A Study on the Visual Thinking in the Sketching of Product Design

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Abstract: Design thinking is the process by which a designer clarifies a design problem, proposes a solution or observation, and makes a design decision. The process of design thinking can also be considered as the process of sketching. The sketch helps the designer to reflect on the design to get the optimal solution to the design problem. The process of sketching requires visual involvement. Visual thinking is a way of thinking through visual perception that helps designers filter what they see. Nowadays, product design students present their design results and sketch quality at the time of independent creation far below their level at facsimile. Therefore, this study explores the visual thinking strategies used in the creative processes of experts and students by the audio-visual retrospective protocol analysis method, trying to clarify the differences in visual thinking processes between product design students and experts during sketch creation. Design educators improve their design courses and improve the quality of sketches for product design students. The research results show that the expert’s visual thinking strategy is trend to visual imagery, while the novice visual thinking strategy is intuitive perception of the visual. The research results clarify the shortcoming of visual thinking in the sketching process of students, providing a scientific reference for design thinking education that teachers can use to improve the teaching structure of the curriculum.

Keywords: visual thinking; protocol analysis; product design

1 Introduction

The development of design is a process in which designers use the cooperation of their hands and brains to repeatedly compare, refine and modify the thinking that makes abstract thinking materialization. It is also called the process of design thinking. Liu (1996) believed that the core of design thinking was how the designer thought of the problem and the resulting solution. Stempfie and Badke-Schaube (2002) showed that the basic elements of design thinking were generation, exploration, comparison, and selection. They thought that generation and exploration expanded the problem space, and comparison and selection reduced the space for the solution. They also believed that when you extend a problem, a solution is generated and the relationship of the solution and the target can be checked. Then, during the iterated design thinking, new solutions could be modified or developed until an optimal solution is found.
Therefore, it requires the designer to clearly define the design problem before all the steps to finish the process of design. After that, the designer needs to collect information to expand the problem, and then generates a solution. Razzouk (2012) showed that there was a strong interaction between unexpected discovery during design thinking process and the need to solve problems. During the sketching process, the designer will contemplate the sketches. When the designer constantly reviewed the points, lines, or other graphics drawn on the paper, new combinations and relationships between these elements were created which was an unforeseen or planned accident. Designers could see some meaningful points, lines, and markers from the image. These elements would lead the designer to convert the previous image by adding, deleting, modifying, or replacing, which made the accidental discovery become the driving force for solving the problem or demand. Sketches promoted designer self-reflection, self-dialogue, and self-criticism, helping to express the designer's intent to identify their own thinking structures and insights to create new combinations. Therefore, the process of sketching could also be considered as the process of design thinking. Designers constantly looked at sketches, stripping and analysing them, all of which require visual thinking. The visual thinking here was different from perception, which was to some extent an interpretation of direct vision. Visual thinking was thinking through visual image and it favoured an insight that was a selection by people’s watching. Miller (1986) thought that psychological intentions had usually visual intent, and it was rational and systematic. At the same time, it helped designers to make intent reasoning. Casakin and Goldschmidt (1999) demonstrated that visual thinking assisted designers re-identify and reconstruct images to stimulate unintended inspiration. Göker (1997) found that experts relied more on their experience and visual information thinking in their design thinking. In contrast, novices relied more on abstract reasoning (the visual thinking here referred to the inference of ideas based on generation of ideas, which gave a great help to make a creation of forms rather than presentation in design). Seitamaa-Hakkarainen and Hakkarainen’s (2001) research on weaving design showed that experts paid attention to the alternation of visual and technical elements in design thinking. It was thus reported that visual thinking was important for the design thinking process for the expert. Nowadays, it happens frequently that most students who major in industrial design with enough drawing skills have no idea of sketching, and their final sketches, as well as design results, are poor. Is it because of the lack of visual thinking in students? Therefore, this study used audio-visual retrospective protocol analysis method to study the conceptual sketching process of product design students (novices) and senior designers (experts), trying to clarify the similarities and differences of visual thinking strategies during their process of sketching in the process of conceptual sketch creation, in order to understand the shortcomings of students’ visual thinking, to improve the design of students’ visual image reasoning and optimize design thinking education.

2 Experimental Process

In order to understand the similarities and differences between visual thinking strategies of novices and experts when creating sketches, this study invited two subjects to be tested by audio-visual retrospective protocol analysis method to analysis their sketch creation. One of the tested persons was a senior designer of industrial design with more than ten years of design experience, while the other was a senior who majored in industrial design with more than three years of design experience. Because the visual thinking of the research discussion refers to the thought and reasoning process that the designer produces after seeing something, the subjects were first invited to view the same picture as a visual clue, as shown in Figure 1.

![Figure 1. The visual cues](image)

In addition, Seitamaa-Hakkarainen and Hakkarainen (2001) pointed out that design thinking is composed of two elements: visual thinking and technical thinking. Therefore, the experimental topics are chosen as a seat design with simple structure and sufficient knowledge reserve for both experts and students. The experimental equipment we chose was a hand paint tool such as a marker and a pencil. The whole experimental process was recorded as a video. Then, we asked the subject to watch the video and synchronize the thought process at the time. Finally, we would combine with the recording data and oral data for coding analysis. When analysing video and audio materials, when a
design intent transfer is regarded as the beginning of a sentence, and when there is a different description of the same item, space, or topic, it was treated as a different sentence (Gero, 1990), and the study uses design intent to transfer as sentence punctuation.

2.1 Coding System
The main purpose of this study is to explore the differences of visual thinking strategies between novice and expert designers in the process of creating sketches, therefore the research uses two sets of coding systems (Tables 1 and 2):

<p>| Table 1. The first coding system |</p>
<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
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<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>S Backtrack</td>
<td>Backtracking visual cues or past design knowledge</td>
<td>T Transfer</td>
<td>Change or answer the problem</td>
</tr>
<tr>
<td>P Mapping</td>
<td>Establishing the correspondence between goals and similar goals</td>
<td>Cs Constraint</td>
<td>Consider more conditions than originally</td>
</tr>
<tr>
<td>Cc Concretize</td>
<td>Using figurative image language</td>
<td>A Drawing abstract</td>
<td>Think from different aspects, such as drawing the relationship between elements and elements or the spatial relationship of elements</td>
</tr>
<tr>
<td>M Modify</td>
<td>Transforming the problem or answer elements</td>
<td>I Inspection</td>
<td>Consider from functional or aesthetic aspects</td>
</tr>
</tbody>
</table>

<p>| Table 2. The second coding system |</p>
<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
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</thead>
<tbody>
<tr>
<td>Ms Item establishment</td>
<td>Transfer the thinking into graphic</td>
</tr>
<tr>
<td>Mr Repeated drawing</td>
<td>Repeat the drawing of the picture</td>
</tr>
<tr>
<td>Mm Modification</td>
<td>Modifying the elements (size, shape, etc.) of sketch</td>
</tr>
</tbody>
</table>

The first group integrates the six basic strategies of visual thinking strategies proposed by McKim (1980) and the five visual analog variables proposed by Casakin (2004). Visual thinking naturally produces three intents of viewing, imagining, and drawing (McKim, 1980), people who are good at using visual thinking will flexibly apply three kinds of intentions that assist each other. Viewing means people intention, it is not true image; imagination is inner perception to intention to help drawing creative thinking; the drawing is the final visual result. The viewing helps the drawing process through deep thinking, like observation, description, interpretation and inference. The three intentions of visual thinking proposed by McKim (1980) can also be subdivided into six kinds of thinking strategies, which are transfer, manipulation, materialization, abstraction, modification and inspection (Wang, 2006). Transfer is between imagination and viewing, that is, changing the perception of the problem. Manipulation is to arrange questions or answer elements again; materialization tends to be a step of visual thinking, somewhere between imagination and drawing. It is focusing on a design problem and developing it, using a specific graphic language. Abstraction means thinking from different levels; modification is between the viewing and the painting, for the transformation problem; inspection is regarded as the intended goal, and the result is previewed. Schon and Wiggins (1992) proposed a see-move-see theoretical model of design thinking. The model illustrates the designer’s use of different types of visualization: visual understanding and judgment of the graphics on paper; through the behaviour of painting, the change of the program, and through the see to the drawn graphics, completing a cycle of design thinking, to proceed to the next stage. In addition, the move in the see-move-see theoretical model has two meanings: one is the process of converting the original image into another image, and the other is the sketching action, such as modifying the existing graphic, modification, drawing symbols, and writing text. As the sketch reasoning is the process of the designer’s continuous drawing, viewing, and modification, the second group uses the moving part of Schon and Wiggins’ seeing-moving-seeing model to clarify the drawing behaviour during the sketch creation process.
2.2 The Research Process of the Novice

The total experimental time of the novice is 23.58 minutes. The experimental process is divided into three stages, which are: the early stage (0min-8min), the middle stage (8min-16min), and the later stage (16min-23.58min). The visual thinking strategy is shown in Figure 2: In the early stage, the first step is to carry out the knowledge backtracking, and then answer the knowledge of the problem (00.00-00.14, “I want it to be a single chair, a stone single chair, I think of the stone pot I saw before, so the chair surface should be smooth, the shape of the chair, the amount, I want to reflect the irregular feeling of the stone”). The first design idea was completed at 04.02 min, as shown in Figure 3.

![Figure 2. The visual thinking process of the novice](image1)

![Figure 3. The first design sketch of the novice](image2)

In the early stage, the novice carried out two backtracking (S); in the first eight minutes -explaining the cognition of the problem (T)- the cycle of drawing element thinking (A), and performed two inspection actions. In the middle stage, firstly, the middle visual thinking actions of the novice is similar to the early stage, and there are more backtracking actions. The main visual thinking action is the process from inspection (“The last two lines are not drawn, so I want to redraw”) to constraint (“I wanted to draw a chair leg on the new chair, but I want to be clearer, so I will draw a chair again”), and backtracking (“Because of the plain feeling, there is wood and stone”) to concretize (“Then three legs and round legs”) to backtracking (“Because the first chair is like this”). In the middle stage, the novices are more concerned about the specification of thinking. In the later stage the novice continues to modify the shape (finally, combine the lower chair and legs, and then draw a little bigger; then thicken the chair because the stone is thicker), second, inspecting (“The line just doesn’t look good”). In the later stage, there was only one action that was thought from the previous experience (“The chair has just said that it should be irregular, just like the first chair”). The rest of the movements are based on the aesthetics of the sketch and are reviewed and modified from the aesthetics of the picture (“The lines are not good, the uneven surface here should be thicker, and the lines should be smoother with the side”).

The drawing action in the visual thinking process of the novice is shown in Figure 4: in the early drawing stage, the novice uses the object creation (Ms) and the repetitive drawing (Ms) cycle action frequently. During the first ten minutes of the creative process, the majority of the raw hands are repeated. In the middle and late stages of drawing, the object creation (Ms) and object modification (Mm) actions are repeated.
2.3 The Research Process of the Expert

The total time for the expert's creative experiment is 22.55 minutes. The experiment is also divided into three stages: the early stage (0min-8min), the middle stage (8min-16min), and the later stage (16min-22.55min). The expert visual thinking strategy process is shown in Figure 5. In the early stage, firstly, the action of the expert is similar to the novice, using backtracking (“In this time, I remember the picture which I saw before, like a puppy dog”). Then, defining the perception of the problem (Then, I want to drawing a double chair). From 00:05 to 01.56 min., the expert completed the first design idea, as shown in Figure 6.

After that, the expert turns into the mapping step, which is building the correspondence between target and similar target (it is modularization of fabric chair). After mapping step, the expert turns into constraint stage, visualizing thoughts based on constraints. In the first eight minutes, the expert focuses on reviewing past experiences, transforming them, and building relationships between past and present goals. During this period, the expert visualized the thinking but rarely evaluated the sketch. There are only two times abstract thinking (A) and one time backtrack (S) actions occurred.
The middle stage is the stage in which the expert is concretizing visual thinking, that is, the sketching stage. In this stage, visual thinking strategy mainly focuses on backtracking (S), adding constraints (Cs), abstract (A), inspection (I) and modifying (M) actions. At this stage, the expert first carries on the experience backtracking (“Such as this soft sofa bag on both sides of headrest is stereo, and the coherent degree is consistent”). Then the expert adds the constraint conditions (“The soft bags on both sides of the headrest can swing toward the middle or both ends”). Then, the expert sketches within the bounds of the constraint, and carries out inspection (I) and modification (M) actions. At this stage, the expert was seen three times backtracking (S) and three times making modification (M).

In the later stage, the expert first examines the modelling, and then visualizes further, that means makes development of the details. At this stage, the visual thinking action of expert has a certain span, from inspection (S) (“It’s important to have a faceted structure when you’re drawing”) turn into transfer (T) (“The part of chair leg should stretch, because of the chair seat becoming longer, the chair leg cannot use trigonometry to support like single person chair leg. So the chair leg of this should be the big four corners, but the basic style is the same”) step. After that, the expert turns into abstract (A) action (“The other side of the leg of the chair is invisible through perspective, so there is no need to draw”), and then, the expert visual thinking action enters backtrack action (“If you want to split the bottom of the chair, it can be divided into a piece of wood, the normal lock 4 empty”). Secondly, in the later stage, expert still has two thinking establishment (Ms) movement throughout the creation process frequently, and each time it appears, it lasts for a long time. Secondly, expert often uses repeated action, that is, modifying the picture which is already drawn, and seldom modifies elements such as shape and size. The entire drawing action has only one modification action (“The camber surface of the chair can be enlarged”).

![Figure 7. The drawing process of expert](image)

3 Experimental Result and Discussion

From the perspective of the above visual thinking strategies, the thinking process of experts and novices is quite different. According to the definition of Lu and Guan (2008), visual thinking strategies can be divided into three types: experiential thinking, imaginative thinking and visual thinking.

The visual thinking process of novices is dominated by inspection thinking, and the inspection action runs through the whole design process. From the early stage, the novice defined stone bionics as the main divergent element, and then carried out inspection actions around the expression of stone elements until the later stage. From the inspection actions, the novice tried to better display the shape of stone. In the whole drawing process of the novice, only the function of the product is paid attention to in the selection of chair legs, and the rest of divergence is based on the expression of aesthetic feeling. Therefore, the drawing process of the novice is more about thinking of the concrete form of visual cues. Secondly, the visual thinking route goes into backtrack (S) action from the perspective of inspection (I) or abstract (A), that is, the novice pays attention to the expression of picture elements rather than the extension of creativity. What the novice thinks back in the given elements is how to better express the painting style. In addition, the novice is more likely to recall visual cues during backtrack step. For example, in the protocol data, the novice said there are pictures of the stone that comes to mind. From the drawing action of the novice to the object establishment (Ms), repeated drawing (Mr) cycle of action, it can be found that the inspection prompted the designer to repeat the drawing action, to a certain extent affecting the fluency of the drawing process. In addition, the quality of composition also affects the presentation of the final sketch. Figure 8 and Figure 9 show the final design result of the novice.
In addition, we combined with the protocol data of the novice to analyse the drawing action: Between 01.22-01.26 min., the novice stopped her painting movement. From the protocol data, the novice thought that the line painting behind the chair was not good and there is no feeling of perspective. Then, the action of drawing and modifying the image appears repeatedly between 01.27-01.34. Between 01.52-03.50, she made repeated modification of the drawn image again, and said that the image was not beautiful enough to draw (she said that the irregular shape did not perform well here, so she wanted to redraw between 01.52-02.03; she also tried to clarify the irregular shape of the chair foot between 02.31-02.35; and focused herself on strengthening the feeling of irregular chairs and added some details between 02.46-03.28). From the drawing action that appears above through the entire drawing process of the raw hand, we could see that the most frequent thing the novice did in the drawing action was modifying the shape and size of the existing graphic which had already been drawn. It could be seen that the novice tends to directly perceive the image rather than understanding and reinterpreting the image during her visual thinking process, which meant that the novice was biased towards the visual sense.

From the type of visual thinking, the expert’s visual thinking is dominated by experiential thinking and imaginative thinking. The expert first looks for the answer to the question from the backtrack and establishes the target relationship corresponding to the question. For example, if the puppy in the previous picture comes to mind in the protocol materials, the expert draws a double chair with modular soft bag. The expert abstracts the dog’s form and then concretizes the thought to push out the final design. At this time, the expert showed a tendency to abstract visual cue thinking strategies. The expert tended to recall the experience in the backtrack, such as the normal board locking four holes. And the expert paid attention to the extension of sculpt and function, protocol materials show that, for example, this structure can be expanded into two parts, which are connected by knobs and recorded with friction pads at the bottom. At this time, the visual thinking of the expert presents multi-aspects thinking strategies.

In the later stage of the sketch process, the expert combined with the inspection thinking, analysed the drawing elements of the completed sketch, and further improved the sketch by using drawing technique. In the drawing action, in the early stage the items establishment is the primary movement of the expert’s drawing process. This indicates that the expert has more fluency in the drawing process than the novice. In the later stage, the expert is

Figure 8. The final design result of the novice

Figure 9. The final design result of the novice
focused on modifying and perfecting the sketch. Therefore, the drawing actions of the later stage used are object modification (Mm) and repeated drawing (Mr). In addition, the expert also used text-assisted method to help the presentation of sketches, which is not seen in the visual thinking strategies of the novice. Figure 10 shows the design result of the expert.

Combining the expert’s protocol data to analyse the sketching action, it is found that the expert will perform the see action after completing the sketching action. For example, the expert stops drawing during 02.39-02.56 min. and discovers new elements from the sketching (“This basic element also belongs to this, you can also do the whole expansion, the expression of the single chair or multi-functional chair form, or the shape of the back of the chair can be richer”); between 04.28-04.41 min. the expert stops drawing, and carries out design thinking expansion again (“Then, if it is expanded by the form of a single chair, it can be turned into a child’s chair or a form of a single recliner”). The expert uses the visual sense to get clues from the images, which is the unexpected discovery described above, and the new product form is inferred from the clues. The expert pays attention to the depth interpretation and form extension of the image in the sketch creation process and is good at changing the original graphics by combining new elements in the completed sketches.

From the analysis of the results, it is found that the visual cues do not have a deeper understanding in the visual thinking of the novice, and only focus on the aesthetics of the picture. The expert uses visual insight to find new elements from the original image. When backtracking, experts will perform multiple information extraction and problem reconstruction for the problem. This is the reason that experts can continue to extend the design. And the expert’s creative process is clearly divided. The early stage belongs to the design clue extraction, the design thinking divergence stage, the medium term is in the concrete thinking stage, and the later stage is the performance of the technique and the styling details. This was not seen in the sketching process of the novice. Therefore, it can be concluded that the expert trend is to use the visual intention reasoning of visual thinking. On the contrary, the novice cannot deconstruct the visual cues, and performs on the aesthetics of the sketch, and modifies the sketch again and again until satisfied.

4 Conclusion

The research uses practical design cases to observe the differences of visual thinking between the novice and the expert in the sketch design process, the result will contribute to students’ design thinking education. From the experimental results, it is found that the expert’s visual thinking strategy favours the visual intent reasoning and finds new clues from existing images to generate new ideas. Therefore, the expert’s sketching process is generating different ideas and extending the design creativity. The visual thinking strategy of the novice is intuitive perception of the visual, without information filtering. Therefore, the sketching process of the novice pays attention to the modification of the aesthetics of the sketch. However, this way leads to the failure of the design thinking of the novice to divergence, which in turn affects the final design result. Therefore, in design education, teachers should focus on cultivating the visual intentional reasoning of design students and strengthen their ability to interpret and extend information clues. This conclusion provides a new reference guide for design educators on the reform of design curriculum.
References


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