Structural Model of Sketching Skills and Analysis of Designers' Sketches

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Abstract: The use of sketches in the generation of design ideas has been considered to have various effects. However, previous studies have yet to elucidate the ways in which sketching skills, such as the use of perspective and shading, influence these effects. To shed light on the role and effects of sketching skills in relation to idea generation in the product design process, this research clarified the elements constituting sketching skills and the relationships among these elements. We observed the process of acquiring sketching skills in a sketching class and evaluated sketches drawn by participating students. By analyzing the evaluation results, we elucidated the relationships among the elements constituting sketching skills and proposed a structural model of sketching skills. Next, by using the proposed model to compare sketches drawn by design students and designers, we clarified the differences between the sketching skills of the designers and students and verified the usefulness of the proposed structural model.

Key words: Sketching Skills, Structural Modeling, Design Idea Generation

1. Introduction

Most product designers use sketches in generating ideas for design features because they recognize that sketches stimulate new ideas and creativity, and most designers continue to use sketching even today, when the use of CAD is widespread (1,2). Given this, sketching skills, which enable a designer to generate ideas for design features while sketching images, are considered to be essential, and a considerable amount of time is spent on acquiring these skills - as represented by the perspective drawing method - in the process of product design education. However, there are almost no examples of research that scientifically considers the role and effects of sketching skills in the generation of ideas for design features. The project discussed here aims at clarifying the role and effects of sketching skills and the relationships among them. First, previously untrained participants engage in sketching training, and the process of acquiring sketching skills is observed. Next, the relationship between the elements making up sketching skills is considered through analysis of participant sketches, and a structural model is created. Finally, we verified the usefulness of the proposed structural model by comparing the differences between sketches of the same subject drawn by designers and students.

2. Related Work

A great deal of research has been conducted on the uses of sketching in design. The following are reported as representative functions of sketching (3-5):

- · Stimulating new ideas and creativity
- · Communicating intentions beyond what can be formulated in words
- Simultaneously linking all elements
- · Providing an interface between implicit expression and verbal expression
- Identifying features that cannot be overlooked
- · Promoting serendipitous discovery of ideas
- Clarifying vocabulary
- Suggesting possibilities for new design proposals

In the field of design science, research taking sketching as a guidepost is being conducted to clarify the structure of creative thought in design (6-8). In the field of cognitive science, research is being conducted on the relationship between creative thought and sketching to shed light on "creation" as a human intellectual activity, and sketching is viewed as an action that assists in design reasoning (9). This research posits the discovery of unanticipated visual attributes, the associative generation of new concepts through the reinterpretation of visual attributes, and the creation of new design demands. As indicated above, despite the fact that a great deal of research has been conducted on the effects of sketching in promoting the generation of ideas for design features, because there has been no focus on the detailed causes of those effects, the role and effects of sketching skills in the generation of ideas for design features have not been clarified.

3. Observation of the training in sketching skills and evaluation of the drawn sketches

3.1 Observation of the training in sketching skills

Training aimed at promoting the acquisition of sketching skills was offered to a group of university students with no previous design education, and the process of skill acquisition was observed. Participants were 13 science students with some mechanical design knowledge. The participants were provided with sketching training consisting of a 90 min lecture and a 210 min practical session. Following training, the participants formulated design proposals using sketching exercises, working with the theme of a self-propelled robot vacuum cleaner. Subjects were required to decide on a sketch-based design concept in 180 min, and then to produce multiple idea sketches based on that concept in a 90 min period.

The skill acquisition process was observed in sketching education. Observations indicated that sketching skill can be classified according to difficulty, as follows:

(1) Skills that are quickly acquired

Many participants mastered basic skills, such as expression of figures and fundamental solids by shading, in a short time. Such skills are considered to be relatively easily acquired.

(2) Skills whose acquisition requires varying amounts of time

For some complex skills such as drawing curved surfaces, freehand drawing, and mastering the parts that constitute design elements, participants had varying levels of accomplishment within the allotted time. Such skills are considered to be relatively difficult to acquire.

In the exercise, each participant successively drew 3 to 14 proposals (91 in total) using the perspective method. The following was verified for each sketch:

(1) Development of structural design

Following sketches for the original proposal, subsequent development of unrelated design elements, such as differing structures or composition of parts or different internal structures. (Figure 1)

(2) Development of exterior design

Following sketches for the original proposal, subsequent development of designs that maintained similar structure but with modified external forms. (Figure 2)

(3) Development of design elements

Development of design proposals in which control and functional components are drawn in a way that describes function or specification as an industrial commodity.



Figure.1 Development of structural design



Figure.2 Development of exterior design

3.2 Evaluation of the drawn sketches

Sketching during design enables designers to clarify ideas in their minds by visualizing images, thus effectively linking ideas to subsequent steps. To clarify ideas, it is essential that designers possesses techniques that accurately express the characteristics of a desired form, allowing it to be captured on paper. To effectively link ideas to subsequent steps, the designer must furthermore be able to develop multiple design proposal candidates, and to select the best from among them. From the above, for this project sketching skills were broadly categorized as expression skills, techniques for the accurate expression of forms, development skills, or techniques for the development of a large number of design proposal candidates, and an attempt was made to elucidate the structure of each skill set.

The items used in the evaluation of expression skills were abstracted from design handbooks introducing sketching techniques.

(E1) Expression of perspective

Does the participant understand perspective drawing and use it correctly to express designs?

(E2) Expression of shadows and materials

Does the participant use shadows to give a sense of 3-dimensionality and adequately express materials?

(E3) Expression of three-dimensional form

Does the participant understand the three-dimensional form of the design, and express it correctly?

(E4) Application of perspective

Has the participant used perspective drawing based on an adequate perspective and setting of vanishing points?

(E5) Expression of ridge line

Has the participant adequately expressed "corner R," as formed by ridge line and vertices?

(E6) Expression of curvature

Has the participant adequately expressed curved forms that describe the curvature of the object?

(E7) Expression of profiles

Has the participant adequately expressed profile lines that describe the external form of the object?

(E8) Expression of constituent elements

Has the participant adequately expressed the position, size, shape, etc. of constituent elements such as operating sections and movable sections that represent design accents?

(E9) Freehand expression

Has the participant drawn smooth freehand lines?

(E10) Expression of emphasis

Has the participant emphasized and expressed the characteristics of the intended form and other features using the boldness, thickness, etc. of lines?

The items used in the evaluation of development skills were abstracted based on the results of the sketching observations.

(D1) Number of uses of perspective

A count of the total number of sketches employing perspective.

(D2) Number of developments of shape

Number of sketches developing different external shapes while maintaining the same structure.

(D3) Number of developments of structure

Number of sketches developing different overall structures.

(D4) Number of developments of shape for same structure

The average number of developments of the shape of the object for the same structure.

(D5) Number of developments of form

Within the development of the shape of the object, the number of variations in basic form that represent design motifs, for example the use of cylindrical shapes and rectangular parallelepipeds.

(D6) Development of constituent elements

Expression of the constituent elements of the subject of the design, such as operating sections and functional components, sketched to demonstrate its function and structure as an industrial product.

(D7) Development of explanation of shape

In addition to sketches from a single perspective, the number of absence of supplementary sketches demonstrating the shape of the object, made to enable correct expression of its shape as a three-dimensional object.

(D8) Development of structural elements

Number of elements intended to demonstrate the structure of the object and the functioning of moving parts, etc.

(D9) Development of detail elements

Number of elements separate from the basic shape, such as sketches including expression of elements providing design accents.

Evaluation was performed by two professional designers and one design teacher using the 10 expression skills criteria and 9 development skills criteria listed above.

4. Analysis and structure of an analysis result of sketching skills

4.1 Correlation between sketching skills

The correlation coefficient to the evaluation result of during expression skills evaluation of ten items, during development skill evaluation of nine items, and between expression skills evaluation of ten items and development skill evaluation of nine items was calculated. As a result, high correlation was shown between each of "skills whose acquisition requires varying amounts of time" and "skills that are quickly acquired." It was thought that expression skills could be typified from this by the time which acquisition takes. Also, high correlation was shown in "skills whose acquisition requires varying amounts of time" between both "development of exterior design ", and "development of design elements."

4.2 Creation of layered structural models

Structural model were created using interpretive structural modeling (ISM) to verify the causal relationship between each of the evaluation items for expression skills and development skills. Each subject's evaluation result for the expression skills were used to create an adjacency matrix. When 80% or more of subjects with a given expression skill A specifically had the expression skill B, it was judged that expression skill B was a necessary condition for expression skill A (Figure 3, 4).

In expression skills "skills whose acquisition requires varying amounts of time," were shown in the levels that imply acquisition of other skills. In development skills, results indicate that "development of external design" is learned after acquisition of "development of structural design" and "development of design elements."

4.3 Categorization of sketching skills

Hayashi's quantification method III was applied to the evaluation data to organize the ten evaluation items relating to expression skills. Because the cumulative contribution ratio up to the third component was 0.8, cluster analysis (Ward's method) was applied to the category scores up to the third component to produce four categories. The four categories of expression skills were named as follows, based on the characteristics of the evaluation items included in the categories:

(1) Skills for expression of perspective



Figure.3 The layered structural model of expression skills



2 Number of developments of shape

- \overline{O} Development of explanation of shape
- 4) Number of developments of shape for same structure
- Development of detail elements
- ① Number of uses of perspective
- ③ Number of developments of structure
- (5) Number of developments of form
- 8 Development of structural elements
- 6 Development of constituent elements

Figure.4 The layered structural model of development skills

This category is made up of (E1) Expression of perspective, (E2) Expression of shadows and materials, (E4) Expression using perspective drawing method, and (E8) Expression of constituent elements. These are skills based on an understanding of the perspective drawing method, enabling expression including expression of constituent elements.

(2) Skills for expression of three-dimensional form

This category is made up of (E3) Expression of three-dimensional form and (E7) Expression of profiles. These are skills for the accurate expression of three-dimensional form, based on an understanding of that form.

(3) Skills for the expression of curved form

This category is made up of (E6) Expression of curvature. This is a skill for the expression of soft curves, enabling accurate expression of curved designs.

(4) Skills for the expression of the object image

This category is made up of (E5) Expression of contours, (E9) Freehand expression, and (E10) Expression of emphasis. These are skills based on skill in freehand drawing, enabling accurate expression of the design image through elements including expression through the relative strength and vigor of lines and the expression of outlines.

Hayashi's quantification method III was also applied to the evaluation data to organize the nine evaluation items related to development skills. Because the cumulative contribution ratio up to the third component was 0.71, cluster analysis was applied to the category scores up to the third component to produce four categories. The four categories of development skills were named as follows, based on characteristics of the evaluation items included in the categories:

(1) Skills for development of structure

This category is made up of (D1) Number of uses of perspective, (D3) Number of developments of structure, (D5) Number of developments of form, and (D7) Development of explanation of shape. These are skills for developing variations on basic structure and form, making up the basic shape of the design.

(2) Skills for development of shape

This category is made up of (D2) Number of developments of shape and (D4) Number of developments of shape for same structure. These are skills for developing differing external shapes for the same basic structures and forms.

(3) Skills for development of constituent elements

This category is made up of (D6) Development of constituent elements. This is a skill for the development of constituent elements that serve as distinctive features of the object, separate from the external shape that constitutes its basic form.

(4) Skills for development of detailed shape

This category is made up of (D8) Development of structural elements and (D9) Development of detail elements. These are skills for developing detail elements such as details and explanations of structure that serve as distinctive features of the object.

4.5 Structural model of sketching skills

Figure 5 shows the category score graph for expression skills obtained by Hayashi's quantification method III, incorporating arrows expressing the causal relationships demonstrated by ISM and the four categories of expression skills. It is thought that acquisition of "Skills for expression of object image" requires acquisition of the "Skills for expression of curved form," "Skills for expression of perspective," and "Skills for expression of three-dimensional form."

Figure 6 shows the category score graph for development skills obtained by Hayashi's quantification method III, incorporating arrows expressing the causal relationships demonstrated by ISM and the four categories of development skills. It is thought that acquisition of "Skills for development of shape" is premised on acquisition of "Skills for development of development of structure" and "Skills for development of detailed shape," in many cases.

Figure 7 shows a proposed structural model of sketching skills, based on the results of a study of the structures of expression skills and development skills. Sketching skills are here divided into expression skills, which enable accurate expression of the shape of a design proposal, and development skills, which enable the development of numerous candidates for design proposals. Each skill is typified from its relation with skills in three groups, "design development of structure" and "design development of element."

5. Analysis of designers' sketching skills using structural model of sketching skills

The differences between sketches of the same subject drawn by designers and students who were in the process of acquiring sketching skills were compared using eight factors constituting the structural model of sketching skills. Sketches were collected under the conditions shown below.

Theme: Projector

Sketch and creation time: 60 min.







Figure.6 The category score graph for development skills



Figure.7 The structural model of sketching skills

Participants were 6 designers with 2 to 7 years of professional experience working for an electric appliance manufacturer and 10 students of design. Sketches' examples produced by participants are shown in Figure 8. The sketches were evaluated based on eight factors shown in the structural model of sketching skills.

First, for evaluating the sketching skills of designers and students, the values were normalized for every evaluation criterion, and the average differences were examined. The average, unbiased variance and the standard deviation for the four factors in the expression skills category and the four factors in the development skills

category are shown in Tables 1 and 2, where for all eight factors for sketching skills, sketches drawn by designers obtained high average scores compared with those drawn by students, suggesting that design experience and practice affect sketching skills.

In examining the unbiased variance and standard deviation, sketches drawn by students showed higher values compared with those drawn by designers for many items. In contrast, in the case of "Skills for development of shape" and "Skills for development of structure", large values were obtained for the sketches drawn by designers compared with those drawn by students. Differences were also observed with respect to many factors in sketching skills according to the level of skill acquisition among students who were in the acquisition stage. In contrast, the difference tended to be greater between designers for "Skills for development of shape" and "Skills for development of structure".

Tables 3 and 4 show the results of a test for equality of variance (F-test) on the data for expression skills and development skills, the results of a t-test on the skills by which the equality of variance was examined, and the results of Welch's t-test on the skills by which unequal variance was examined. The results of the test for equality of variance showed that for three factors in the expression skills category (with the exception of the "Skills for expression of 3-D form," where the distribution was 0 since all six designers received the highest evaluation score) and all four items in the development skills category, the p value exceeded 0.05, and it was shown that the variance for designers and students is equal in general.

As a result of the t-test and Welch's t-test based on the test for equality of variance, for all four factors in the expression skills category and all four items in the development skills category, the one-tail p value was 0.05 or



Figure.8 Sketches produced by participants

Table 1. The average, unbiased variance and the standard deviation of the expression skills

Table 2. The average, unbiased variance and the standard deviation of the development skills

	Designer (n:6)			Student (n:16)				[Designer (n:	6)	Student (n:16)			
	Average	Unbiased	Standard	A	Unbiased	Standard		A	Unbiased	Standard	A	Unbiased	Standard	
		variance	deviation	Average	variance	deviation		Average	variance	deviation	Average	variance	deviation	
Curved form	0.949	0.247	0.497	-0.356	0.822	0.906	Constituent elements	1.081	0.294	0.542	-0.405	0.661	0.813	
The object image	0.830	0.489	0.699	-0.312	0.859	0.927	Detailed shape	1.074	0.405	0.636	-0.403	0.631	0.794	
Perspective	0.504	0.456	0.675	-0.189	1.109	1.053	Shape	0.894	0.847	0.920	-0.335	0.677	0.823	
3-D form	0.890	0.000	0.000	-0.312	0.972	0.986	Structure	0.717	1.252	1.119	-0.268	0.701	0.837	

Table 3. F-test and T-test result for the expression skills

Table 4. F-test and T-test result for the development skills

	F-1	test		T-test					F-test			T-test				
	Statistic	P valu	ie	Statisticit	Two-tail	one-t	ail		Statistic:F	P value		Statisticit	Two-tail	one-t	one-tail	
	Statistic.	1 Value		Gtatistic.t	p value	p value			otatistic.i	i value		Gratistic.c	p value	p value		
Curved form	3.569	0.166		3.691	0.001	0.001	**	Constituent elements	2.250	0.379		4.117	0.001	0.000	**	
The object image	3.648	0.160		3.212	0.004	0.002	**	Detailed shape	1.559	0.656		4.068	0.001	0.000	**	
Perspective	2.074	0.436		1.903	0.078	0.039	*	Shape	1.250	0.670		3.028	0.007	0.003	**	
3-D form	7.E+31	0.000	**	4.987	0.000	0.000	**	Structure	1.786	0.352		2.247	0.036	0.018	*	

less, and it was shown that the sketching skills of designers are more developed than those of students. Among these, the one-tail p value for perspective drawing skills and structure development skills was large compared with that for other skills, and it was shown that the difference in skills was small. In the case of structural model of sketching skills (Figure 7), it was shown that these skills are fundamental and requisite for the acquisition of other sketching skills. From this, it is considered that design education promotes the acquisition of a certain skillset in students as well.

6. Conclusions

In this research, for the purpose of clarifying the role and effects of sketching skills in relation to the generation of design ideas in the process of product design, we observed the process of acquiring sketching skills in a sketching class and evaluated sketches drawn by participating students. By analyzing the evaluation results, we elucidated the relationships among the elements constituting sketching skills and proposed a structural model of sketching skills. Next, by using the proposed model to compare sketches drawn by design students and designers, we clarified the differences between the sketching skills of the designers and students. This confirmed the generality of the model towards clarification of the role and effect of each aspect of sketching skills in relation to design idea generation. Use of this model would allow transformation of sketching training, in which so much time is conventionally spent on acquiring basic skills, into an avenue for effective acquisition of techniques for generating ideas for design features. We intend to further elucidate the function and role of sketching in the generation of ideas for design features on the basis of this model.

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