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FORMAL DESCRIPTION OF CONCEPT-SYNTHESIZING PROCESS FOR CREATIVE DESIGN

Taxonomical relation and thematic relation

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Abstract. We describe a design synthesizing process which has been pointed out to be a key to creative design. We describe two topics of design study. First, from the perspectives of creativity, the concept-synthesizing process is formed with the 1st primitive of the concept-synthesizing process being 'concept abstraction' with the principle of 'similarity' in 'taxonomical relations', the 2nd primitive being 'concept blending,' in which the principle is 'similarity' and 'dissimilarity' in 'taxonomical relations', and the 3rd primitive being 'concept integration' and with the principle of 'thematic relations'. Second, design experiments using protocol analysis were conducted to identify what/how design primitives are related to higher creativity. As a result, in the process of synthesizing concepts, thematic relations between two concepts significantly extend the design space, which led to higher creativity. Given this, the creative design process can be driven by the 3rd primitive of the concept-synthesizing process.

1. Introduction

Many studies have been conducted to analyze the characteristics of the design thought process from the viewpoint of creativity. As a result, it has been found that concept-synthesizing processes, such as combining, blending or integrating two different concepts, are keys to creative thinking. Analogical reasoning and metaphor are known to play very important roles in creative design (Gero and Maher 1991; Goldschmidt 2001). For example, the 'Swan chair' is a famous example of design, which had been imaged using analogy. Its form resembles a swan, and users understand its message

of ‘this chair is soft and elegant like a swan’. Figure 1 shows some examples of design analogy. Chairs designed using analogical reasoning resemble a swan, a mushroom and a helicopter (Swan chair 1958; Mushroom stool 2003; Easy chair 2000). Figure 2 shows a sample of a product designed using metaphor. Its message is that ‘this is a new object that will induce mellow feelings in your daily life’.

From the viewpoint of mental cognition in the domain of cognitive science, Finke et al. (1992) described conceptual synthesis as an efficient means of developing creative insights into new inventions, and carried out experiments on creation as mental products generated by imagery synthesis. For supporting human creativity, it has been pointed out that it is significant to develop creative thinking that is related to the transforming of concepts (Boden 2004). Creative thinking is comprehended as conceptual space (Gardenfors 2000). On the other hand, in studies on cognitive linguistics, Fauconnier (1994) focused on the construction process of meaning in ordinary discourse. He analyzed how conceptual integration creates mental products and how to deploy systems of mapping and blending between mental spaces. From the viewpoint of mental space theory, he showed that conceptual integration operates on two input mental spaces to yield a third space which is called ‘the blend’. That blended space inherits partial structures from the input spaces and has emergent structures of its own. Both mental products, imagery and discourse, have shown emergent features and they have stimulated creativity. Fauconnier and Turner (2002) suggested that a watch is designed by conceptual blending.

Although it has been pointed out in many studies that synthesizing two concepts is the key to creative design, these concept synthesizing processes have not yet been formerly described, and the kinds of primitives and how these primitives are related to creativity have not been clarified. In order to gain a deeper understanding of the nature of creative design and to develop methodologies for creative design, it is important to determine primitive processes for concept-synthesis. We assume that primitive processes are useful for explaining creativity in design, rather than a general process model in which only the superficial design action is generalized and the hidden thought mechanism is not dealt with.

Normally, an ‘abstraction process’ based on a ‘taxonomical relation’ is regarded as a primitive process in creating a new concept. In addition, another important process for recognizing two concepts is pointed out. It is called the integrating process, in which two concepts are related thematically. For example, from the two concepts, milk and cow, a scene of milking a cow can arise from the thematic relating process. This process is expected to be effective for creative design. However, how the thematic relation is effective for design creativity has not been clarified.

In this paper, we describe two topics. First, the concept-synthesizing process (combining, blending, and integrating) is formed from the viewpoint of creativity. Second, the relationships between creativity and design primitive processes, focusing particularly on the relation types- taxonomical relation or thematic relation - are empirically studied.

Figure 1. Swan Chair (left), Mushroom stool (center) and Easy Chair (right)

Figure 2. 'Sound Object' designed by Anna Von Schewen (2002)

2. Form description of synthesizing process

2.1. CONCEPT ABSTRACTION

Analogical reasoning and metaphor are understood to be methods of concept creation via the transfer of a new concept from an existing concept. In practice, they are frequently used in the design process. For example, `designing a musical instrument like a dress' is one way of creating a new concept of a musical instrument. We can imagine many new instruments in this way by using metaphors, for example, 'an instrument like a harp', Figure 3. In this thought process, the design result (a musical instrument) is designed such that it and a dress share some common features, such as shape

and function. Generally speaking, the primitive process of recognizing common features is the 'abstraction process' based on 'taxonomical relation (explained in Section 2.3)' focusing on the 'similarity' between two things. Therefore, the 1st primitive of the concept-synthesizing process is 'concept abstraction,' and its principle is 'similarity' in 'taxonomical relations.'

Figure 3. An idea designed by using metaphor

2.2. CONCEPT BLENDING

Although we recognize that analogical reasoning and metaphor are powerful for generating a new concept, we suspect that there is a more creative design method because the main roles of analogical reasoning and metaphor are to understand or to transfer a known concept; that is, it is analytic rather than synthetic since its primitive process is the extraction of some features from a known concept by analyzing it.

We can think of a concept-blending process as that in which two basic concepts are blended at an abstract level and a new concept that inherits some abstract features of the two base concepts but concrete features of neither are generated. For example, 'design something by combining the concepts of a musical instrument and a dress,' where the design result could be a guitar, the outside and sound of which can be changed to suit the surroundings like changing a dress, or a melody costume, that is, a wearable musical instrument. Another example is a wine glass which induces melody by blending a concept of party and that of strings, Figure 4. This concept-blending process seems to be similar to analogical reasoning or the metaphor process. However, these two processes are different in the following points. In the case of analogical reasoning, the harp, a musical instrument, is predicted to induce dressy feelings of elegance and distinction. Therefore, the harp is a medium and the dress is an intention similar to a relationship

between sign and meaning in semiotic relations. Also, in the metaphor process, a musical instrument again has the role of a medium to give the meaning of dress. In both cases, the roles are the same. In contrast, the relationship between a musical instrument and a dress in the concept-blending process is different. One does not express the other. The new concept is not just the medium of an instrument nor is it a dress. It has no strong association with the two base concepts. Therefore, it presents a high possibility of creating a novel concept. In the concept-blending process, not only 'similarity' but also 'dissimilarity' is pointed out, since the specific features belonging to each individual concept are blended. Therefore, the 2nd primitive of the concept-synthesizing process is 'concept blending' and its principle is 'similarity' and 'dissimilarity' in 'taxonomical relations.'

Figure 4. An idea designed by concept blending

2.3. CONCEPT INTEGRATION

In the research on recognizing the relation between two concepts, it is pointed out that there are two kinds of relations (taxonomical relation and thematic relation) between two concepts. Wisniewski and Bassok (1999) studied the relative tendency to use comparison versus integration in making similarity judgments by orthogonally varying pairs of objects so as to be taxonomically or functionally related. As a result, it was shown that not only a taxonomical relation but also a thematic relation is important in recognizing the two objects. The former is a relation that represents the physical resemblance between the two objects, for example, "milk and coffee are drinks." The later is a relation that represents the relation between two concepts through a thematic scene. For example, a scene of milking a cow is recollected from the two concepts of milk and cow. In such a sense, milk and cow are related to each other. In this kind of thematic relation, a

dress is not physically related to a musical instrument but people imagine a scene in which a dressy lady plays the violin.

In design, the result (product) must be meaningful to people. Therefore, the designer must carefully consider not only its attributes (shape, material, etc.) but also its function and interface with the user, that is, consideration of the human factor is important. Recognizing objects in a thematic relation is to recognize them from the human viewpoint. Consequently, the thematic relation is expected to be closely related to design creativity.

Therefore, the 3rd primitive of the concept-synthesizing process is 'concept integration' and its principle is 'thematic relations.'

We summarize the formal description of the concept-synthesizing process in design in Table 1.

TABLE 1. Three kinds of design process primitives and principles

	Design Process Primitive	Principle
1st	Concept Abstraction	taxonomical relation (similarity)
2nd	Concept Blending	taxonomical relation (similarity and dissimilarity)
3rd	Concept Integration	thematic relation

3. How design principle affects the design creativity

How the design principle (taxonomical relation or thematic relation) affects the design creativity is clarified using both the design results and the thought process, focusing on the extension of idea space.

Also, the 2nd and 3rd design process primitives are made to relate more closely to a higher creative process in design than the 1st. In this research, we focus on the 2nd and 3rd primitives, with emphasis on the concept-synthesizing process caused by different types of relations – taxonomical or thematic - between two concepts.

3.1. METHODS

To elucidate the structuring process of design ideas, analyzing not only the design outcomes but also the design processes, that is, design thinking process and midterm representations, provide crucial keys (Lawson 1997). In this research, a design experiment is performed, and not only the design results but also the process of design thinking are analyzed. In particular, the

difference in the extensions of design spaces in the concept-synthesizing process, focusing on the extension process of idea space of the subjects and the effect of the difference in the relationships (in taxonomical relations for the 2nd primitives, or in thematic relations for the 3rd primitive) on creativity is analyzed in this study.

3.2. ANALYSIS OF DESIGN PROCESS

In this research, protocol analysis and semi-structured interviews are implemented. The think aloud method is adopted for acquiring utterances as protocol data for designing (Ericsson and Simon 1984). In this method, the subjects are requested to say aloud what they are thinking while performing a task. The utterances are recorded and the data are analyzed. In order to identify which relationship between two concepts the subject considered, the reason behind the design idea is examined. However, it is difficult to obtain data on such reasons, because the subjects do not always state the reasons behind their thinking. Therefore, in this research, the method of protocol analysis based on the explanation of design activities is adopted (Taura et al. 2002).

3.3. CREATIVITY EVALUATION OF DESIGN RESULT

The design results are evaluated based on the method of Finke et al. (1992), that is, from the two viewpoints of practicality and originality, on a five-point scale.

3.4 METHOD OF EXPERIMENT

In this research, with the aim of examining the conceptual synthesizing process, the design experiment is conducted focusing on the extension process of idea space which is formed through design space blending (Taura et al. 2005).

We analyze the design thinking process from the following two perspectives.

- From the macroscopic perspective, does the design process involve thematic integration or taxonomical blending?
- From the microscopic perspective, is the design process associated with thematic relations or taxonomical relations?

The experiment is composed of two parts, the design session and the interview session.

3.4.1. Design task

The subjects were asked to perform two kinds of design tasks at random. Base concepts were selected based on the research of Wisniewski and Bassok (1999).

- Task 1: Design new furniture starting from the word "Cat-hamster"
- Task 2: Design new furniture starting from the word "Cat-fish"

The reason for showing the synthesized word as "Cat-hamster" and "Cat-fish" is that the subject will be able to understand the idea of "conceptual blending" easily (Harakawa et al. 2005).

3.4.2. Method of experiment

The design experiment is structured as follows.

1) Design session (10 minutes)
The subject is made to perform the design task by the think-aloud method, and the utterances and the sketch are recorded with a tape recorder and a video camera. The purpose of this session is to obtain the protocol data and the sketch.
2) Interview session (30 minutes)
The subject is asked to explain the reason for each design activity while monitoring the video of the design session. The purpose of this session is to determine the reasons why new concepts were generated (Questionnaires; 'where did it come from?', 'why did you draw this shape?', and so on).
3) Creativity evaluation
The design results are evaluated based on the two viewpoints of practicality and originality on a five-point scale. Only the designs with more than 3 practicality points are evaluated from the viewpoint of originality.

3.5. RESULT OF DESIGN EXPERIMENT

The design experiment was conducted with three subjects. In total, fifteen design ideas were presented. Because the subjects were not experienced designers, creativity was evaluated on the basis of the design concept. The experimenter prepared design concept summaries on the basis of the design idea and the interview of the subject. Fifteen design concepts for two tasks (No.1-15) are shown below as the design results.

・Task A: Design new furniture starting from the term "Cat-hamster"

Design result 1

'A wardrobe with pet rooms'

There are rooms for the cat and hamster in the lower drawers of the wardrobe. When the higher drawer is opened, the cat's meow is heard. When the second drawer is opened, the hamster begins to play.

Design result 2

'A wardrobe shaped like a cat'

The wardrobe can move like a cat. The person orders the hamster to bring a suit. The hamster goes to touch the cat's tail, and then the cat delivers the suit.

Design result 3

'Traveling bag that cares for the pet during travel'

A panel is attached on the side, and an image of the pet is displayed when the panel is opened. Some buttons on the panel enable food to be given to the pet or the pet to be fondled.

Design result 4

'Chest of drawers-ball'

This chest of drawers is ball-shaped and it moves about restlessly. It can enter narrow spaces. Because it is a ball that moves about freely, the chest of drawers can be repositioned easily.

Design result 5

'Desk-chair'

This chair is like a desk. In a word, it is the size of a desk although its appearance is that of a chair. We use it as a chair.

Design result 6

'Chair that can be folded like an umbrella'

A chair that can be folded by the mechanism of a folding umbrella can be stored in a narrow space. It is possible to store it in an underground compartment after use.

Design result 7

'Chair which runs about trying to escape'

This chair runs away when a desk approaches. It resembles a rat being chased by a cat.

Design result 8

'A revolving shoebox'

This rotary shoebox is doughnut-shaped and the size of a person. It rotates when the user stands in front of it, and shoes can be chosen. It is easy to choose shoes appropriate for the outfit because the section for the feet is transparent.

・Task B: Design new furniture starting from the word "Cat-fish"

Design result 9

'A sideboard with a monitor'

Usually an image of fish in an aquarium is displayed on the monitor. However, it is also a television that can be operated by remote control. The monitor is at eye level when the viewer is sitting on a chair.

Design result 10

'A case for marine sports'

It has a heater so items such as a wet suit can be dried. Part of the case is a water tank in which fish can be kept.

Design result 11

'Water tank with casters'

There are legs like those of a chair attached to the bottom of the water tank. Because they have casters, it is possible to move the tank easily.

Design result 12

'A coat hanger that refuses to hang clothes'

This coat hanger will not hang clothes. The clothes will be dropped when hung on this hanger.

Design result 13

'Chest of drawers that eats oneself'

This is a nested chest of drawers behind a door. There are more drawers inside the drawers.

Design result 14

'Water tank table'

This is a table of a hollow structure made of glass. It is possible to store water inside it like a water tank. A fish appears to be swimming in the table.

Design result 15

'Sea cushion'

This cushion can float in the sea. It is possible to sit and to sleep on it. It is possible to join many of them to form a lounger.

Figure 5 shows samples of sketches for design idea No.15 by a subject who is a postgraduate design student.

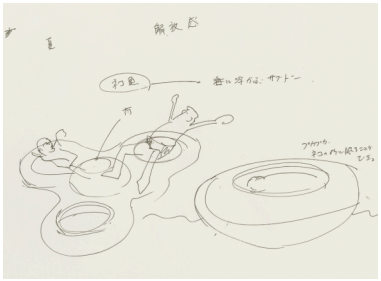

Figure 5. Sketch of design idea No.15 'sea cushion'

3.6. CREATIVITY EVALUATION OF DESIGN RESULT

The design results (design concepts) are evaluated based on the two viewpoints of practicality and originality; on a five-point scale by 8 people (4 of them are experienced in design).

According to the judging standard, the practicality ratings of No.1, No.2, No.4, No.7, No.12 and No.13 are less than 3 points, whereas the following nine satisfy the required practicality score.

No. 3 'A travelling bag that cares for the pets in transit'
No. 5 'A desk-chair'
No. 6 'A chair that can be folded like an umbrella'
No. 7 'A chair that runs about trying to escape'
No. 8 'A revolving shoebox'
No. 9 'A sideboard with a monitor'
No. 10 'A case for marine sports'
No. 11 'A water tank with casters'
No. 14 'A water tank table'
No. 15 'A sea cushion'

These nine ideas can be called as creative design ideas. Table 2 shows the average rating for these nine design concepts which were satisfied the judging standard. These ten ideas can be called as creative design ideas.

TABLE 2. Creativity evaluation of nine selected design concepts

No.	Task	Practicality	Originality	Order of high creativity
3	A	3.750	2.875	6
5	A	3.000	2.375	8
6	A	4.125	3.875	1
8	A	3.000	3.625	2
9	B	4.250	2.625	7
10	B	3.750	3.500	3
11	B	4.125	2.000	9
14	B	4.250	3.000	4
15	B	4.125	3.000	5

Originality is high in the order of No. 6, 8, 10, 14, 15, 3, 9, 5 and 11. As a result, it can be said that there is no difference in the between the design tasks A and B. It is said that creativity is also high in this order. Therefore the highest creativity is shown by No. 6.

3.7. EXTENSION OF IDEA SPACE

To identify the extension of idea space, new nouns have been extracted from the utterances recorded during the design task and in the interview, by protocol analysis. There are many new nouns in the nine creative design ideas as we determined (No. 6, 8, 10, 14, 15, 3, 9, 15 and 11), as shown in Table 2 (bold-faced type). This result reveals that there is a relationship between the number of new nouns and high creativity. (No. 3, 6, 8, 9, 10, 12, 14 and 15).

TABLE 3. The numbers of new nouns

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
New nouns	6	5	**12**	5	5	**7**	3	**11**	**13**	**11**	5	**7**	5	**9**	**21**

Next, focusing attention on the distance between concepts, we examine the relationship between the new nouns arising during the experiment and the terms Cat, Hamster, Fish and Furniture. The distance of the new nouns from Cat, Hamster (Fish) and Furniture is measured using the concept dictionary (Concept Dictionary 2005). The scatter charts for No. 6 and No. 11 are shown in Figures 6 and 7. No. 6 shows the highest creativity, and No. 11 has the lowest creativity result. The abscissa indicates the distance from Cat or Hamster. The ordinate indicates the distance from Furniture.

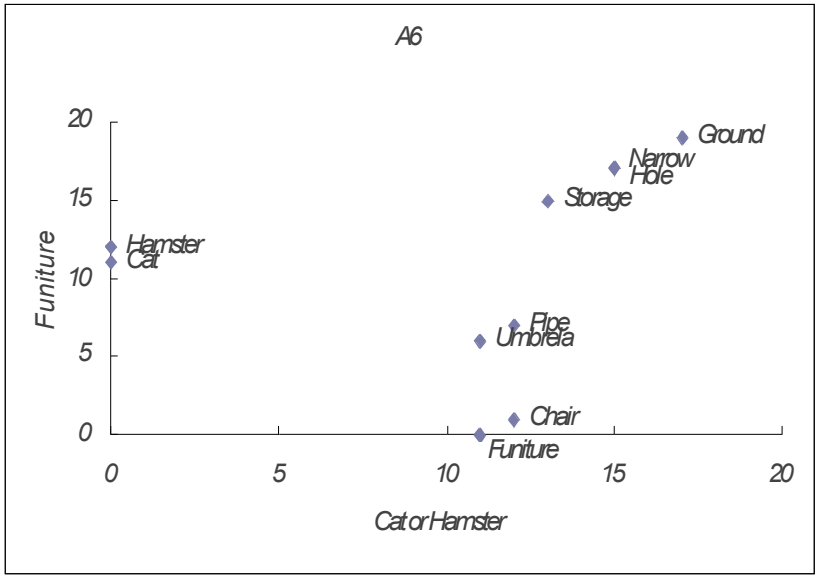

Figure 6. The distance of the new nouns from Cat or Hamster and Furniture in No 6

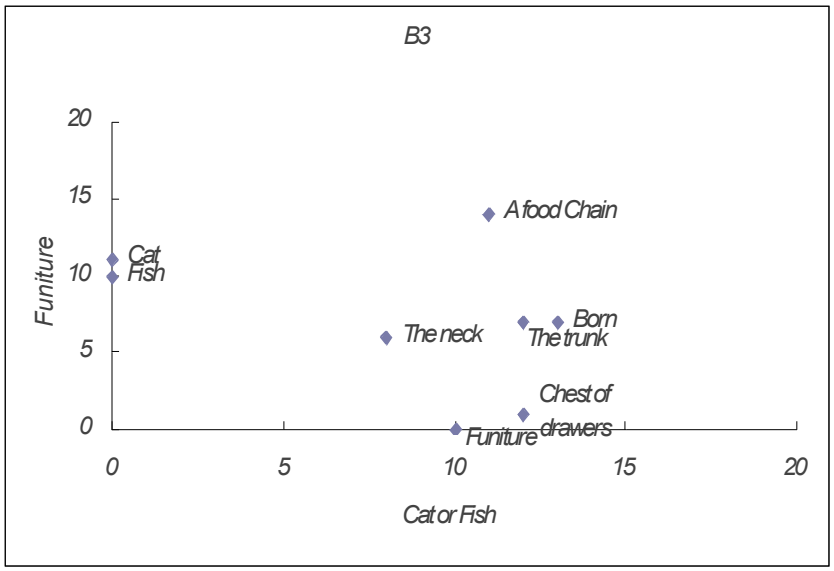

Figure 7. The distance of the new nouns from Cat (or Fish) and Furniture in No. 11

It is understood from the scatter chart that No. 6 is evaluated to have high creativity since many new nouns are concentrated away from the two axes. We examine the extension of idea space on the basis of distance between the concepts. The extension of the design space (idea space) is defined as follows.

If $n_i(x_i, y_i)$ is a new noun in design result D,

then $\sum_{i=1}^{N} \frac{\sqrt{x_i^2 + y_i^2}}{N}$ (N = number of new nouns) is the extension of idea space.

Table 4 shows the mean and the standard deviation of creativity and the extension of idea space. Figure 8 shows the scatter chart. The correlation coefficient ρ is 0.73087 ($F(1, 7) = 8.02713$, $p < .05$), and it is significant. It is understood that there is a strong correlation between creativity and the extension of idea space. It is shown that there is a strong correlation between the extension of design space and design results with high creativity.

TABLE 4. The standard deviation of creativity and the extension of idea space.

	Creativity	Extension of idea space
$\bar{X}$	2.986	13.862
SD	0.573	1.148

3.8 FACTORS FOR THE EXTENSION OF IDEA SPACE

From the macroscopic perspective, we determined that the design process involves thematic integration or taxonomical blending. We judged the types of relations between the two base concepts (‘cat and hamster’ or ‘cat and fish’) during not only the initial process but also the whole process. Table 5 shows extracted relations between the two base concepts and which kind of relation; taxonomical or thematic, stimulated design synthesizing processes in the nine creative design ideas.

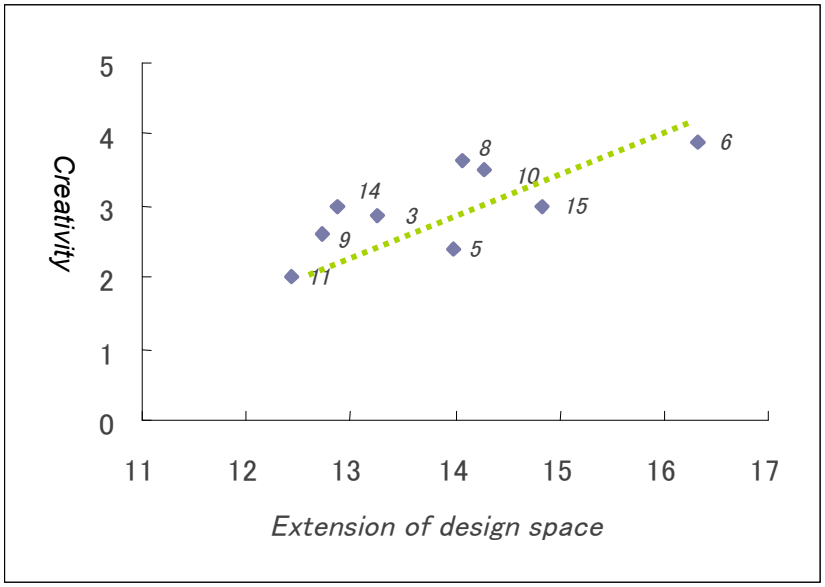

Figure 8. Correlation between creativity and the extension of idea space

As shown above, most of the design results evaluated to have high creativity showed thematic integration from a macroscopic viewpoint.

It is also important to recognize the factors of the extension of design space precisely. Therefore, the design process associated with thematic relations or taxonomical relations is determined from the microscopic perspective. To identify which relations between concepts were connected

with the extension of design space, we examined the concepts (nouns) uttered by the subjects during the design task in detail and judged whether relations were thematic or taxonomical for No.#6 (highest creativity) and No.#11 (lowest creativity) using EDR. Relationships between a pair of two sequential concepts were examined as to whether they were aligned in taxonomical relations or nonaligned but related in thematic relations recalling a scene. The examples of the judgments of design processes are shown in Table 6.

TABLE 5 Types of relations in the top nine creative designs

	No.	Relations during the initial process	Main relations in whole process	type of relation
1	No. 6	Cat eats hamster	Cat chases hamster/Thematic	Thematic
2	No. 8	Hamster is a small cat	Cat=Hamster	None
3	No. 10	Cat eats fish	Fish live in water	Thematic
4	No. 14	Cat eats fish	Fish live in the sea	Thematic
5	No. 15	Cat eats fish	Cat sits on a cushion	Thematic
6	No. 3	Both are pets	Both are in a bag	Taxonomical
7	No. 9	Cat eats fish	Fish live in the sea	Thematic
8	No. 5	Cat eats hamster	Desk eats chair	Thematic
9	No. 11	A scaly cat	Cat/Fish has legs	Taxonomical

As a result, a considerable degree of thematic relation was evident in the design process in the case of No. 6, which was evaluated as having the highest creativity, from a macroscopic perspective.

It is understood that the nouns judged to be far from the two axes, Figure 5, were thought up when the subject recollected various scenes. It is thought that the new nouns leading to the extension of the idea space were uttered under the influence of the relationship between cat or fish and the new concept that the subject conceived in the design process.

We extract the characteristics of the factors to extend the idea space, focusing on the thought process during the design task. Therefore, the process for No. 6 shows the highest creativity result and the highest extension of idea space in Figure 7. No.11 shows the lowest creativity among the nine creative ideas and its idea space is only slightly expanded.

Table 7 shows the degree of thematic relations in each process (31% for No. 6 and 16.3 % for No. 11).

TABLE 6. Examples of judgements of design process for No. 6

Number of sequential pairs	Nouns	Distance from a noun before	Type of relations	Scenes (from the subjects' explanation)
33	Structure – Umbrella	9	Thematic	Structure of umbrella
34	Umbrella– Folding umbrella	1	Taxonomical	A kind of umbrella
35	Hole– Ground	19	Thematic	A hole in the ground
36	Ground –Narrow space	6	Thematic	digging a small hole in the ground
37	Narrow space – Umbrella	17	Thematic	An umbrella which goes into a gap
38	Chair –Umbrella	7	-	Chair is umbrella
39	Folding umbrella – Ground	7	Thematic	Producing a Folding umbrella from the ground

TABLE 7. Features of the process and design space with high creativity

	No. 6	No. 11
Creativity	3.875 (highest)	2 (lowest)
Extension of design space	16.32 (highest)	12.43 (lowest)
The number of concepts	42	37
Types of relations in initial/whole process	Thematic	Taxonomical
Thematic relation between consecutive concepts	13 pairs (31.0%)	6 pairs (16.3%)

The results indicate that there can be correlations between the thematic relations in the new nouns in terms of time (before and after) and the extension of the idea space in creative design. The result reveals that the thematic relation, which is the principle of concept integration (the 3rd

design process primitive) in the design process, as we described above, may stimulate higher creativity in design through the extension of idea space.

We summarized the results as follows.

(1) The mechanism of the extension of design space, which is associated with design creativity, was confirmed precisely.
(2) From the macroscopic perspective, during the design process associated with higher creativity, conceptual synthesis was initialized by thematic relations between two concepts, and thematic integration took precedence throughout the whole process.
(3) From the microscopic perspective, a characteristic of a design process with high creativity was a high level of thematic relations between the two consecutive concepts.

5. Conclusion

In this study, two topics were examined. First, primitives and principles of the concept-synthesizing process (combining, blending, and integrating) from the viewpoint of creativity were formed. The 1st primitive of the concept-synthesizing process is 'concept abstraction,' and its principle is 'similarity' in 'taxonomical relations'. The 2nd primitive of the concept-synthesizing process is 'concept blending,' and its principle is 'similarity' and 'dissimilarity' in 'taxonomical relations'. The 3rd primitive of the concept-synthesizing process is 'concept integration,' and its principle is 'thematic relations'. Second, the relationships between creativity and the design primitive processes, focusing particularly on the extension process of idea space in terms of the difference between taxonomical relation and thematic relation, were empirically studied. From the results, it was found that, as a consequence of systematizing the concept synthesizing processes during design creation, concept integration (the 3rd design process primitive) may have an effect on higher creativity. Based on the analysis of design space and focusing on the 'thematic relation' between two concepts, the concept -integration process can be associated with the extension of design space.

In this study, we showed 3 primitives. However, there may be other primitives. For example, we hypothesize that the process by which idea space (design space) is created may be another principle. We will continue to describe the forming of primitives and principles in the future.

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