization level

[-]	decrease of the determinization level

The intercoder reliability measures of all of the 16 samples for both Triad and Determinization categories exceeded the proper PRL level of .70 (Rust & Cooil, 1994). The PRL level for Triad categories ranged from 0.92 to 0.98 (*M*: 0.95), and the PRL level for Determinization categories ranged from 0.91 to 0.98 (*M*: 0.95).

4. Results

The experimental results include (1) protocol analysis results on Triad categories by the determinization level of the trashcan design task, (2) protocol analysis results on Determinization categories by the determinization level of the design task, and (3) comparative questionnaires results according to the determinization level of the design task.

4.1 Patterns of the Triad Categories by Determinization Level

The protocol data were analyzed by the Triad categories in order to examine how the patterns of the Triad categories are affected by the determinization level of the design task.

Some effects of the determinization level on the patterns of the Triad categories were found in the accumulative segments of each Triad category. Figure 2 shows the accumulative segments of each Triad category of the designer number 1's problem-solving process with respect to the normalized order of a designer's thought processes. The protocol data was analyzed by order instead of time interval because the transition of a designer's design activity is more important than how much time a designer spends on each design activity. The order of a designer's thought processes correspond with the segment of a protocol. Due to a difference in total segment number, both the order of each designer's thought processes and the accumulative segments of each Triad category were normalized into 100. The accumulative segments of each Triad category of the other designers' problem-solving processes can be found in (Kwak, 2008).

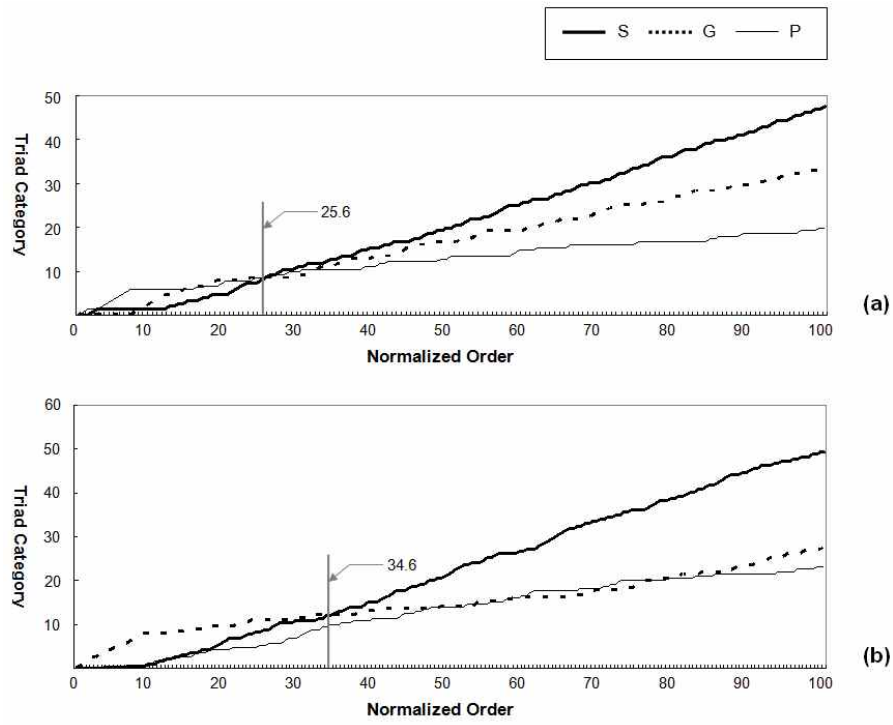

Figure 2. Patterns of Each Triad Category: (a) Task 1 and (b) Task 2

According to the different determinization level, the normalized order where S exceeded G was different as shown in the vertical marks in Fig. 2. In the accumulative segments of each Triad category of all designers except the designer number 5 and 6, the normalized order where S exceeded G in task 1 appeared in the earlier order than that in task 2 as described in Table 2.

Table 2. The Normalized Order Where S Exceeded G

Designers	1	2	3	4	5	6	7	8
Task 1	25.6	14.4	4.92	1.06	84.6	89.1	32.7	29.3
Task 2	34.6	52.0	13.9	8.47	72.6	24.7	74.1	45.0

The starting point of the S category in task 1 was shown in the earlier order than that in task 2 in the protocol data of all designers. Also, an analysis of variance (ANOVA) examining the effects of the determinization level on the starting point of the S category, displayed the determinization level of the design task to be significant ($F_{(1, 7)} = 21.553$, $p < 0.05$). The F ratio is the result of an analysis of variance, a statistical technique that indicates the size of the between-groups mean square relative to the size of the within-groups mean square (Lindman, 1992; Levin, Fox, & Forde, 2010). The p-value is defined as the smallest level of significance that would lead to rejection of the null hypothesis H_0 (Montgomery, 2001). The mean of the normalized order where the S category started in task 1 ($M = 3.25$) was displayed in the earlier order than that in task 2 ($M = 7.22$).

The P category displayed different patterns according to the different determinization level of the

design task. The starting point of the P category in task 1 was shown in the earlier order than that in task 2 in the protocol data of all designers except the designer number 4 and 7 as shown in Table 3.

Table 3. The Normalized Order Where the P Category Started

Designers	1	2	3	4	5	6	7	8
Task 1	0.64	4.58	1.64	4.26	2.08	8.16	16.4	4.42
Task 2	3.66	12.2	14.6	2.54	3.82	16.5	2.87	13.6

4.2 Patterns of the Determinization Categories by Determinization Level

The protocol data were analyzed by the Determinization categories in order to examine how the patterns of a designer's determinizing process are affected by the determinization level of the design task. The percentage of the [+] Determinization category was different according to the different determinization level of the design task. Among the eight designers, five designers displayed more [+] Determinization categories in task 2 than task 1 as described in Table 4.

Table 4. The Percentage of the [+] Determinization Category

Designers	1	2	3	4	5	6	7	8
Task 1	37.4	41.4	39.7	53.8	46.0	35.6	44.9	44.8
Task 2	43.7	45.1	42.0	49.6	43.6	38.5	46.8	44.0

In order to find some patterns of designers' determinizing processes, the accumulative segments of each Determinization category were analyzed. Figure 3 displays the accumulative segments of each Determinization category of the designer number 3's problem-solving process with respect to the normalized order of a designer's thought processes. The horizontal axis indicates the order of a designer's thought processes, which is identical to the segment of a protocol. Due to a difference in total segment number, both the order of each designer's thought processes and the accumulative segments of each Determinization category were normalized into 100. The accumulative segments of each Determinization category of the other designers' problem-solving processes can be found in (Kwak, 2008).

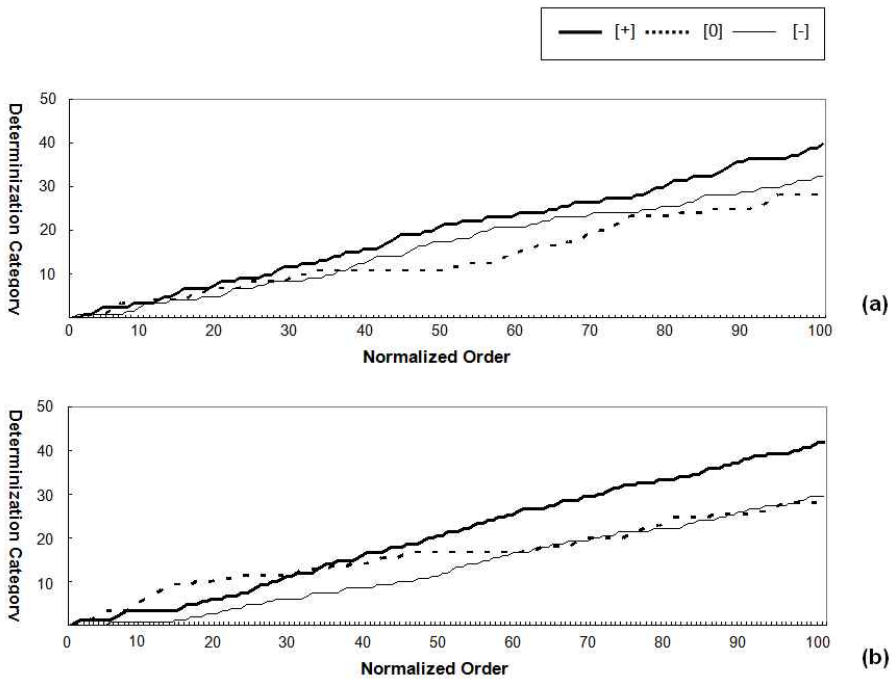

Figure 3. Patterns of Each Determinization Category: (a) Task 1 and (b) Task 2

In the accumulative segments of each Determinization category, all of the [+], [0], and [-] categories were consistently displayed throughout all phases of a protocol, such as the former and the latter of the protocol. This demonstrates that throughout the whole protocol, designers not only determinize the design problems concretely but also abstractly when they solve design problems.

In order to compare the increment per segment unit for each Determinization category, we calculated the slope of the accumulative graph of each category by estimating linear regressions. In simple linear regression, the data model is written as $y = \beta_0 + \beta_1 x + \varepsilon$, where β_0 is the y intercept, β_1 is the slope of the line, and ε is a random error, the difference between an observed value of y and the mean value of y for a given value of x (Mendenhall & Beaver, 1994). We had linear regressions that had the normalized order of each designer's thought processes as a predictor variable, and the normalized accumulative count of each Determinization category as the criterion variable. The every linear regression model was significant with a p-value less than 0.0005. The p-value explains the significance of regression, that is to say, if at least one of the regressors $x_1, x_2, \ldots, x_k$ contributes significantly to the model (Montgomery, 2001; Brace, Kemp & Snelgar, 2000). In every regression, the normalized accumulative count of each Determinization category was significantly positively correlated with the normalized order of each designer's thought processes. The p-value of the predictor variable was less than 0.0005. The p-value of the predictor variable indicates the influence of each predictor variable to the criterion variable (Brace, Kemp & Snelgar, 2000).

An ANOVA was conducted to examine the effects of the Determinization categories and the determinization level of the design task, on the slope. There was a significant main effect of the

Determinization categories ($F_{(2, 14)}$ = 35.101, p < 0.0005). The slope of [+] category (M = .437) was larger than the slope of [-] category (M = .335; $F_{(1, 15)}$ = 64.689, p < 0.0005), and the slope of both of these categories were larger than the slope of [0] category (M = .228; $F_{(1, 15)}$ = 70.265, p < 0.0005 for [+] category, and $F_{(1, 15)}$ = 19.812, p < 0.0005 for [-] category).

4.3 Comparative Questionnaires Results by Determinization Level

The comparative questionnaires results about the design problem, the problem-solving process of design, and the design solution were analyzed by the determinization level of the design task as shown in Table 5. The numbers in the 3rd column in Table 5 indicate the number of designers who selected task 1 as a dominant task about each evaluation item while those in the 4th column indicate the number of designers who selected task 2 as a dominant task about each evaluation item. Some designers evaluated the design task equally, such as concept generation in process and appropriateness and functional utility in solution.

Table 5. Comparative Questionnaires Results between Design Task 1 and 2

	Evaluation Criteria	Task 1	Task 2
Problem	easy	6	2
	interesting	6	2
Process	generated the design concept well	5	2
	creative	7	1
	concretely	2	6
	determined / planned	2	6
	easy	7	1
	interesting	6	2
	redefined the design problem well	7	1
Solution	appropriateness	5	2
	aesthetics	6	2
	creativity	5	3
	functional utility	5	2
	usability	3	5
	better	7	1

In case of the questionnaire about the problem of the trashcan design, designers evaluated task 1 easier and more interesting than task 2. In regards to the questionnaire about the problem-solving process of design, designers evaluated problem-solving process of task 1 more creative, interesting, and easier. The designers' evaluation results on the easiness of the design problem and the problem-solving process were consistent with the protocol analysis results on the point where S exceeded G. As described in the protocol analysis results on Triad categories, the point where S exceeded G in task 1 appeared in the earlier order than that in task 2 which means that task 1 is easier to produce solutions than task 2. Also, in the

problem-solving process of task 1, they generated the design concepts better and redefined the design problem more than in the problem-solving process of task 2. Conversely, designers answered that they developed the design solutions of task 2 more concretely. This result is consistent with the protocol analysis results on Determinization categories which reported that designers increased determinization level more when solving the design task at a high determinization level. Also, designers evaluated the problem-solving process of task 2 more determined than that of task 1. About the design solution, designers assessed the solution of the task 1 more dominant than that of the task 2 in all the evaluation criteria for the design solution except the usability.

5. Discussion

The experiment results about the effect of determinization level on Triad categories, Determinization categories, and comparative questionnaires can be summarized as follows.

The patterns of the Triad categories were affected by the determinization level in regards to the point where the S category exceeded the G category, the starting point of the S category, and the starting point of the P category.

The point where S exceeded G in task 1 appeared in the earlier segment than that in task 2. This implies that when more concrete goals are given, that is to say, when the determinization level of the design task is high, it is more difficult for designers to produce solutions. Also, it is inferred that when designers solve the design task with a high determinization level, they consistently reflected on the given goals in order to produce a solution which satisfies the given goals.

The starting point of the S category in task 1 was displayed in the earlier segment than that in task 2. This implies that designers observe existing solutions (products) or create solutions in the earlier stage of the problem-solving process when they solve the design task with a low determinization level than that with a high determinization level.

The starting point of the P category in task 1 was shown in the earlier segment than that in task 2. It is inferred that designers started with reviewing the given goals rather than finding problems of the existing solutions when they solved the design task with a high determinization level.

The patterns of designers' determinizing processes were different according to the different determinization level of the design task. The percentage of the [+] Determinization category in task 2 was higher than that in task 1. This indicates that designers increase determinization level more when solving the design task at a high determinization level than that at a low determinization level. That is to say, designers approach with more scientific approach when solving the design task at a high determinization level than that at a low determinization level.

In regards to the patterns of the designer's determinizing process, some general patterns were found: First, all of the Determinization categories were consistently displayed throughout all phases of a protocol: design activity includes not only the increase of the determinization level but also the decrease of the

determinization level throughout the whole problem-solving process of design. Second, as the problem-solving activities progressed, the [+] determinization level increased most while the [0] determinization level increased least.

The patterns of the designer's determinizing process support the fact that the triad problem-solving model of design can describe the simultaneity of both paradigms of design. From a microscopic point of view, all of the Determinization categories were displayed throughout the whole protocol, and this illustrates the reflective property of design activity in the paradigm of reflective practice. Conversely, from a macroscopic point of view, the fact that the [+] category displayed most explains the rational problem solving processes which requires hierarchical decomposition along functional lines for a better design process (Simon, 1969, 1992; Dorst, 1997).

In the comparative questionnaires results by determinization level, designers considered the design task with a low determinization level easier and more interesting to solve such that the problem-solving process of that was also evaluated as easy and interesting. In the problem-solving process of the design task with a low determinization level, designers redefined the design problem more with more free-flowing process and developed the process more creatively generating the design concepts better. And more creative and free-flowing problem-solving process produced more creative, beautiful, and useful design solutions, which satisfied the design problem more. Conversely, the problem-solving process of the design task with a high determinization level was more determined such that more concrete design solutions with better usability were produced.

The comparative questionnaires results validate the concept of the control of the determinization level in a goal evaluation. In a goal evaluation, in the condition of insufficient creativity a decrease of the determinization level is needed while in the condition of an ambiguous and inefficient problem-solving process, an increase of the determinization level is necessary (Kwak & Kim, 2008). A decrease of the determinization level corresponds with the design problem with a low determinization level which induces more creative problem-solving process and solutions, and an increase of the determinization level relates to the design problem with a high determinization level which leads to more determined problem-solving process and produces more concrete solutions.

These findings have some implications for design. For example, the control of determinization level could be an effective way to manage design activity. When designers perceive the design problems difficult or uninteresting, the design educators or managers can decrease the determinization level of design task. In addition, the decrease of determinization level of design task can be used to increase the creativity, aesthetics, and utility of the design solutions. Searching for solutions or redefining the design problem from the early stage of design activity is another way to increase the creativity of design. On the other hand, the increase of determinization level of design task can be effectively used to increase the usability of design solutions or to produce more concrete design solutions.

There are several limitations to this study. First, our participant pool was limited to student subjects majoring in industrial design. Replicating this study with people of different expertise, backgrounds,

personality, and cultures is an important next step. Second, we investigated the effect of determinization on design activity using only one design task. In future studies, we could analyze design activity by determinization level featuring different tasks, such as high technology products versus low technology products. Third, we studied design activity in a lab setting. Design activity in more natural settings may produce different results.

6. Conclusions

We had developed a triad problem-solving model of design with a controllable determinization level in our previous study (Kwak & Kim, 2008). The aims of this study were to investigate the dynamics of design activity based on the established model and to examine the effect of the determinization level of the design task on the dynamics of design activity as well as on design problems, process and solutions.

In order to analyze design activity by determinization level of the design task, a protocol analysis was conducted with design tasks at two different determinization levels. Eight designers solved two types of design tasks at different determinization levels; a trashcan design with a high determinization level and with a low determinization level. In order to code the data, coding schemes of the established model were constructed: the Triad categories which are composed of Problem (P), Goal (G), and Solution (S) and the Determinization categories which consist of [+](increase of the determinization level), [0](halt determinization level), and [-](decrease of the determinization level).

According to the different determinization level of the design task, the patterns of the Triad categories were distinguished in regards to the point where the S category exceeded the G category, the starting point of the S category, and the starting point of the P category. The earlier appearance of the point where S exceeded G in task 1 indicates that designers produce solutions more easily when the design task is at a low determinization level. The earlier display of the starting point of the S in task 1 explains that designers analyze existing solutions or produce solutions in the earlier order when the determinization level of the design task is low. The earlier appearance of the starting point of the P in task 1 means that designers start with analyzing the problems of the existing solutions rather than reviewing the given goals when they solve the design task with a low determinization level. The Determinization categories were distinguished by the different determinization level of the design task in regards to the number of [+] category. Designers exhibited more [+] Determinization in task 2 than task 1. This demonstrates that designers solve design tasks more concretely when solving the design task at a high determinization level than that at a low determinization level.

The designers assessed the design problem, the problem-solving process of design, and the design solution. These were analyzed according to the different determinization level of the design task. Designers evaluated the design task with a low determinization level and the problem-solving process as easier and more interesting than that with a high determinization level. Also, the design task with a low determinization level led designers to more free-flowing and creative problem-solving process. The

free-flowing and creative process produced more creative, beautiful, and useful design solutions, which satisfied the design problem more. Conversely, the problem-solving process of the design task with a high determinization level was more determined such that more concrete design solutions with better usability were produced.

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