DUAL PROTOCOL ANALYSIS
BASED ON DESIGN INFORMATION AND DESIGN PROCESS:
A CASE STUDY

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Abstract. A case study has been conducted to explore design activities of four expert designers through protocol analysis. We examined relations among design information, process patterns and solution qualities with two complementary coding schemes based on design contents and design process. Relation between personal creativity modes and design activities has been examined as well. Regarding design process, an adequate distribution of activities in process may be necessary to bring out a good solution. It seemed that the more design contents about context, external knowledge, and general feature are used, the more unique design concepts are made. Regarding personal creativity modes, not much of differences in that design activity were observed while only a few relations between designer's personality and design activity were observed. The fact that the designers participated are all experienced designers could explain this.

1. Introduction

Among the empirical research methods for analysing design activity, protocol analysis is the one that has received the most use and attention in recent years (Cross et al. 1996). It has become regarded as the most likely method to bring out somewhat mysterious cognitive activities of designers. The objective of this study is to explore design activities such as design cognitive process and design information through protocol analysis of design sessions of expert designers. We examined relations between design information which designer mentions in problem-solving, design process patterns represented by protocol data, and design solution qualities. Especially we instituted dual coding schemes based on design information and design process.

With the purpose of identifying relations between various cognitive characteristics and design creativity, an experiment was conducted earlier using personal creativity mode test, constructive perception test, visual reasoning test, spatial perception test and idea generation test, design task test for students with varying level of experiences in design (Kim et al. 2005). In this study we tried to find relations between cognitive personality by personal creativity modes and design activities represented by protocol analysis.

2. Experimental Design

Tests conducted in this experiment and experimental methods are described below.

2.1. PERSONAL CREATIVITY MODE TEST

Based on Jungian creativity theory, Professor Wilde of Stanford University developed a *personal creativity mode test* (PCMT) (Wilde 1999). PCMT has been used at many universities including Stanford and Sungkyunkwan in composing design teams in project-based design courses (Kim and Kang 2003). The personal creative modes are intrinsically related with the personal cognitive preference (Wilde and Labno 2001). Based on the cognitive theory of Jung, personal cognitive preferences can be identified based on four aspects, perceiving/judging preference, factual/conceptual perception, thinking/feeling judgment, and introverted/extroverted cognitive motivation. With these cognitive preferences, eight different modes of creativity can be identified as shown in <Table 1>. Also recently, the traits of the creativity modes have been described by another research (Levesque 2001). Each participant in this test did computer-based PCMT before design task test.

TABLE 1. The Eight Personal Creativity Modes

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

2.2. DESIGN TASK TEST

The specific task given to for the design task test (DTT) is explained in the form as given in the test.

Design Assignment:
A Small Playground utilizing water in a Kindergarten

Seeing an existing playground in the kindergartens, there is no play tool that utilizes water. You should design a small playground utilizing water for kindergarteners. When designing the tool, you have to consider that children can easily touch and manage water or it must use characteristics of water in its mechanism. It can be handled by one child but it is preferred that a group of children use it to play together. Play tool should be safe and it should be possible to play without swimming suit. Also, installation must be easy and can be placed either indoor or outdoor with proper size.

Design Task:
When solving this task, the problem solving process follows; problem understanding, idea generation and proposing and explaining design solution consequently.

2.3. EXPERIMENT

In the experiment, four expert designers over five years of design practice careers participated. The equipments used in this experiment for protocol analysis were as follows: Video camera & Pinnacle board, video presenters, and voice recorder, and video capturing program (Pinnacle Studio & TV Plus). The experiment setting is shown in <Figure 1>. Before giving DTT to subjects, we gave them small task as an exercise to practice ‘think aloud’ for 5 minutes. DTT was carried out for 60 minutes independently in a closed experimental environment.

Figure1. Scene of Design Task

3. Protocol Analysis Coding Scheme

Collected data were video data, voice data, sketches acquired from design task. We recorded all of voice data for protocol analysis. Video data was employed as support data and sketch was used in assessing design solution.

3.1. INFORAMTION CATEGORIES

Information categories are divided as shown in <table 2>. Each category addresses design contents with meaning and concept.

TABLE 2. Information Categories

Main categories	Subclass	Examples
Form visual factor	**Overall Shape (OS)** -Main object, Size, Color	with many curved shape
	Component Shape (CS) -Unit	speaker, LCD, fountain, lighting
Function	**General Feature (GF)** -Common function, Usage	able to hold water, drain naturally, gives sense of stability
	Technical Feature (TF) -Explicit function, Operation	Bore a hole, attach a foothold
Context	**External Knowledge (EK)** -User social context	Kindergarten, seven-years-old, paddle their feet in water
Human	**Physical Elements (PE)** -Body elements, Human moving, Gestures	dip their feet, sit
	Mental Elements (ME) -Feeling, Responses	Boring, bears no burden
Designer	**Intent (IN)** -Domain knowledge -Designer’s prediction or Judgment -Process management	What children want, it appears to be a big fountain, lighting is needed too First of all, basic analysis about target user is needed.

In <table 2>, categories are largely classified into form, function, designer, human and context so as to correspond possible overall data. Form is visible factors, which is divided into overall shape (OS) and component shape (CS). Function is referred to general feature (GF) and technical feature (TF). GF is a functional definition forming product characteristics and TF is a content to look for technical solutions. Human category contains physical elements (PE) and mental elements (ME) such as user's movement, behaviour, psychological state, feeling and responses. Context is external knowledge (EK) regarding social relationship, context, and resource information associated with design problem. Especially, intent (IN) in designer category is related to designer's prediction and judgment, domain knowledge, process management. This IN content is an integral part of design process as it is clearly distinctive from other categories.

3.2. DESIGN PROCESS

The design process modeling basically consists of problem understanding phase, idea generating phase, and design elaborating phase. Goldschmidt (1996) used Remarks (agenda, joke, miscellaneous) as a design activity in a coding scheme. In this study we used 7 activities for design process and added 'designers' informal remarks (A1) in order to capture the process for designer's informal. Especially, we divided the design evaluation activity into two steps (D4 & D6) in the whole design process. The first evaluation step is called D4 which can be considered as pre-evaluating step where judgment of ideas, problems, and design constraints are constantly happens before detailed design. However the other step, called D6, occurs during the course of elaboration design to re-evaluate problems found in the process so a design activity for an improvement can be triggered.

D1. Understand Problem and User
: understanding design task, problem situation, user, and context
D2. Define Constraints and Requirements
: constraints, design objective, user and product requirements
D3. Generate Idea: generating ideas, partial solutions, analogy
D4. Judge ideas and context
: previous design task judgment, idea evaluation
D5. Elaborate function and form
: finding technical solution, realizing function, and embodying shape
D6. Evaluate solutions: solution assessment, design problem-grasping
D7. Refine the solution: improving the solution
A1. Designer's Informal Remarks

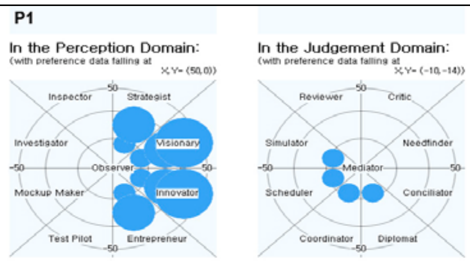
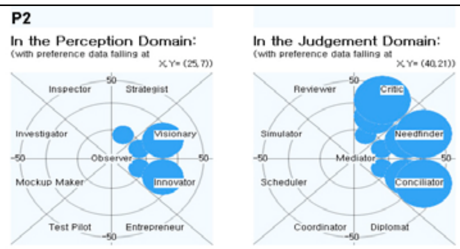
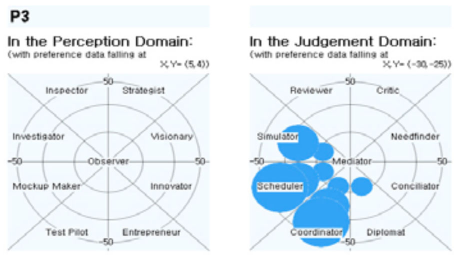
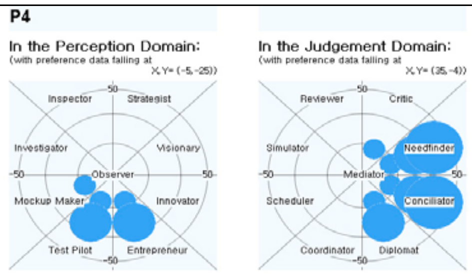
4. Results

The results of PCMT and DTT are presented as below and the results of examining the relations among design information, design process, the quality of solution and PCMT through protocol analysis are provided.

4.1. PCMT

Four designers' personal creativity modes and each mode's traits are provided in <table 3>. As shown in <table 3>, as dominant creativity mode, participant P1 has synthesizing creativity; P2, evaluating Creativity; P3, organizing creativity; P4, teamwork creativity.

TABLE 3. PCMT Results

Partici-pants	PCMT	PCMT Result Diagram
P1	**Synthesizing Creativity** : the extroverted conceptual mode : involves rearranging various elements into new configurations. : typical role - innovator	
P2	**Evaluating Creativity** : the introverted feeling mode : entails comparing perceived information and potential actions : typical role - needfinder	
P3	**Organizing Creativity** : the extraverted thinking mode : entails impersonal logical arrangement of external things : typical role - scheduler	
P4	**Teamwork Creativity** : the extraverted feeling mode : concerns control of or by external human emotional factors : typical role - conciliator	

4.2. EVALUATION OF DESIGN SOLUTION

A designer's aim is normally to achieve a high-quality design, with novelty or creativity being treated as only one aspect of an overall, integrated design concept (Kruger and Cross 2001). In this study, each solution was rated by 5 criteria which are concept, aesthetics, functional utility, technical aspects, and usability. The scores are presented in <table 4>.

TABLE 4. Scores of Solution Assessment in each Aspect (10 scale)

Participants	Concept	Aesthetics	Functional Utility	Technical Aspects	Usability	Sum (100%)
P1	8.5.	9.5	9.0	8.5	9.0	44.5(89)
P2	6.5	7.0	6.0	9.5	6.5	35.5(71)
P3	8.0	7.0	8.0	8.5	8.0	39.5(79)
P4	9.5	9.0	8.0	7.5	7.5	41.5(83)

4.3. DESIGN INFORMATION RESULT

We examined the relations among information categories, PCMT and products' qualities. As shown in <figure 2>, the amount of data flow in each information category shows consistency with a few exceptions. This result may demonstrate that design activities in expert domain are standardized to some degree and have uniform pattern.

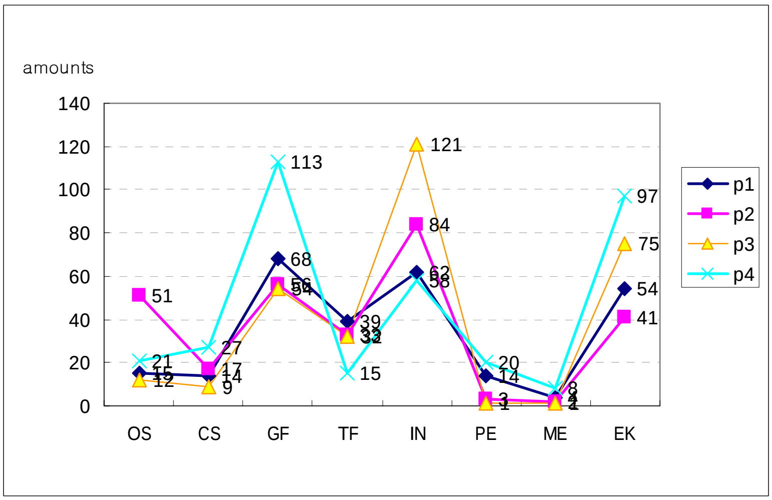


Figure 2. The Amount of Information Subclasses

TABLE 5. The Amount of Information Subclasses each Participant

Participants	OS	CS	GF	TF	IN	PE	ME	EK	Sum
P1	15	14	68	39	62	14	4	54	270
P2	51	17	56	33	84	3	2	41	287
P3	12	9	54	32	121	1	1	75	305
P4	21	27	113	15	58	20	8	97	359
Aver.	24.8	16.8	72.8	29.8	81.3	9.5	3.8	66.8	305.3

4.3.1. Overview of Designer's Design Information

P1's amount of information shows general pattern in overall sense and was least in amount. IN was less than the average but TF and PE were higher than the average. In case of P2, the amount of OS was relatively higher and amount of PE and EK were less than others. In case of P3, the amount of information was different from overall average. OS, PE, and ME were much less than the average, while IN was the highest among participants. The amount of information P4 mentioned was the highest, especially GF, PE, ME, and EK were the highest as compared to other designers.

4.3.2. Information and PCMT

The information types used in design task varied according to PCMT types as you can see in <figure 2> and <table 3>. For example, the information categories used by P4 in problem solving process showed more frequent use of vocabularies of 'human-related factor (PE, ME)' and 'context and external knowledge (EK)' compared to others having different types. In other words, he put relatively greater emphasis on user's physical status, context, social relationship and psychological state as compared to other designers. This coincides with the type of traits Levesque (2001) mentioned.

In case of P3, the frequency of vocabulary use related to designer's intention (IN) was greatly high whereas Human-related factors (PE, ME) were hardly mentioned. These results can be interpreted as coincidental with the traits of scheduler having analytic and logical thinking disposition rather than emotional aspect.

4.3.3. Information and Solution Quality Score

a) As you can see in <Table 4> and <Table 5> the higher the scores on the concept, the more amount of External Knowledge and Context (EK) was observed. This relation shows that analogy from external knowledge and effort to comprehend design problem in association with social relationship or context bring out solid and original concept in designing. Designer's continuous endeavor to transfer his external knowledge into appropriate designing property could be considered as the main reason in establishing an original concept. Employment of external knowledge is shown in many occasions and this fact works as a design motive in establishment of concepts. In fact, P4's EK category includes playing with tubes, ropes, horizontal bars, seesawing and running, and such information occurred in P4 to help establish concepts. Note that a designer who comes up with a well-understood analogous concept may be able to manage a variety of concerns and insights by integrating them into an already coherent conceptual structure (Craig 2001).

b) Our assumption of OS in relation to the aesthetics could not be seen in this study. P2 has much OS but his score on aesthetics was not notable. The reason may be interpreted that P2's technical aspect is the highest among participants because P2’s design result is based on mainly modular concept, and there are much information related to OS as a result of pursuing shape variety.

c) When there were many GF contents, the concept score was also high. In case of P4, GF was overwhelmingly high and his concept score was the highest among the participants.

d) We predicted that the usability score is related to PE and ME, but there was not much relation shown in them. Our prediction came from an assumption that PE and ME address ergonomic aspect of design so the usability of the product would be high. However, P3 showed very little amount of information.

4.4. DESIGN PROCESS RESULT

Analysis was done on coded data obtained through 7 design activities in each time period and informal statements. The detailed process was divided into three phases: (1) Problem Understanding Phase which includes Understand and Define, (2) Idea Generation Phase which involves Generate and Judge, and (3) Design Elaboration Phase having Evaluate and Refine steps in it.

4.4.1. Overview of Designer’s Process Pattern

Design data coded from the process aspect are shown in <Figure 3> where the level of activities in each process step is indicated by colors: the darker, the more activities. The horizontal axis indicates the time progression stages.

a) Participant 1

Generally activities were allocated adequately according to the passage of time stages and activities increased in latter part of the process. During the Problem Understand Phase, P1's activities were found steadily from the beginning to a little after the midpoint stage. The activities of Idea Generation Phase were presented after the mid stage of the process. Especially in the Elaboration Design Phase, P1's activities were more vigorous as compared to other participants halfway passed in the phase. Informal Remarks happened in the beginning and the mid stage.

b) Participant 2

Much of P2's vigorous activities were presented in the beginning stage and tendency of frequency in his activities decreased in the latter stage. In Problem Understanding Phase activities were occurred only in the beginning phase. During Idea Generation Phase infrequent activities occurred in the beginning and middle part, and stopped soon after. For Elaboration Design Phase, activities started in the beginning irregularly. Informal Remarks happened in beginning and middle stage.

c) Participant 3

Activities occurred mostly in the middle stage and not many different of activities are shown in the latter phase. In Problem Understanding Phase activities happened from the beginning until the midpoint and activities occurred vigorously in the halfway of Idea Generation Phase. Only small numbers of activities were shown after the middle part of Elaborate Design Phase. Informal Remarks steadily occurred throughout the whole process.

d) Participant 4

Much of his activities occurred in the beginning stage and for Problem Understanding Phase, activities vigorously occurred from the beginning until the middle stage. Noticeably, the occurrences of activities were presented busily and consistently from the beginning to the ending step of Idea Generation Phase. Also not many different activities occurred in the end phase of Elaborate Design Phase. Informal Remarks were very seldom made.

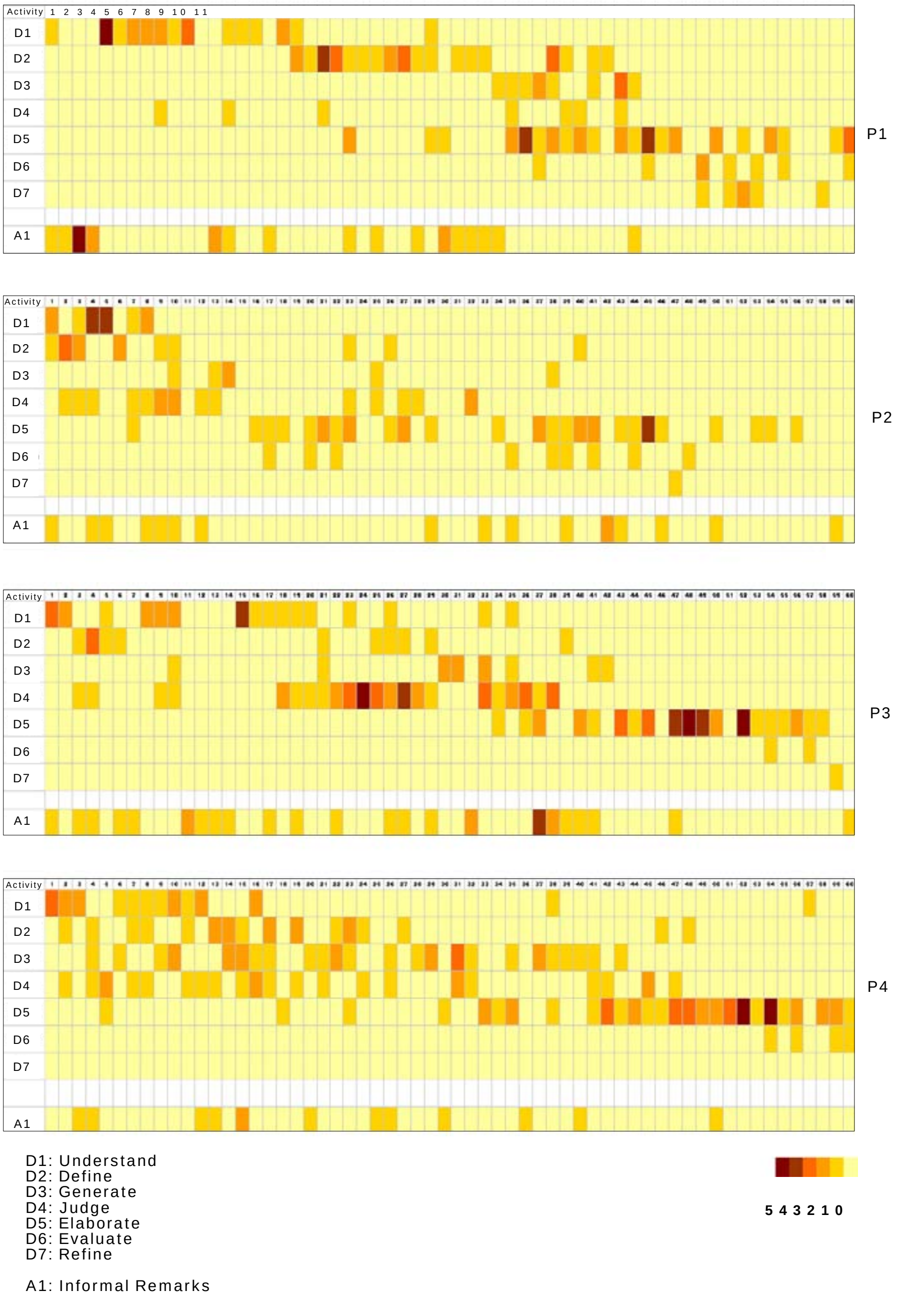


Figure 3. Designer's Activities in Design Process

4.4.2. Process Pattern in Each Phase

Even though defining a standardized design process pattern is difficult, a desirable process pattern can be defined by the stages of process performing appropriate activities in sequence.

P1’s design process seems to follow this pattern as shown in <figure 6>. In case of other three designers’ patterns, however, their patterns also have significance due to the following reason. Overall design process of P2, P3, and P4 appears to oscillate between problem and solution rather than one-way process of first defining the problem and then searching the solution. This result is similar to the study of Cross (1997). According to his study, creative designing seems to proceed by oscillating between sub-solution and sub-problem areas, as well as by decomposing the problem and by combining sub-solutions.

4.4.3. Design Process and PCMT

No significant difference has been found in design process pattern in terms of the types of PCMT. As a whole, the problem solving process of four designers showed similar patterns which took the same route from the phase of problem-understanding to problem-solving. The fact that all four participants are trained design experts with more than five years of design practice could account for this result.

In case of P3, whose dominant mode is organizing creativity, the fourth step (D4) ‘Judge ideas and context’ was of great quantity and the frequency of informal remark (A1) was high. This result means that P3 focused on the analysis of a problem in problem solving process and he had a great deal of confirmation regarding the procedure and process of problem-solving. It is somewhat associated with organizing creativity traits.

P4 who has teamwork creativity mode spared more time for problem-understanding stages than other participants, and in this phase he took ‘external knowledge (EK)’ among design information into great consideration (as identified in <figure 10>). In this respect, he might understand and define problem by considering users’ physical situations, psychological states, and social contexts. It may coincide with the traits of extroverted feeling creativity mode.

4.4.4. Process and Solution Quality Score

Comparing process-based coding data and solution qualities, the following observations could be obtained.

a) In the relation between process and solution quality, we could observe that an adequate distribution of activities throughout all the processes may be necessary to bring out a good solution. For instance, in case of P1, who scored the highest in the solution score, the frequency of his design activities occurred evenly over all the steps of the process. In case of P4, whose solution received second highest score, though his activities were vigorous in the beginning compared to P1, his activity pattern presents relatively even distribution.

b) Problem Understanding Phase: Participants P1, P3, and P4 who showed high activities in problem understanding phase received high concept scores, while P2 who showed low activity in this phase gained low total and concept scores. As a result, we could identify that problem understanding is very important.

c) Idea Generation Phase: P2 who showed relatively low activities in this phase received low score in functional utility, while P4 whose activities were vigorous in this phase gained high scores on concept and aesthetics. In P3, activities associated with idea judgment were exceptionally high.

d) Design Elaboration Phase: P1, whose solution gained the highest score, did many design activities oscillating through the three steps of the design elaboration phase. P2's activity was not well focused in the final stages of the process and his solution scored the lowest.

4.5. RELATIONS BETWEEN DESIGN INFORMATION AND PROCESS

Comparing the data from the two dual coding schemes together, observations on relation between design information and design process could be obtained. The design information used and mentioned as the design task proceeded is shown in <Figure 4>. From <figure 3> and <figure 4>, the following relations could be observed.

EK appears relatively in the beginning stages of the design process. Note that P4's high activities in the Understand and the Define in relation to strong appearance of EK. IN design information category and the Judge part of the process happen almost concurrently. Note that the judge process and the intent information occurred together in P3. OS and CS are related to the shape of products and they mainly take parts in dealing with the specific shape of products. Hence the two categories are presented in the elaboration design process. CS occurring after OS means that CS is relevant to specific shape of the design. TF is related to the latter process concerned with concretization of design and evaluation. P1 and P3 show these characteristics and P2 starts this activity in the early phase and continues until the latter part. The TF activity of P4 is not significant.

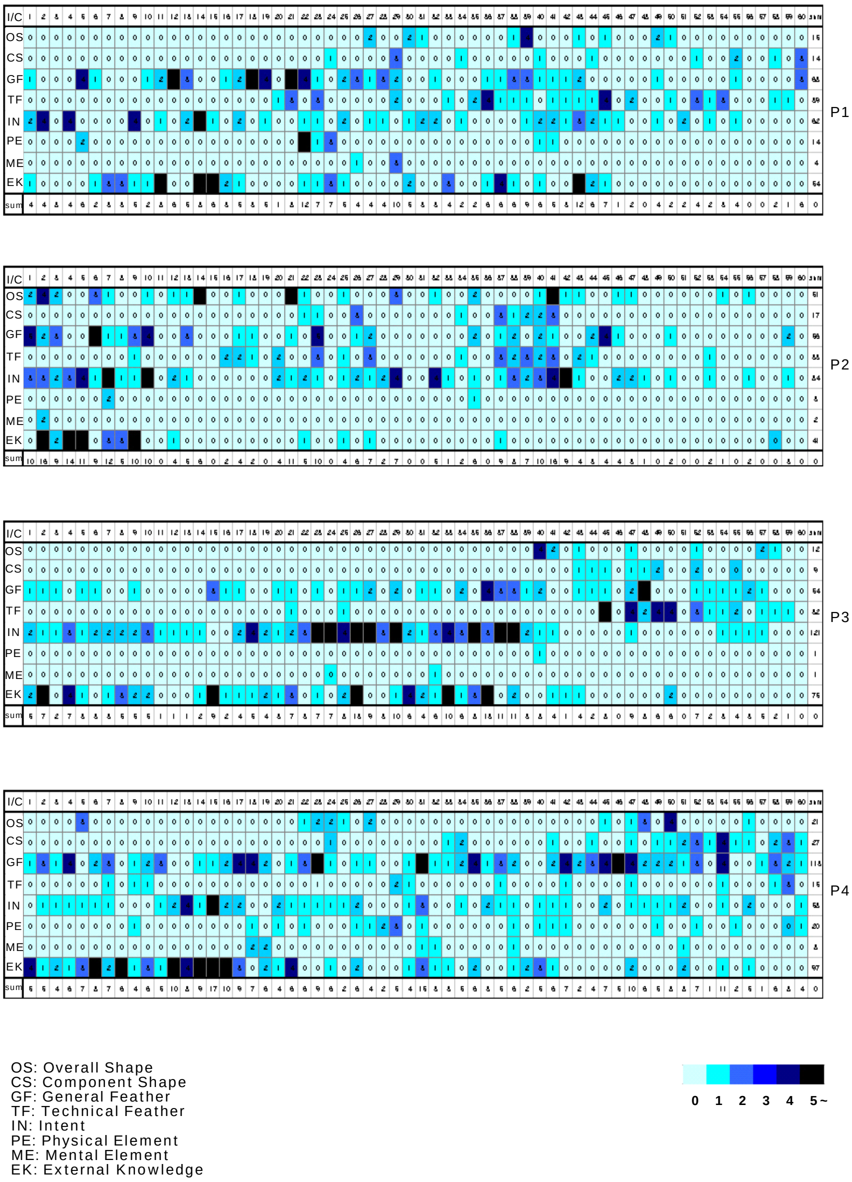


Figure 4. Flow of Each Information Category

5. Summary and Conclusion

In this study, we encoded the design information and process for expert designers with two complementary coding schemes based on design process and information contents. In addition, we explored the relation between designer's cognitive personality and design process.

Concerning the design information, the frequency of information in expert designer formulates a regular pattern except a few cases. It seemed that the more design contents about context, external knowledge, and general feature are used, the more unique design concepts are made.

Regarding design process, an adequate distribution of activities in process may be necessary to bring out a good solution. The products' scores varied according to the degree of activities' distribution in problem understanding phase, idea generation phase and design elaboration phase.

Regarding personal creativity modes, not much of differences in that design activity were observed. Only a few relations between designer's personality and design activity were observed. Two designers showed some association with their design process and design information. Feeling oriented personal cognitive characteristics as observed in P4 resulted in rich uses of external knowledge and general features and emphasis on problem understanding and early idea generation phases rather than elaboration phase. Organizing creativity mode revealed by P3 could be associated with rich intent information category that includes process management issues.

As cognitive process may be influenced by a variety of factors such as personal cognitive ability, experiences, expertise and environment, further research to understand the relations between design process and various variables is needed. Investigation on the differences between novice designers and expert designers as reflected in protocol data based on design information and design process coding schemes is to be done to understand more detailed design cognitive processes. Also study on the relation between design process and personal creativity modes for novice designers is to be done to examine whether the influence of personal cognitive style on design process varies according to the degree of expertise or domain experience. Also, how personal process patterns observed through this protocol analysis can be utilized in composing design team will be investigated.

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