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# Need of Design Knowledge and Use of Novice Designer for Product Sketching †

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**Abstract:** Design knowledge is the basis for designers to solve design problems. In product design, sketches assist designers in thinking as an important step. Novice designers need to use different types of design knowledge in sketching to solve design problems and find product solutions. In this study, we determined the novice designers' knowledge needs and processes in sketching and discovered their sketch ideas to understand how they solve design problems.

**Keywords:** design knowledge; sketching; design process; design education

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## 1. Introduction

Design knowledge refers to the information on product processes including multi-level information such as user communities, product attributes, organizational strategies, and technical principles that promote design innovation [1,2]. In the innovation design of products, the early design is usually vague and undefined and is difficult to disintegrate under fixed standards. Designers solve such design problems with personal experience in capturing, storing, and reusing various knowledge by analyzing and visualizing the possible effects of the solution. Designers have flexibility in conceptual design according to design requirements to show different results. Manolya and Gero studied the differences between experienced and novice designers in the use of knowledge in the conceptual design process and found that their knowledge supported the thinking process [3]. They also found that expert designers were more structured in cognitive activities and used knowledge more strategically, resulting in more than three times higher productivity than novice designers [3]. Thus, the challenge for novice designers is how to strategically access and filter effective knowledge for innovation in any given situation [4].

In the conceptual design of products, designers rarely use a computer-aided system (CAD) because the exact geometric information is not defined yet. Instead, they sketch to stimulate their design thinking [5]. Sketches show the core idea of designs and play an irreplaceable role in the positioning, development, expression, deduction, and formation of product concepts [6,7]. The analysis of design knowledge in the sketching process is a dynamic process involving knowledge acquisition, processing, and application [8]. Previous studies revealed that the design knowledge in the sketching process could be effectively and explicitly described by design protocols [9]. However, in this study, we try to discover how novice designers use their knowledge to stimulate a variety of product ideas during the sketching process. For this study, cognitive activities, sketching behaviors, and sketching outcomes of novice designers are recorded in sketching by Protocol Analysis. Based on the function behavior strategy (FBS) ontology and the theory of creative segmentation, we select and code the design knowledge in sketching and graphically describe the use of knowledge in different stages of sketching to describe how knowledge is used in the creative activities of novice designers. The findings are useful to find the type of support that design education needs to provide for novice designers.

## 2. Theoretical Backgrounds

### *2.1. FBS Ontology*

FBS ontology is used to identify knowledge in the sketching process and describe knowledge use patterns. In the FBS model, Gero used two categories of variables to describe different aspects of the design: function variables to describe the teleology of the object and behavior variables referring to what the object does including expected behavior variables and structural behavior variables [10]. The structure variable refers to the objects' components and their relationships. The FBS ontology interprets the design process based on the design requirement (R) with which designers construct the connection among function, behavior, and structure according to their experiences [10]. Specifically, the designer ascribes the function (F) to the expected behavior (Be), at the same time derives the structural behavior (Bs) from the feasible structure (S), compares the expected behavior with the structural behavior, and represents the design description (D). Additionally, the FBS framework proposes eight fundamental knowledge processes for all design activities (Figure 1).

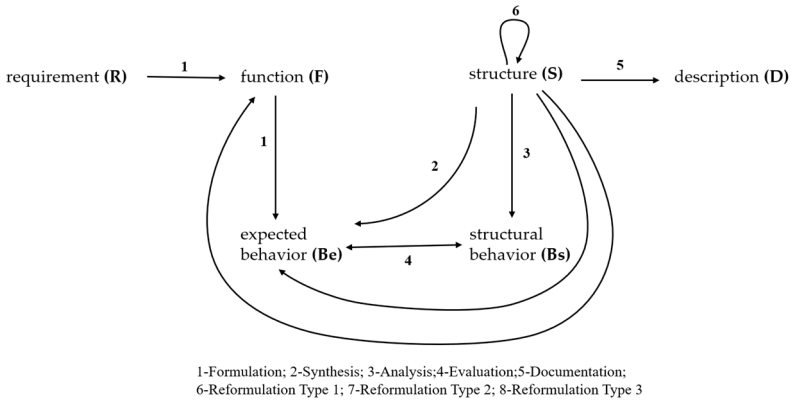


**Figure 1.** FBS Frameframework and fundamental knowledge processes.

### *2.2. Creative Segment Theory*

In the sketching process, the designer constantly generates inspiration from multiple perspectives. Each acquisition of inspiration is regarded as a knowledge process and provides possibilities for new design solutions. Thus, the process of sketching consists of multiple segments. In the Creative Segment Theory, Creative Segments (CS) are used as nodes to describe the sketching process, and a tree structure is adopted to describe the relationship between creative activities [11]. Usually, a designer's sketching process contains more than one creative segment, alternating between finding ideas and expressing them. During sketching, designers have different knowledge processes and applications and involve various design information. When finding new ideas, designers constantly stimulate their minds to explore the influence of design knowledge. When expressing ideas, designers elaborate and evaluate newly generated ideas [8]. After the creative segments are divided, it is better understood how knowledge supports designers' creative activities and builds knowledge patterns.

## 3. Research Method

To understand the needs and use of design knowledge by novice designers, we studied the knowledge process of product sketching through an experimental design. We recruited two sophomore students majoring in product design. Their average age was 18.5 years old. They received one year of fundamental training in product design but had not participated in product practice projects. They were regarded as novice designers. We refer to them as Designer 1 and Designer 2 hereafter.

### *3.1. Experiment Design*

The experiment design required the two designers to design a "Better Reading Lamp" as their topic. A product idea was provided. The maximum time for design was limited to 45 min. Designers used paper and pens for their sketching. In this experiment, the sketching processes of the two designers did not interfere with each other. They found the development direction of the product concept according to their points of view and recorded the derivation process of the product concept until they finally came up with the most satisfactory one (Figure 2).

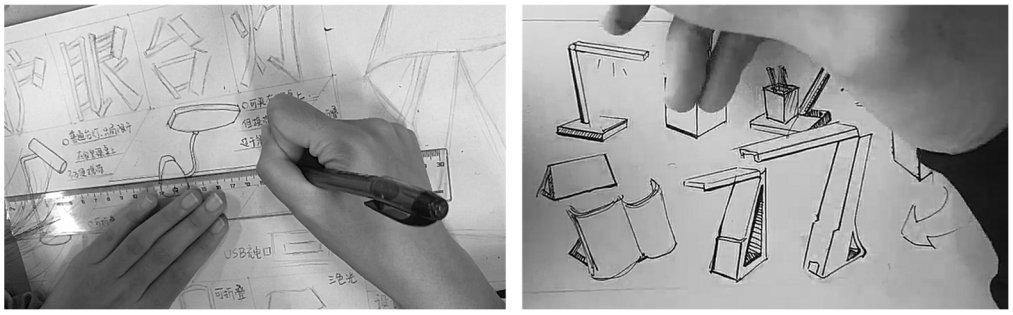

**Figure 2.** Sketching process of Designers 1 and 2 (the Chinese in the Figure has no effect in understanding the experiment).

### *3.2. Data Collection and Coding*

The two designers were required to report their ideas during the sketching process. Thinking Aloud was used for protocol analysis. This method required designers to verbally report their thinking while completing the design task. The design protocols reflected what the designer saw, thought, and did at the cognitive level and could be objectively restored in the time series of the designer's thinking [12]. The video equipment was used to record the audio-visual data of the designers. After the experiment, we processed the data by segmenting and coding and discussed the results to obtain consistent results.

## 4. Results and Discussion

### *4.1. Creative Segment of Sketching Process*

Through manual identification, nine Creative Segments were identified in the sketch data of the two designers. The Creative Segment Trees displayed the path from the conventional to the most satisfactory lamp (Figure 3).

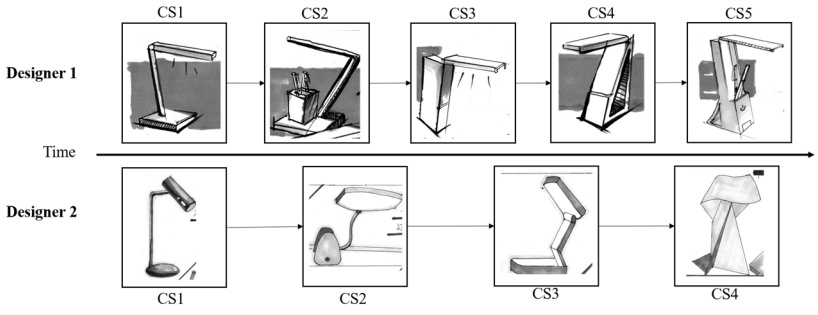


**Figure 3.** Creative Segment Tree of sketching process.

Under the design requirement, Designer 1 first thought of a table lamp. Since most of the reading behavior occurs at the desk, the table lamp needs to be stably placed on the desk. CS 1 consisted of a head, a body, and a base. The lamp head could be folded to adjust the range of light irradiation up and down. Designer 1 compared this lamp with the conventional table lamp used in daily life and thought a multi-function table lamp would be better. CS2 had a large volume pen holder on the lamp base, and its body could be adjusted. Considering that the pen holder would take up too much space on the desktop and would

easily clash with the body, Designer 1 changed the overall shape of the lamp into CS3 which had a foldable lamp head and the pen holder below the lamp head. Designer 1 found that the shape of CS3 was not stable when the lamp head was unfolded, so the square-shaped support was changed into a more stable triangle one, and the storage space of the pen holder was reduced (CS4). Designer 1 reduced the volume of the supporting structure, making CS5 a more unique and stable Z-shape, and added buttons and other details.

At the beginning of sketching, Designer 2 also thought that the most common object suitable for reading was a table lamp, whose light source could be adjusted (CS1). By replacing the lamp base with a clamp structure, Designer 2 proposed CS2, which could be clamped on the table. Designer 2 thought that reading would not only take place at home, so a portable lamp was better. By associating with the M-shaped folding structure seen in life, Designer 2 puts forward a small-size CS3 which was portable but not light enough. CS4 simulated the structure of a paper airplane. The body of CS4 was changed from a block to a surface and folded to make the lamp portable and stable.

### *4.2. Analysis of Design Knowledge Needs*

Based on the FBS ontology, 251 codes were extracted from the design protocols: 119 from Designer 1 and 132 from Designer 2. The data distribution is shown in Table 1. In terms of the proportion of the number of codes, F was mentioned the least. Given R, both novice designers relied on their life experiences to find out potential product functions. Behavior variables in the FBS model were classified as Be and Bs. In the sketching process, designers usually compare the two variables to evaluate the design solutions. Among all the FBS codes, knowledge of product structure was the most mentioned in the sketching process, accounting for nearly half of the data of Designer 1 and about one-third of the data of Designer 2. The two novice designers spent more time in the later stage of sketching to use the accumulated structural knowledge and frequently hesitated over which structure could be used for a more satisfactory solution. Therefore, novice designers needed to be supported in accessing and filtering effective knowledge on product structure.

**Table 1.** FBS codes of Designers 1 and 2.

| Code | Designer 1 | Designer 2 |
|---|---|---|
| F | 5 (4.2%) | 9 (6.8%) |
| Be | 19 (16.0%) | 26 (19.6%) |
| Bs | 23 (19.3%) | 27 (20.5%) |
| S | 62 (52.1%) | 47 (35.6%) |
| D | 10 (8.4%) | 23 (17.4%) |
| Total | 119 (100%) | 132 (100%) |

### *4.3. Analysis of Knowledge Processes*

After being given the design task, the two designers first understood the design requirement, then searched for existing cases in life to determine the functions of the first product, then developed design ideas, and enhanced the product details. To further understand the knowledge processes based on different creative segments, we presented the relationships between F, Be, Bs, and S in time series according to the FBS framework, as shown in Figures 4 and 5.

During Designer 1's sketching process, analysis (S→Bs) was present in every Creative Segment. Structure, as core knowledge, mostly appeared between adjacent segments from CS2 to CS5. Designer 1 explored the reformulation of the lamp body structure to the next one many times (Reformulation Type 1, S→S'). Formulation (F→Be) appeared in the early CS1, CS2, and CS5, which represented a product function breakthrough in the designer's sketching process. Evaluation (Be↔Bs) appeared mainly in the last three Creative Segments, and the interaction of behavioral knowledge and structural knowledge finally led to the most satisfactory lamp for Designer 1.

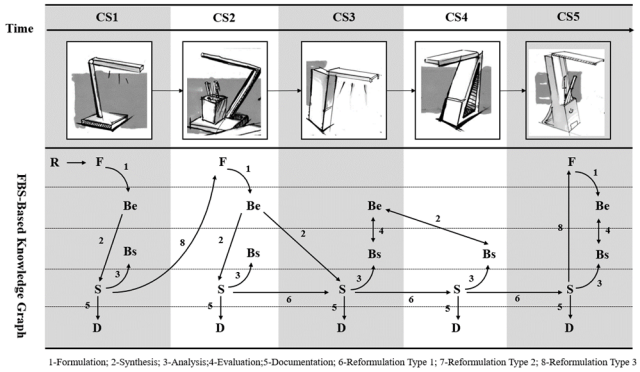


**Figure 4.** Knowledge graph of Designer 1's sketching.

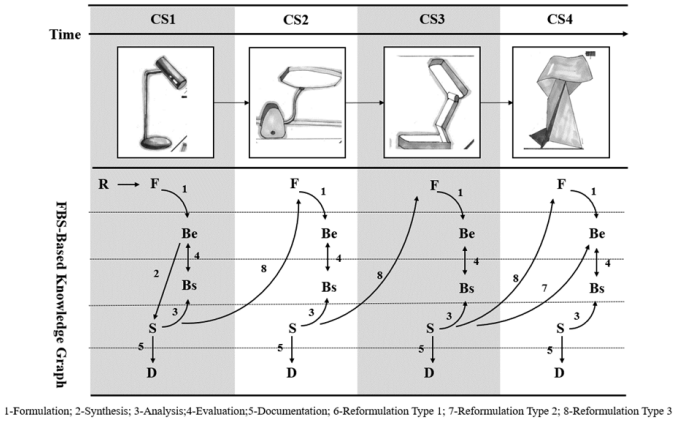


**Figure 5.** Knowledge graph of Designer 2's sketching.

Designer 2 conducted frequent Formulation (F→Be), Analysis (S→Bs), and Evaluation (Be↔Bs) in the four Creative Segments. This pattern of using knowledge was different from that of Designer 1. Designer 2 used Reformulation Type 3 (S→F) between Creative Segments, leading to four significant breakthroughs. The lamp that Designer 2 is most satisfied with is proposed according to life experience. In CS4, Designer 2 evaluated the expected behavior and structural behavior (Be↔Bs), while enriching the functional details of a product concept.

## 5. Conclusions

In the process of product conceptual design, knowledge supports the thinking of designers which is important in design education. Knowledge in the design process is usually the information stored, organized, and integrated by the designer in memory. We used the FBS ontology and the Creative Segment Theory to analyze design knowledge needs and the sketching process. In the early stages of product design, sketches aided designers in thinking and focusing a large amount of knowledge. Novice designers lack strategic design knowledge and design practices for the sketching process. We found that novice designers had common knowledge needs in the sketching process. They could quickly access the functional knowledge of each solution according to the design requirements. However, to promote the innovation of the solution, they needed to master the appropriate structural knowledge, which is a major concern in design education. Novice designers could develop the habit of using knowledge during the sketching process. The knowledge process with the connection point between creative segments would promote the inheritance relationship of product features. The innovation process of product development with the core knowledge leads to significantly different product features. However, both approaches allowed novice designers to find the ultimate design solution.

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