ABSTRACT

The objectives of this study are to explore design activities such as design process and design information through protocol analysis of design sessions of expert designers and student designers and to understand the relations between their personal creativity characteristics and design activities. In protocol analysis, we instituted dual coding schemes based on design information and design process. Regarding design process, an adequate distribution of design activities in process may be necessary to bring out a good solution. It has been identified that design processes of expert designers are more effective than those of student designers. Regarding personal creativity, relatively widely different characteristics have been identified for the eight participants, and much of personal creativity traits can be associated with observed design activities. This suggests that personal creativity characteristics could be utilized in understanding design activity characteristics and such understanding could be helpful in improving individual or team-based design problem solving.

Keywords: Protocol Analysis, Design Process, Design Information, Personal Creativity Mode Test.

1. INTRODUCTION

Among the empirical research methods for analyzing design activity, protocol analysis has been used as the most likely method to bring out somewhat mysterious cognitive activities of designers in the design research recently [3]. Akin and Lin studied the behaviors of designers using techniques of cognitive psychology in general and protocol analysis in particular [1]. They analyzed verbal-conceptual and visual-graphic data obtained from the protocol analysis and explored the relationships between design activities and design decisions. Suwa and Tversky examined the information that architects think of and read off from their own freehand sketches and revealed how they perceptually interact with and benefit from sketches through a protocol analysis with retrospective reports [13]. Therefore, the concurrent protocol data is necessary as well as the sketches in a product design domain.

Personal creativity modes have also drawn a considerable attention since it can be used for promoting performances of creative design activities as individuals or teams [15]. Personal creativity modes represent the different creativity modes of individuals, which are intrinsically related to their personal cognitive preferences according to the cognitive theory of Jung [16]. Therefore, it is of much significance to study the relationships between the personal creativity modes of designers and the characteristics of their design activities.

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 [10]. In this study, we try to find relations between cognitive characteristics of personal creativity modes and design activities through protocol analysis. At the Creative Design and Intelligent Tutoring Systems (CREDITS) research center, research work
toward design creativity education is being conducted such that various underlying cognitive elements of design creativity are identified and then these design creativity elements can be enhanced through training methods reflecting individual learner’s characteristics. For example, visual reasoning capability has been identified as a critical element of design creativity [10], and an intelligent tutoring system has been developed for visual reasoning [14].

The objectives of this research are to explore design activities through the dual protocol analysis and to understand the relations between their personal creativity modes and design activities. In the dual protocol analysis, two complementary coding schemes have been used: (1) design information and (2) design process. A case study is carried out by conducting design task of four expert designers and four student designers whose personal creativity modes have been identified. The results of design task are analyzed through the dual protocol analysis and the visualization tool of coded data representing design activities is developed. The relations among design information, design process, personal creative modes and solution quality scores are examined in this paper.

The overview of the design experiments is stated in section 2. In section 3, the protocol analysis coding scheme with design information and process is presented. The design experimental results, including personal creativity modes, the evaluation of design solutions, design information results, and design process results, are followed in section 4. In section 5, the relations among the experimental results are analyzed and discussed. Finally, the summary and discussion are given in section 6.

2. DESIGN EXPERIMENT

Two main tests were conducted in the design experiment: (1) Personal Creativity Mode Test (PCMT) and (2) Design Task Test (DTT). In this section, the overview of PCMT and DTT is described and the detailed experimental procedure is also presented.

2.1 Personal Creativity Mode Test (PCMT)

Based on Jungian creativity theory, the PCMT has been developed by Professor Wilde at Stanford University [15]. Personal creativity modes are intrinsically related to their personal cognitive preferences [16]. According to the cognitive theory of Jung, there are four aspects in the personal cognitive preferences including perceiving/judging preference, factual/conceptual perception, thinking/feeling judgment, and introverted /extroverted cognitive motivation. These four aspects can further be deployed into eight different modes of creativity, as shown in Table 1 [15].

<table>
<thead>
<tr>
<th>Modes</th>
<th>Conceptual (Intuitive)</th>
<th>Extroverted Modes</th>
<th>Introverted Modes</th>
<th>Responsive Modes</th>
</tr>
</thead>
<tbody>
<tr>
<td>PERCEPTUAL MODES</td>
<td>Factual (Sensing)</td>
<td>Synthesizing</td>
<td>Transforming</td>
<td>Objective (Thinking)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Experiential</td>
<td>Knowledge -based</td>
<td>Subjective (Feeling)</td>
</tr>
<tr>
<td>RESPONSIVE MODES</td>
<td></td>
<td></td>
<td>Analyzing</td>
<td>Teamwork</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Evaluating</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: The eight personal creativity modes [15]

The characteristics of each personal creativity mode have also been described in a more recent work [12]. The PCMT has been used at many universities including Stanford University and Sungkyunkwan University when composing design teams in project-based design courses, since it is believed that the personal creativity modes are strongly related to the traits of design activities of individuals [9]. Each participant in this test did computer-based PCMT before DTT.

2.2 Design Task Test (DTT)

A specific design task was given to each participant to obtain the information of their design activities during the design experiments. The task was to design a small water play tool in a kindergarten with the following description:

*When seeing playgrounds in the kindergartens, there is no play tool that utilizes water. Designers should design a small play tool utilizing water for kindergarteners. When designing the tool, designers have to consider that children can easily touch and manage water. In addition, the designed play tool must use characteristics of water in its mechanism. It can be played by one child but it is preferred that a group of children use it to play together. The play tool should be safe and it should be possible to play without swimming suit. Besides, installation must be easy and it can be placed either indoor or outdoor with proper size.*

2.3 Experiment

Four expert designers and four student designers participated in the design experiments. The former group consisted of product designers having over five years of design practice experiences in industry and the latter was composed of those majoring in industrial design without professional experiences. During DTT, a think-aloud method was used to capture the design activities of each participating designers. In a think-aloud method, the designers were asked to talk their thoughts during the design process. A voice recorder was used to capture the data of designers’ talk for a protocol analysis. A video camera was also set up to monitor the design sketch activities of each participant. Video capturing software such as Pinnacle Studio and TV plus was used to process recorded video data. Overall experimental procedure is as follows. Each participant conducted the PCMT, and think-aloud exercise. Then, each carried out DTT for 60 minutes independently.

3. PROTOCOL ANALYSIS CODING SCHEME

Two complementary coding schemes have been proposed for protocol analysis: (1) Design Information Coding Scheme, and (2) Design Process Coding Scheme. The collected data including video data, voice data, and sketches during DTT have been coded and analyzed according to the proposed protocol analysis coding scheme.

3.1 Design Information Coding Scheme

In the design information coding scheme, the primary classes can be categorized into Form, Function, Human, Context and Designer. In addition, each primary class can further be classified into subclasses. Form is a visible factor, which can be divided into Overall Shape (OS) and Component Shape (CS). Function can be classified into two subclasses including General Feature (GF) and Technical Feature (TF). GF is
defined as a functional definition forming product characteristics and TF addresses technical solution realization. Context refers to External Knowledge (EK) regarding social relationship, context, and resource information associated with design problem. Human class contains Physical Elements (PE) such as user behavior and movement, and Mental Elements (ME) including psychological state, feeling and emotion. In particular, Intent (IN) and Management (MG) in Designer category are related to designer’s prediction and judgment, and process management, respectively. These IN and MG compose the integral part of design process, which are clearly distinctive from other categories. This coding scheme including primary classes and subclasses is summarized in Table 2 with corresponding example remarks by participants.

Table 2: Design information coding scheme.

<table>
<thead>
<tr>
<th>Primary Class</th>
<th>Subclasses</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Form</td>
<td>Overall Shape (OS)</td>
<td>main object, size, color using a curved shape</td>
</tr>
<tr>
<td></td>
<td>Component Shape (CS)</td>
<td>unit, layout speaker, LCD, fountain, lighting</td>
</tr>
<tr>
<td>Function</td>
<td>General Feature (GF)</td>
<td>specification, common function hold water, drain naturally, assembled automatically</td>
</tr>
<tr>
<td></td>
<td>Technical Feature (TF)</td>
<td>technical realization boiling a hole, attach a foothold</td>
</tr>
<tr>
<td>Human</td>
<td>Physical Elements (PE)</td>
<td>ergonomic elements, human behavior, user action</td>
</tr>
<tr>
<td></td>
<td>Mental Elements (ME)</td>
<td>feeling, emotion, sense tiresome, familiar with water</td>
</tr>
<tr>
<td>Context</td>
<td>External Knowledge (EK)</td>
<td>external information, user context kindergarten, seven-years-old, water balloon, tree</td>
</tr>
<tr>
<td>Designer</td>
<td>Intent (IN)</td>
<td>prediction or judgment in view point of education, these factors seems to be desirable</td>
</tr>
<tr>
<td></td>
<td>Management (MG)</td>
<td>process management basically user analysis is needed.</td>
</tr>
</tbody>
</table>

3.2 Design Process Coding Scheme

The design process coding scheme basically consists of three design phases including Problem understanding, Idea generation and Design elaboration, and additionally contains Process remarks. Goldschmidt et al. introduced ‘remarks’ such as agenda, joke and miscellaneousness, as a design activity in the coding scheme [5]. In the coding scheme proposed in this paper, the designer’s remarks, referred to as process remarks, are further divided into two subclasses: Manage the process (Mp) and Informal remarks (Ir). The proposed design process coding scheme is summarized in Table 3 with example design actions. As can be seen in Table 3, each of four primary classes can further be divided. The problem understanding phase consists of three subclasses such as D1, Understand problem and requirement (Un), D2, Gather user context and information (Ga), and D3, Clarify constraint and direction (Cl). In the phase of idea generation, there exist two subclasses including D4, Generate ideas (Gi) and D5, Judge ideas and information (Ju). The detailing and evaluation of generated ideas can be done in the design elaboration, the third primary phase of the coding scheme, which is composed of three subclasses: D6, Elaborate form and function (Ef), D7, Evaluate the solution (Es), and D8, Refine the solution (Rs). Finally, A1, Manage the process (Mp) and A2, Informal remarks (Ir) can be considered to be subclasses of the process remarks.

Table 3: Design process coding scheme.

<table>
<thead>
<tr>
<th>Primary Class</th>
<th>Codes</th>
<th>Subclass</th>
<th>Example Actions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Understanding</td>
<td>D1</td>
<td>Understand (Un)</td>
<td>understanding design assignment and task</td>
</tr>
<tr>
<td></td>
<td>D2</td>
<td>Gather (Ga)</td>
<td>collecting data about user or external information</td>
</tr>
<tr>
<td></td>
<td>D3</td>
<td>Clarify (Cl)</td>
<td>defining design constraints and objectives</td>
</tr>
<tr>
<td>Idea</td>
<td>D4</td>
<td>Generate (Gi)</td>
<td>generating helpful idea for partial solution</td>
</tr>
<tr>
<td>Generation</td>
<td>D5</td>
<td>Judge (Ju)</td>
<td>evaluating ideas and data</td>
</tr>
<tr>
<td>Design</td>
<td>D6</td>
<td>Elaborate (Ef)</td>
<td>Finding technical solution, realizing function and shape</td>
</tr>
<tr>
<td>Elaboration</td>
<td>D7</td>
<td>Evaluate (Es)</td>
<td>assessing the solution</td>
</tr>
<tr>
<td>Process</td>
<td>D8</td>
<td>Refine (Rs)</td>
<td>improving the solution</td>
</tr>
<tr>
<td>Remarks</td>
<td>A1</td>
<td>Manage (Mp)</td>
<td>controlling and distributing the design activities</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>Informal (Ir)</td>
<td>may I ask a question?</td>
</tr>
</tbody>
</table>

4. DESIGN EXPERIMENT RESULTS

The experimental results including (1) personal creativity characteristics, (2) design solution evaluations, (3) protocol analysis results on design information, and (4) protocol analysis results on design process, are described for all eight participants.

4.1 PCMT Results

The personal creativity modes of eight participants have been identified, as shown in Figure 1, with the characteristics of each mode [12, 16]. The personal creativity characteristics of 8 participants are described as below. Note that the selection of eight participants of experiments turned out to be very effective since 6 different primary personal creative modes have been obtained out of total 8 modes.

(1) Expert designer 1 (E1): E1’s primary creativity mode is the synthesizing creativity. As can be seen in Figure 1, E1 shows the strong perception aspect while his judgment aspect is weak. In addition, he also has some transforming creativity mode and the strong aspect of intuition.

(2) Expert designer 2 (E2): E2’s personal creativity mode is identified to be strong evaluating creativity. He is introverted and feeling oriented. In addition, the aspects of visionary and innovator are also shown in the perception domain, and some intuition aspect can also be found in E2.

(3) Expert designer 3 (E3): E3 has very strong organizing creativity. The typical role of scheduler would fit to this mode. E3 shows very neutral characteristics in the perception domain.
<table>
<thead>
<tr>
<th>PCMT Results</th>
<th>PCMT Result Diagram</th>
<th>PCMT Results</th>
<th>PCMT Result Diagram</th>
</tr>
</thead>
</table>
| **E1**   | **Synthesizing Creativity**  
: the extroverted conceptual mode 
: rearranges known concepts into novel systems  
: typical role: Innovator | ![PCMT Result Diagram E1](image1) | **S1**   | **Synthesizing Creativity**  
: the extroverted conceptual mode 
: rearranges known concepts into novel systems  
: typical role: Innovator | ![PCMT Result Diagram S1](image2) |
| **E2**   | **Evaluating Creativity**  
: the introverted feeling mode 
: uses personal values to distinguish between good and bad  
: typical role: Needfinder | ![PCMT Result Diagram E2](image3) | **S2**   | **Experiential Creativity**  
: the extroverted factual mode 
: discovers new ideas and phenomena by direct experience  
: typical role: Mock-up maker | ![PCMT Result Diagram S2](image4) |
| **E3**   | **Organizing Creativity**  
: the extroverted thinking mode 
: efficiently manages resources and enforces specifications  
: typical role: Scheduler | ![PCMT Result Diagram E3](image5) | **S3**   | **Organizing Creativity**  
: the extroverted thinking mode 
: efficiently manages resources and enforces specifications  
: typical role: Scheduler | ![PCMT Result Diagram S3](image6) |
| **E4**   | **Teamwork Creativity**  
: the extroverted feeling mode 
: concerns control of or by external human emotional factors  
: typical role: Conciliator | ![PCMT Result Diagram E4](image7) | **S4**   | **Knowledge-based Creativity**  
: the introverted factual mode 
: physically self-aware, values, practice and known technique  
: typical role: Inspector | ![PCMT Result Diagram S4](image8) |

**Figure 1:** PCMT results of 4 expert designers and 4 student designers.

4. Expert designer 4 (E4): E4 has strong teamwork creativity. He is feeling oriented and human oriented, and shows much interest in human and social context. Some extroverted nature is shown in the perception domain.

5. Student designer 1 (S1): S1 shows the dominant synthesizing creativity. Similar to E1, S1 shows the strong perception aspect while his judgment aspect is weak. However, S1 is more extroverted than E1.

6. Student designer 2 (S2): S2’s dominant creativity mode is the experiential creativity, but its aspect is not so strong. S2 also has the knowledge-based creativity and evaluating creativity. Individuals having the experiential creativity are factual oriented, and have the tendency to depend on the direct experience to discover new ideas and phenomena.

7. Student designer 3 (S3): The dominant personal creativity mode of S3 is the organizing creativity, but not as strong as that of E3. S3 also shows some introverted aspect in the perception domain.

8. Student designer 4 (S4): S4 has the knowledge-based creativity with the transforming creativity to some degree as well. Individuals having knowledge-based creativity has the attitude of concentration and are good to detect and correct errors. Its typical role is inspector. S4 also shows some thinking oriented aspect in the judgement domain.

4.2 Evaluation of Design Solutions

As described in the section 2.2, DTT was conducted for designing small water playground in a kindergarten. Some sample sketches during DTT are shown in Figure 2.

**Figure 2:** Sample sketches during DTT.
A designer’s aim is normally to achieve a high-quality design with novelty or creativity [11]. Therefore, it is necessary to evaluate design solutions to assess the effectiveness of design activities during a whole design process. The design solutions obtained from DTTs were rated in terms of the following 5 criteria: originality, aesthetics, functional utility, technical aspects, and usability. The scores are presented in Table 4.

Table 4: Design solution quality scores (10 scales).

<table>
<thead>
<tr>
<th>Participants</th>
<th>Originality</th>
<th>Aesthetics</th>
<th>Functional Utility</th>
<th>Engineering Aspects</th>
<th>Usability</th>
<th>Sum (100 %)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>9</td>
<td>9.5</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td>45.5 (91)</td>
</tr>
<tr>
<td>E2</td>
<td>6</td>
<td>7.5</td>
<td>7</td>
<td>9.5</td>
<td>7.5</td>
<td>37.5 (75)</td>
</tr>
<tr>
<td>E3</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>8.5</td>
<td>8.5</td>
<td>40 (80)</td>
</tr>
<tr>
<td>E4</td>
<td>9.5</td>
<td>9</td>
<td>8</td>
<td>7</td>
<td>8.5</td>
<td>42 (84)</td>
</tr>
<tr>
<td>S1</td>
<td>5.5</td>
<td>6.5</td>
<td>7.5</td>
<td>8</td>
<td>7.5</td>
<td>38 (76)</td>
</tr>
<tr>
<td>S2</td>
<td>7</td>
<td>7.5</td>
<td>8.5</td>
<td>9</td>
<td>7.5</td>
<td>40 (80)</td>
</tr>
<tr>
<td>S3</td>
<td>7</td>
<td>9</td>
<td>9</td>
<td>7</td>
<td>8.5</td>
<td>44 (88)</td>
</tr>
<tr>
<td>S4</td>
<td>8.5</td>
<td>6.5</td>
<td>8.5</td>
<td>8</td>
<td>7.5</td>
<td>41 (82)</td>
</tr>
</tbody>
</table>

Overall, E1 has the highest score on the design solution among the expert designers, and S3’s score is the highest among the student designers. On the other hand, E2 and S1 received the lowest overall scores on their design solutions, respectively. In more details, E1 received high scores in each of 5 evaluation criteria, and his scores on aesthetics, functional utility and usability are highest. In terms of originality, E4 received the highest score. E2 received the highest score in terms of engineering aspects. In the case of student designers, S3 who scored highest overall received high scores on each criterion except originality and engineering aspects. S4 scored highest in the criterion of originality, and S2’s solution was best in terms of engineering aspects.

Each of these evaluation criteria and its scores can have the relationships with the protocol analysis data. For example, the criterion of aesthetics can be related to OS and CS in the design information, and the functional utility can be related to GF and TF. In addition, EK can have a relationship with the originality. The overall scores can be related to the design process distribution.

4.3 Design Information Results

4.3.1 Overview of Design Information

In the protocol analysis, the design information was extracted from the collected data during DTT by utilizing the proposed design information coding scheme. The counts of each design information coded in the protocol analysis data are summarized in Tables 5 and 6. In addition, the graphs of the design information counts with time span are given in Figure 3.

(1) Expert designer 1 (E1): In the case of E1, OS, GF, CS and TF appear in the second half of the entire design process, as can be seen in Figure 5.

(2) Expert designer 2 (E2): As can be seen in Table 6, E2’s count of OS is highest among four cases. On the other hand, E2’s PE and ME are relatively smaller than those of other expert designers. In addition, as shown in Table 6, E2’s OS appears in the beginning stage of the entire design process, while other designers addressed OS in later stages.

(3) Expert designer 3 (E3): E3 has the lowest counts of CS and the highest counts of IN. E3’s EK counts are also bigger than average value of all four cases. Similar to the case of E1, OS, CS and TF appear after mid-stage of the entire design process.

(4) Expert designer 4 (E4): The total counts of design information mentioned are the highest. In particular, the counts of GF, PE and EK are higher than those of other designers.

(5) Student designer 1 (S1): As can be seen in Table 7, S1 has the highest counts of IN. From Table 6, it is also observed that S1’s GF is strongly focused in the second half of the entire design process. In addition, CS, OS and TF appear in the second half.

(6) Student designer 2 (S2): In the case of S2, the counts of CS, GF and TF are the highest among the students while ME is the lowest. Meanwhile, OS and CS appear in the beginning stage of the design process.

(7) Student designer 3 (S3): PE of S3 is the highest among the student while S3’s MG seldom appears. S3’s CS and OS appear a little before the mid-stage, as shown in Figure 3.

(8) Student designer 4 (S4): In the case of S4, MG and EK are the highest. S4’s MG appears steadily in all time spans and EK strongly appears from the early stage to mid-stage of the entire design process.

Table 5: The counts of design information subclasses of each expert designer.

<table>
<thead>
<tr>
<th>Partici-pants</th>
<th>OS</th>
<th>CS</th>
<th>GF</th>
<th>TF</th>
<th>PE</th>
<th>ME</th>
<th>IN</th>
<th>MG</th>
<th>EK</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>18</td>
<td>34</td>
<td>73</td>
<td>30</td>
<td>19</td>
<td>4</td>
<td>53</td>
<td>29</td>
<td>29</td>
<td>289</td>
</tr>
<tr>
<td>E2</td>
<td>50</td>
<td>17</td>
<td>50</td>
<td>36</td>
<td>8</td>
<td>3</td>
<td>40</td>
<td>47</td>
<td>34</td>
<td>283</td>
</tr>
<tr>
<td>E3</td>
<td>15</td>
<td>9</td>
<td>50</td>
<td>25</td>
<td>8</td>
<td>16</td>
<td>90</td>
<td>34</td>
<td>66</td>
<td>313</td>
</tr>
<tr>
<td>E4</td>
<td>22</td>
<td>26</td>
<td>109</td>
<td>11</td>
<td>41</td>
<td>8</td>
<td>56</td>
<td>7</td>
<td>76</td>
<td>356</td>
</tr>
</tbody>
</table>

Table 6: The counts of design information subclasses of each student designer.

<table>
<thead>
<tr>
<th>Partici-pants</th>
<th>OS</th>
<th>CS</th>
<th>GF</th>
<th>TF</th>
<th>PE</th>
<th>ME</th>
<th>IN</th>
<th>MG</th>
<th>EK</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>45</td>
<td>40</td>
<td>110</td>
<td>31</td>
<td>21</td>
<td>11</td>
<td>138</td>
<td>36</td>
<td>81</td>
<td>513</td>
</tr>
<tr>
<td>E2</td>
<td>46</td>
<td>78</td>
<td>181</td>
<td>73</td>
<td>21</td>
<td>3</td>
<td>71</td>
<td>15</td>
<td>42</td>
<td>530</td>
</tr>
<tr>
<td>E3</td>
<td>37</td>
<td>38</td>
<td>166</td>
<td>32</td>
<td>39</td>
<td>11</td>
<td>84</td>
<td>3</td>
<td>54</td>
<td>464</td>
</tr>
<tr>
<td>E4</td>
<td>19</td>
<td>35</td>
<td>126</td>
<td>23</td>
<td>17</td>
<td>8</td>
<td>119</td>
<td>55</td>
<td>117</td>
<td>519</td>
</tr>
</tbody>
</table>

4.3.2 Design Information Pattern

Figure 4 shows the patterns of design information subclasses used in the DTT of expert designers and student designers. As can be seen in Figure 4, the patterns of overall design information subclasses are similar in the cases of expert designers and student designers. In both cases, the amounts of GF and IN are more than other design information subclasses.
4.4 Design Process Results

The protocol analysis based on the design process coding scheme was done as well. Of all 10 subclasses, 8 subclasses are related to specific design activities and two are associated with designer’s process remarks, as shown in Table 3.

4.4.1 Overview of Designer’s Process

The graphical representations of coded data of design activities of each participant are shown in Figure 5. In these representations, the level of design activities is expressed by colors: the darker, the more activities in that specific time slot.

The horizontal axis indicates the time progression in minutes. After analyzing the graphical representations of design activities of expert designers and student designers shown in Figure 5, the following observations can be obtained.

(I) Expert designer 1 (E1): Generally, the design activities were allocated adequately according to the step-by-step evolution. During the problem understanding phase, E1’s activities were found steadily from the beginning to the midpoint stage. D3 (Cl) count is the highest among the designers, and Mp happened in the beginning stage of the design activities in a focused manner.
(2) **Expert designer 2 (E2):** Total amount of activities is the lowest among designers. Of the design activities of E2, D6 (Ef) count is the most but, D2 (Ga) count is the least. Much of E2’s vigorous activities were concentrated in the beginning stage so that problem understanding and concept judgment happened together, and the frequency of his activities decreased in the latter stage. His design elaboration activity started earlier than other designers.

(3) **Expert designer 3 (E3):** The design activities occurred mostly from the mid-stage and the most of them were concentrated on design elaboration in the latter stage of the entire design process. E3’s counts of D5 (Ju) and A1 (Mp) are the most among the designers.

(4) **Expert designer 4 (E4):** All design activities occurred constantly through the entire time span. In the beginning stage, the activities associated with the problem understanding class occurred for a relatively long period. It is also noticed that the design activities related to the idea generation class occurred constantly from the early to later stages of the entire design process. D2 (Ga) count is the most, but D7 (Es) count is the least among the designers. In addition, A1 (Mp) happened scarcely.

(5) **Student designer 1 (S1):** The design activities of S1 were divided into two separate phases. In the first half of the design process, the activities of problem understanding, idea generation and rough solution elaboration occurred. These activities were repeated in the second half. Of the design activities, D5 (Ju) count is the most among the student designers, but the count of D6 (Ef) is relatively low.

(6) **Student designer 2 (S2):** The design elaboration started earlier, and most of design activities in the second half were concentrated on D6 (Ef). The count of D2 (Ga) is the least and that of Ef is the most among the student designers.

(7) **Student designer 3 (S3):** The design activities of S3 were relatively well-distributed during the whole design process. D6 (Ef) appears from the mid-stage and continues to the later stage. D4 (Gi) count is the most among the student designers, but A1 (Mp) and A2 (Ir) did not occur.

(8) **Student designer 4 (S4):** The design solution was produced relatively earlier, and the activities associated with the evaluation of the solution occurred in the latter stage. S4’s D2 (Ga) count was the most. Also, the counts of A1 (Mp) and A2 (Ir) were the most among the students. S4’s design process seems to be scattered and wandering overall, especially in the later stage.

**Figure 5:** Design process counts with time span.
4.4.2 Design Process Pattern

The patterns of design process subclasses used in the DTT of expert designers and student designers are shown respectively in Figure 6. The amounts of D2 (Ga) in the case of expert designers are similar, but varied in the case of student designers. E1 shows the largest amount of D3 (Cl). E4 and S3 show larger amounts of D4 (Gi), which can be related to their idea generation capabilities. In the case of D5 (Ju), two different groups can be classified in the case of expert designers, but the student designers do not show the significant difference in terms of the amount. However, in the case of D6 (Ef), the opposite can be observed. The expert designers show similar amounts of D6 (Ef), but the student designers are divided into two distinct groups. This activity of D6 (Ef) is significant to form the design solution, and there is no such considerable discrepancy in the case of expert designers. The amounts of A1 (Mp) are similar except the cases of E4 and S3. This observation is coincident with the small amount of MG, which is shown in Figure 4. In the case of A2 (Ir), the differences are not significant in the case of expert designers, but large in the case of student designers.

5. RELATIONS AMONG THE RESULTS

The design information, design process, quality of solutions and PCMT results are related together, and their relations are discussed in this section.

5.1 Design Information and PCMT Results

The relations between design information and PCMT results were examined in this section. As can be seen in Table 4 and Figure 1 and 3, the design information used in the DTT varied according to personal creativity modes as discussed below.

(1) Teamwork Creativity and Human-related Factors/External Knowledge

During the problem solving process of E4 having teamwork creativity, more frequent use of vocabularies of human-related factor (PE) and context and external knowledge (EK) were observed. In other words, she put relatively greater emphasis on user’s physical status, context, social relationship and psychological state as compared to other designers. This coincides with the traits of extroverted feeling type which Levesque mentioned [12].

(2) Organizing Creativity and Designer’s Intent

In case of E3, the frequent use of prediction and judgment related to designer’s intent (IN) was greatly high. Since E3 is characterized by organizing creativity and tries to efficiently manage resources, E3 may use a lot of activities of prediction and judgment to avoid the possible inefficiency of the process during the design.

(3) Experiential Creativity and Design Details

S2 having the experiential creativity shows high counts of CS, GF, and TF. This may be due to the factual-oriented aspect of S2, and, as a result, much design information related to concrete shape, structure and function may appear.

(4) Knowledge-based Creativity and External Knowledge

S4 has the highest counts of EK in the design activity. This is related to S4’s knowledge-based creativity, and useful for the design motivation in the early design stage.
5.2 Design Process and PCMT Results
The relations between individual cognitive characteristics and design process were examined and are shown in Figure 1 and 5.

(1) Organizing Creativity and Process Management
E3 and S4 have done a lot of A1 (Mp) activities and they both had a thinking oriented trait. In case of E3, whose dominant mode is organizing creativity, D5 (Ju) and A1 (Mp) were of great quantity. This result means that E3 focused on the analysis of a design problem and had a great deal of confirmation in problem solving process. It is somewhat associated with organizing creativity traits. On the other hand, S3 having the organizing creativity trait showed low A1 (Mp) activities. It might be explained by borrowing the concept of shadow [8]. The opposing personality is a shadow mode [6], and Wilde regarded that the opposing personality could be playing supporting role [16]. The low A1 (Mp) activity of S3 can be explained by the opposing personality of organizing creativity.

(2) Synthesizing Creativity and Design Elaboration
Both E1 and S1, whose dominant mode is synthesizing creativity, have many focused activities in design elaboration phase in later stage. It may be due to their strong intuition traits.

(3) Evaluating Creativity and Problem Understanding
E2 and E4 basically had the trait of a needfinder, which means feeling oriented and human oriented. It can be believed that their many problem understanding activities in early design stage was made from these inclinations.

(4) Experiential Creativity and Design Elaboration
S2 showed vigorous D6 (Ef) activities due to his factual-oriented trait. Therefore, considerable time has been used for extroverted activities, while the amount of D2 (Ga) activity was small.

(5) Perception Orientedness and Gathering Information
E1, S1 and S4 showed vigorous D2 (Ga) activities due to their perception oriented trait.

(6) Judgment Orientedness and Combined Problem Understanding and Judgment
E2, E3, E4 and S3 conducted not only the activity of problem understanding, but also that of D5 (Ju) vigorously in the early design stage. This may be due to their judgment-oriented trait.

5.3 Solution Quality Score and Other Results

(1) Concept Originality and External Knowledge
As can be seen in Tables 4 and Figure 3, design concept originality scores are related to the amount of external knowledge (EK) mentioned by designers. The higher the scores on the originality, the more the counts of EK were observed. This relation shows that analogy from external knowledge and effort to comprehend design problem in association with social relationship or context can bring out solid and original concepts. Designer’s continuous endeavor to transfer his external knowledge into an appropriate design domain could be considered as the main element in establishing an original concept. For example, E4 used EK such as playing with tubes, ropes, horizontal bars which is helpful for the establishment of original concepts. According to Craig, a designer having a well-understood analogous concept may be able to integrate a variety of concerns and insights into a coherent conceptual structure, whereas a designers working with a set of fragmented beliefs may show inefficient and erratic use of information [2].

(2) Concept Originality and Design Process
Design concept originality score could be related to problem-solution co-evolution aspect of conceptual design process. As can be in Table 4 and Figure 5 for the case of E4, the originality score of E4 is the highest and she combined conceptual design and problem understanding activities vigorously in the first half of a whole design process. This result is similar to the study of Dorst et al. [4]. According to their study, creative design seems more to be a matter of developing and refining a design solution, with constant iteration of analysis, synthesis and evaluation process between the two notional design spaces – problem space and solution space.

(3) Solution Quality Score and Process Distribution
When comparing the patterns of process distribution of each participant with their solution quality scores, it can be observed that an even process distribution during the entire design may bring out a good solution. For example, in the case of E1 having the highest solution quality score, his design activities occurred evenly over the entire design process. Similarly, S3 whose activities were evenly distributed also received the highest solution quality score among the student designers.

(4) Functional Utility and General Feature
Those who have the large amount of general feature (GF) usually receive high scores on their design solutions. In the case of E1, E4, S2, and S3 who received high scores on functional utility, the counts of GF are substantial in their design activities.

5.4 Complementary Characteristics between Design Information and Design Process
Design information can be considered as design contents generated in the design activities, and design process is the characteristics of evolution and management of design contents. As a result, they are complementary to each other in analyzing design activities.

(1) OS and CS are related to the specific shapes of products, and therefore those two design information subclasses are presented in association with design elaboration phase of design process. As a result, this information is mostly shown in later stage of the entire design process. Generally, CS is shown after OS. This means that CS plays an important role in determination of the specific shapes of the design solution.

(2) GF is an information subclass covered by a wide range of the design process, and involved in gathering information and establishing design direction in problem understanding phase, generating features in idea generation phase, and detailing features in design elaboration phase. This information is mainly associated with D2 (Ga), D3 (Cl), D6 (Ef), and D8 (Rs) activities in design process. These subclasses are included in different process activities depending on participants.

(3) TF is generally presented in the later stage, which is concerned with detailing and evaluation of a design solution. In particular, this information is strongly related to design elaboration phase. However, in case of S2 and S3, they started design elaboration in the early stage, and, therefore, TF appears in the mid-stage of the entire design process, as shown in Figure 3 and 5.
6. SUMMARY AND DISCUSSION

In this study, we analyzed the design activities of expert designers and student designers with two complementary coding schemes based on design information and process. In addition, we explored the relation between designer’s personal creativity and design activities.

Concerning the design information, the frequency of information in most participants formulates a similar pattern except a few cases. It seemed that the more design contents about context and external knowledge are used, the more unique design concepts are made. Regarding design process, an adequate distribution of the design process may be necessary to bring out a good solution, which could be seen in the case of expert designers. On the other hand, student designers showed the aspect of scattered design activities and their step-by-step process patterns were unstable. The degree of relation of design information and design process used in the protocol analysis can differ according to the characteristics and creativity modes of designers. Design information and design process can be used as complementary coding schemes to analyze individual’s design activities.

Regarding personal creativity modes, close relationships between designer’s personal creativity modes and design activities were observed. The characteristics of each personal creativity modes E4 having feeling oriented personal cognitive characteristics used much external knowledge and many general features, and put an emphasis on problem understanding and early idea generation phases rather than design elaboration phase. Organizing creativity mode revealed by E3 could be associated with rich intent information category that is related to the management of the design process. S2 having factual oriented mode showed the tendency to conduct design elaboration with extroverted character. S4 characterized by the perception oriented mode had the trait of scheduler and was concentrated on problem understanding and process management.

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 factors is needed. While we compared the design activities of expert designers and student designers in this work, the design activities of more novice designers such as undergraduate students can be included for the analysis in the future. More detailed study on the relation between design process and personal creativity modes of designers considering diversity in expertise and domain can be addressed. In addition, the relation between team-based design and personal creativity modes of each team member can also be studied in the future.

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