Comparison of Designer's Design Thinking Modes in Digital and Traditional Sketches

Associate Professor Jun-Chieh Wu, Huafan University, Taiwan

Mr. Cheng-Chi Chen, Chiao Tung University, Taiwan

Mr. Hsin-Chia Chen, Huafan University, Taiwan

Abstract

The internal design thinking behaviour of designers in the concept development has been an important issue of cognitive psychology. In this study, the design thinking process designers have in applying digital media and traditional paper in the early concept development stage was explored. Special focus was made on the structure and procedure of problem solving. With the verbal data obtained, the protocol analysis was employed to analyse designer's thinking behaviours in using different media.

From the study, the author had reached the following conclusions: (1) The proficiency and related knowledge designers have for the design project has a big impact on the construction of the design problem and the efficiency of problem solving and completeness of detail design. (2) Compared with the traditional way of idea development, digital media makes it possible for designers to have an in-depth description of the detail design with the help of related functions in digital media. (3) Designers can have an effective thinking process regarding the micro and macro aspects of a design project because of the function of software, enhancing the completeness of the design thinking while in traditional pen and paper environment, designers use the synthetic and contrast way to manipulate their idea development. The results obtained in this study will benefit both the design education and practical design activity where digital media is applied.

Key words

design thinking, computer-aided conceptual design, paper-pen sketching, Wacom interactive digital pen input system

Introduction

Regarding designer's design thinking behaviours, researchers concern about the clear presentation of the behavioural models designers have in the interior situation logic and decision-making process in their idea development (Rowe, 1987). During the design thinking activity, there are all sorts of variables and possibilities. Based upon the concept of information processing, Simon (1996) considers the design procedure a process developing from the initial state to the goal state, in which there are various searching paths and procedure. Therefore, the whole design procedure is often looked upon as a problem solving procedure. Schön & Wiggins (1992) claims that for designers, sketches not only serve as the descriptive tool for designers to record what within their minds but also a tool for designers to reinterpret the

sketches previously made and to reorganise their concepts. Tovey & Newman (2003) claim that sketches can be used to facilitate problem solving and creative efforts in the repetitive design process. The roles computer media plays in design can be divided into three layers, the design representation tool, design thinking media, and conceptual development tool. And different kinds of design media may result in different design thinking modes and representation styles (Liu, 1996). Currently, Wacom interactive digital pen input system has made it possible for designers to make sketches right on the computer screen. As a result, the role of computer media has been promoted from previous representation tool and manufacturing assistant tool to the design thinking and conceptual representation tool. In other words, the role of digital media has been changed from the simple representation tool to one that can help designers with their conceptual development.

The purpose of this study is twofold: (1) to explore whether there are differences for designers to apply Wacom interactive digital pen input system and traditional pen and paper in terms of their macro- and micro-strategies in their design thinking modes when they draw sketches for conceptual development; (2) with the diversity of tools provided by computer-aided conceptual design tools, is there a significant influence on the designer's idea development?

Literature review
Design thinking

In performing design activities, all steps of design problem definition and the transformation of solutions are covered in the design thinking behaviour. In such a design problem domain, problems can be divided into well-defined problems, ill-defined problems and wicked problems (Rowe, 1987). And because there is no definite end of the problem solving activity in design, we need to redefine the problem and process analysis and evaluation of the solutions if we expect to complete the design. Through the concept of information processing (Hayes, 1978, Newell & Simon, 1972; Simon, 1973; Simon, 1979), the manipulation of design problem can be referred to as the exploitation of knowledge state in the problem domain and the procedure of decision making. Furthermore, the input of knowledge state and the generation of the knowledge for feasible solutions construct the outcome of design thinking, from which the usable solutions can be evaluated and presented in the design output with the

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representation of new knowledge. Therefore, such kinds of external representations can be regarded as the concrete performance of designers in the design problem solution procedure.

Design sketches

During the design thinking procedure, the initial concept design is often considered the most creative design stage. In this stage, making design sketches (sketching) is the most critical behaviour. Many scholars claim that many prospective messages can be found from designer's sketches (Schon & Wiggins, 1992; Goldschmidt, 1994; McGown, Gree & Godgers, 1998; Suwa, Gero & Purcell, 2000; Cross, 2001), which can help designers to successfully develop their ideas. Therefore, designers usually present their proposals or generate their ideas by sketches. Due to different interpretations of the potential concepts, there are many views regarding the role of sketches in design, the major of which are: (1) seeing as (Goldschmidt, 1994), (2) moves (Schön & Wiggins, 1992), (3) lateral transformation (Goel, 1995), and (4) focus shifts (Suwa et al. 2000). In making design sketches, designers often use the episode knowledge,

rather than theoretical knowledge, from their personal experience (Visser, 1995). Through such kind of "dialog procedure" of graphic media, designers can redefine or reconsider possible ideas and at the same time, take down possibilities of these ideas by the ambiguity and uncertainty of sketches.

Computer-aided conceptual design

Kavalki, Scrivener & Ball (1998) point out that since 1965, when Sutherland proposed the interactive computer graphic system, all kinds of digital CAID tools have become more and more influential in the design process due to the rapid technical development in these forty years. CAID tools have become new methods for idea development, not just technical graphic tools (Jonson, 2005). In conceptual design, computer-aided conceptual design has become a new and important issue (Dijk, 1995). In the past, some studies had compared the differences between computer aided sketches and traditional pen and paper sketches in idea development. Because the digital tools cannot properly express the uncertainty of sketches in the idea development stage, all researchers report that the traditional pen and paper is

Figure 1. Wacom interactive digital pen input system

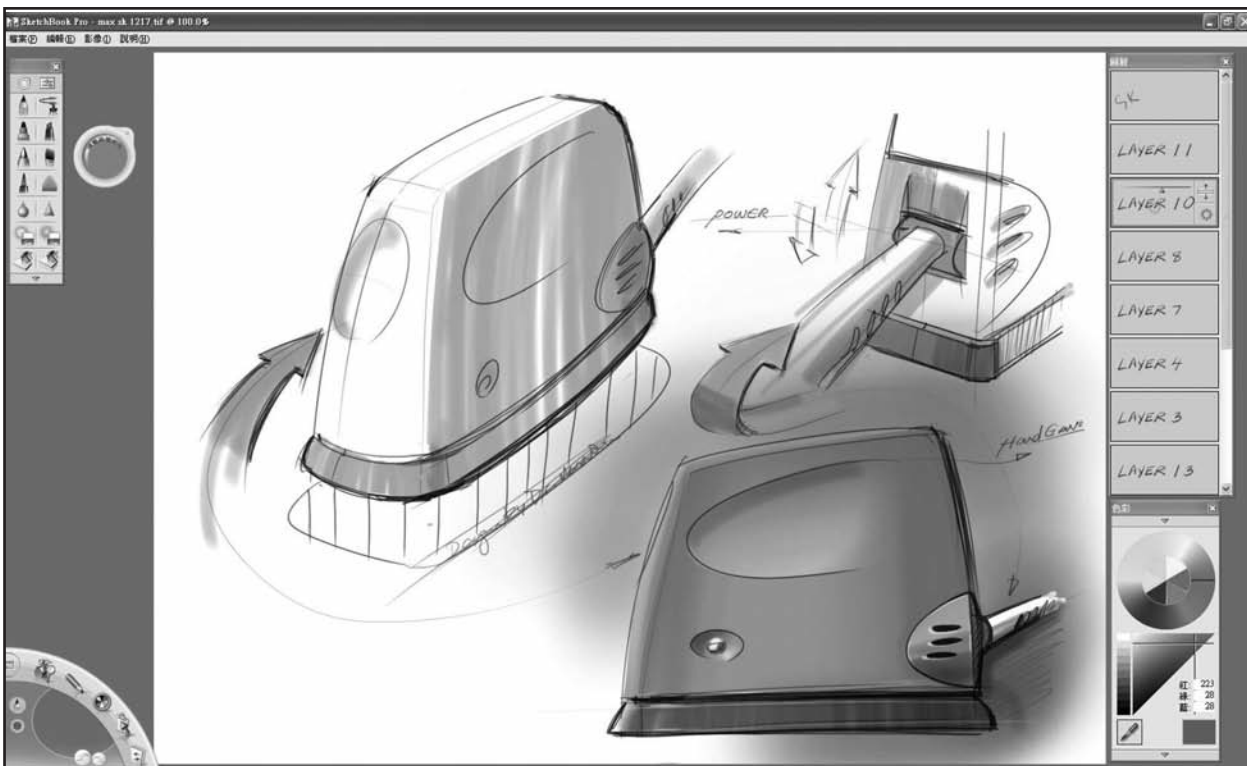# Comparison of Designer's Design Thinking Modes in Digital and Traditional Sketches

Figure 2. The interface of Autodesk Sketch Book Pro

better than digitalised environment in concept development. In light of this, it is more important whether the digital tools can reproduce the characteristics of traditional pen and paper sketches (Dijk, 1995).

Though the digital tools were considered not appropriate for the concept development in previous studies, scholars also pointed out that in the use of digital tools, there existed differences among designers (Bilda & Demirkan, 2003). Nowadays, Wacom interactive digital pen input system can provide ways to help with design concept development similar to those in the traditional pen and paper environment. In addition, because of the diversity and recording ability of software tools, the digital tools may have different impacts on the concept development from the simple pen and paper tools.

Graffiti input system and digital sketches

The digital sketch pen is the major medium in a Graffiti input system where designers can draw sketches freely in the computer environment. Such a system simulates the features and functions of pens and papers so as to reach the designer's intentions just like the traditional pen and paper system. Figure 1 illustrates a newly released Wacom interactive digital pen input screen. With the direct feelings of brush touches, the users can process their drawings on

the screen in an intuitive way. The supporting software for this interactive digital pen input system is Autodesk Sketch Book Pro, the interface of which is shown on figure 2. Such a system makes it possible for designers to select pen brushes, colours, upload and download pictures to assist their drawing tasks in design routines.

Protocol analysis

Protocol analysis has been applied in multiple scientific domains, especially in cognitive science and linguistics. In design research field, the technique of protocol analysis has been adopted to help analyse the designing activity (Cross, 2001; Gero & McNeill, 1998; Cross, Christiaans, & Dorst, 1996; Someren, Barnard, & Sandberg, 1994; Ericsson & Simon, 1993). According to Cross (2001), Protocol analysis is flexible in the analysis of the forming of design problems, the generation of solutions, and the usage of design strategy in design process. Protocol analysis is composed of the following steps: design hypothesis or observation trend, experimental task design, subject performs the task, generate materials in the experiment, specify the coding scheme, process content coding, analyse the coding, and infer possible conclusions (Ericsson & Simon, 1993; Gero & McNeill, 1998).

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According to the experimental procedure, there are two kinds of protocol analysis: concurrent probing and retrospective probing (Ericsson & Simon, 1993). The former gathers the subject's verbal data right on the task for analysis, one of which is the think aloud method; the latter collects the verbal data after the experimental task by recalling the behaviours the subject conducted in the task. For the completeness of the data representation, the audio & video retrospection is often adopted. Though these methods of protocol analysis vary, each of them is effective in the collection and analysis of the subject's individual course of action. The difference between concurrent probing and retrospective probing is that concurrent probing is often helpful for the studies whose focus is set on the design procedure and more precise in catching the episode phenomenon whereas retrospective probing is concentrated on the design content and offers clues for recall (Dorst & Dijkhuis, 1995).

Method
Experimental methodology and procedure
Four designers with more than three years of experience were invited in the experiment. Among them, three subjects were rich in the experience of digital pen input systems. These three subjects used the 19-inch Wacom interactive pen input system and Autodesk Sketch Book

Pro while one used the traditional pen and paper tools. The same design project was conducted for four subjects. Furthermore, video and audio of the design episodes in think aloud were taken down by video shooting. In the experiment, subjects first had a five minute warm up to get familiar with the think aloud procedure. After a short break, a forty five minute experiment was conducted. In the design task, subjects were asked to generate idea sketches for a portable MP3. In the limited time interval, they were asked to finish at least three or more complete conceptual designs. After the think aloud experiment, the subjects were asked to recall their behaviours by watching the video in the video/audio retrospection method. This compensates for the shortage of think aloud experiment.

Analytical method
With the data obtained, the authors process the coding for analysis according to the questions to explore in this study. To explore the features designers have in digitalised and traditional pen and paper environments and the influences two kinds of media have on designer's searching strategies for their design thinking, two coding modes: F-B-S and Fw-Bw were adopted.

F-B-S coding mode (Function, Behaviour, and Behaviour schemes) is primarily used to analyse the intentions

Coding Schemes of Problem Domain for Design Episode		
Function, Structure, and Behaviour		
Abbr.	Code Name	Descriptions
F	Function	The designer is reasoning the relations with the function aspects.
S	Structure	The designer is reasoning the relations with the structure aspects.
B	Behaviour	The designer is reasoning the relations with the behaviour aspects.
Depth levels of abstraction		
Abbr.	Code Name	Descriptions
R	Requirements	The designer is redefining or modifying the initial requirements.
0	System	The designer is considering the whole system.
1	Interactions	The designer is considering the interaction between the sub-systems.
2	Sub-systems	The designer is considering the details in a part of sub-systems.
3	Details	The designer is considering the detailed workings of a sub-system.

Table 1. The coding of problem domain used in the design episodes

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Coding Schemes of Micro Strategies for Design Episode		
Working Forward Strategy and Working Backward Strategy		
Abbr.	Code Name	Descriptions
Fw	Working Forward	The designer starts to search solutions form lower level of framework to higher one.
Bw	Working Backward	The designer starts to search solutions form higher level of framework to lower one.
	Strategy Continuing	It does not fill codes and keep blank when the designer does change the strategy.

Table 2. The coding of micro strategies used in the design episodes

designers have in dealing with the design problem domain. Two orthogonal dimensions for the representations reflected from the whole design behaviours can be divided into the intention of inference and the depth levels of inference. In the intention of inference, it is categorised into activities of function, structure, and behaviour. Activity of function refers to the intentions designers have for the inference of functional problems in the design project; activity of structure is the manipulation of the product structure and the hierarchical relationships among parts; activity of behaviour represents the actions designers have for the process or procedure in operating the product. On the other hand, the depth levels of abstraction of inference signify whether the designers are thinking about the whole product or only the details. The codes of five depth levels of inference and their descriptions are listed in Table 1.

Fw-Bw coding mode (Forward and Backward schemes), on the other hand, is used for the behaviours of designers in the search and manipulation of problem solutions, which can be seen as the manipulation of micro strategies. Based on the abstraction levels of F-S-B coding mode, if the problem solution starts from a higher level of abstraction (of smaller numerals) to a lower level of abstraction (of bigger numerals), it is a Forward working (Fw) strategy. If it is in an opposite direction, then it is considered a Backward working (Bw) strategy. The coding and descriptions for Fw-Bw mode are listed in Table 2.

Results and discussions
Briefing for the experimental procedure
Digital medium group
Designer A first manipulated the design layout in the holistic but in-depth concept for the project. With the features of digital medium, the concept of layers was used for the sketches. Initial concepts of fairly messy lines were first worked out for possible interface layouts, scales, and the whole product forms and styles. After a certain period of idea development, a more complete and delicate sketches were made by using the functions of "layer opacity effect" and "add a new layer". Moreover, the zooming function was used for the details in design. After he finished Idea a1(figure 3), Designer A made use of the interface in first concept, only changing the abstract total styles and worked out Idea a2 and Idea a3, two ideas totally different from Idea a1.

Designer B first defined the possible contexts, operations, and ways for place and carry along, from which the major interface designs were considered. Next, Designer B started the design of Idea b1 (figure 4). Similar to Designer A, Designer B manipulated the project in a holistic view with design depth in priority related layouts. With the concept of layers and undo function, the sketches were revised in a repetitive way. Obviously, Designer B put more emphasis on the relations among products, environment, and users. Therefore, he spent more time in the idea development for placing, holding, and carrying along in specific contexts. Therefore, the differences of sketches of Designer B's concepts lie in the relative differences of portability, placing, and holding while no remarkable differences are seen in the details of interface layouts (see Idea b2 and b3 in figure 3).

Designer C started the consideration of the project title and analysed the meaning of portability, video and audio and added his own definitions and conditions for the project. Moreover, Designer C took into consideration the differences among different users, for example, for the aging people, a holistic product concept in design thinking. In the beginning, Designer C got a specific holistic product concept and added design situations from his definitions of the projects. Furthermore, the protocol analysis of

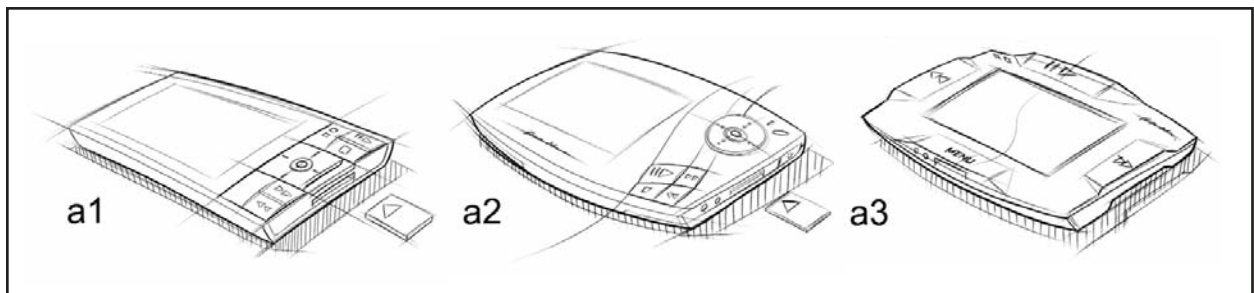# Comparison of Designer's Design Thinking Modes in Digital and Traditional Sketches

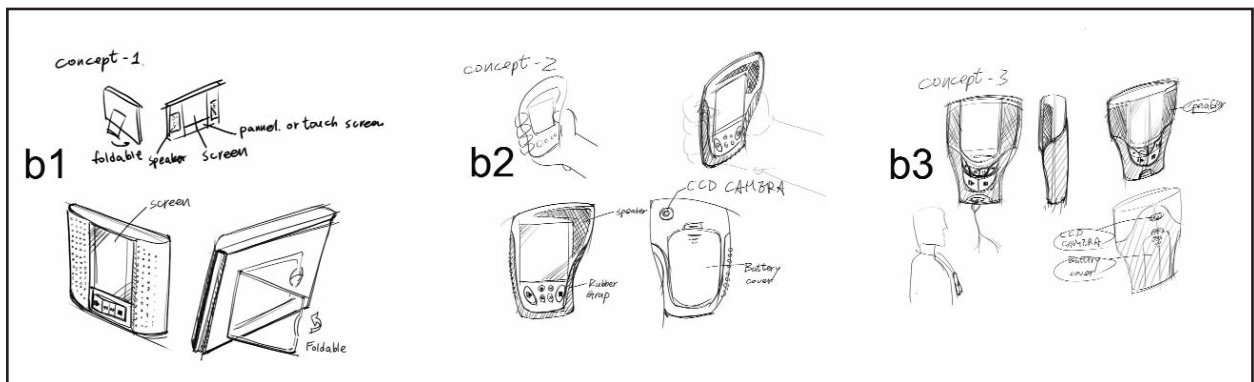*Figure 3. The idea sketches of Designer A in the experiment*

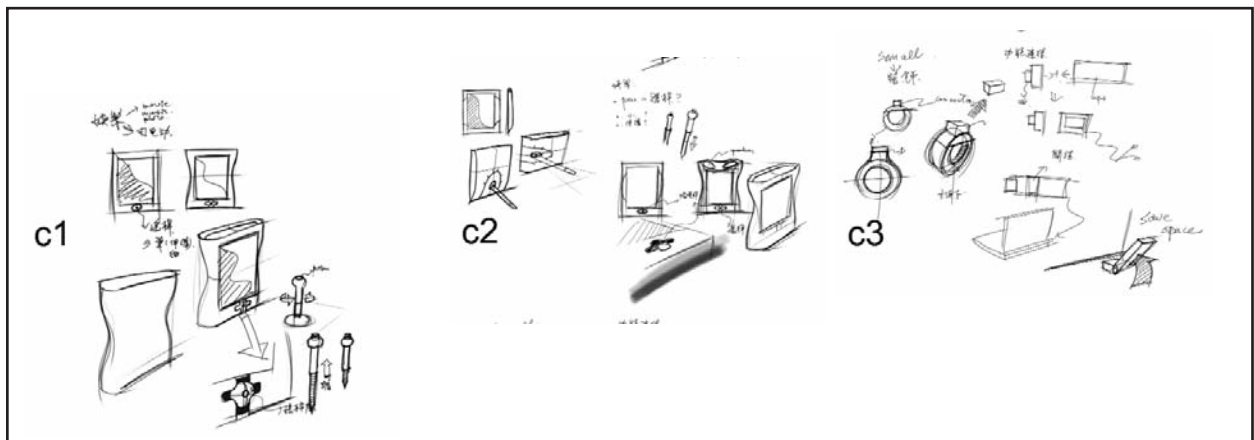*Figure 4. The idea sketches of Designer B in the experiment*

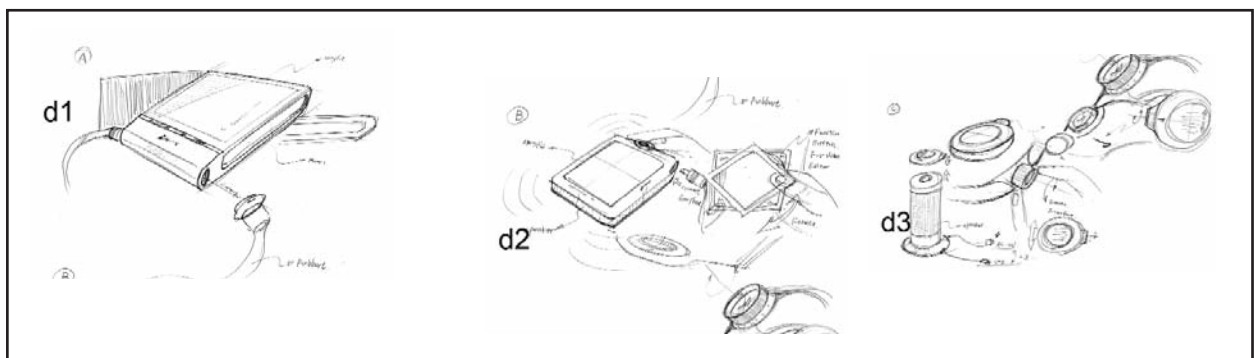*Figure 5. The idea sketches of Designer C in the experiment*

Figure 6. The idea sketches of Designer D in the experiment

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Designer C revealed that, in Designer C's first idea sketches, Idea c1(figure 5), he first thought about the entertaining features of the Audio/Video player. From this, he adjusted the product form and functions, resulting in a bigger screen. Later on, it was considered not suitable for a user to hold and watch a big screen in a long period of time. Then possible frame for placement and related integrations were manipulated for Idea c2 and Idea c3. Among three designers, Designer C was busier in the cyclic process. In the project, many design conditions were added after evaluations or revised. Therefore, some errors of scale in sketches could be seen and revised in Designer C. This was rare in Designer A and Designer B.

Traditional Medium Group
Designer D first considered the definition of portability as well as other convenient devices to connect. His first idea, Idea d1 featured the concept of a hi-tech style (see figure 6). In an in-depth holistic conceptual view, Designer D first manipulated the possible product forms, screen types, operational ways, portable carrying and textures. Then the connection methods and types were taken into consideration. The details of interface were then added with drawings and descriptive texts. From first Idea d1, Designer D worked out Idea d2 from the simplification of product form to a rectangular shape as well as a double layer interface design. Its operation seemed resplendent but not too complicated. Designer C spent a little more time manipulating the connection for the ear phone because he didn't take this into consideration in the beginning. In working on Idea d3, the concepts of shuttle and wrist watch were more innovative. Other devices such as the speaker, computer, and direct recharging source for the player were also considered. At last, Designer D placed three ideas on the table and inspected for further refining. For instance, in Idea d1, because the original idea was too square in shape, rounded corners were added for a better feeling in holding. Moreover, other details in Idea d1 were refined. In Idea d3, the original circular product form was revised to circles of eccentric centers to enhance the sense of layers in design.

The design thinking mode for designers in the digital medium group
The results of protocol analysis reveal that three designers (Designers A, B, C) in digital medium group use Fw design strategy for different ideas and the analysis of sub-problems in different hierarchies as well as related solutions to the design problem.

Designer A's searching policy in design thinking
In the design thinking of the whole design problem, Designer A started all of his three ideas from conceptual problems on level 0 abstraction, then developed into details on level 2 and level 3, and switched back and forth between levels 2 and 3, solving the sub-problems repeatedly (refer to figure 7). Protocol analysis showed that because Designer A was familiar with the design project and critical technology, he was pretty sure about the definition of the problem space in idea development, so that he could quickly decompose the design problem into sub-problems and solve them efficiently. Though he also adopted the backward searching policy for design problems not previously defined, the phenomenon was not frequently seen. This indicates that the designer's familiarity with knowledge and technology critical for design project will definitely influence the problem searching policy.

Designer B's searching policy in design thinking
After Designer B had set up the core design concept, further definitions for other serial sub-problems were
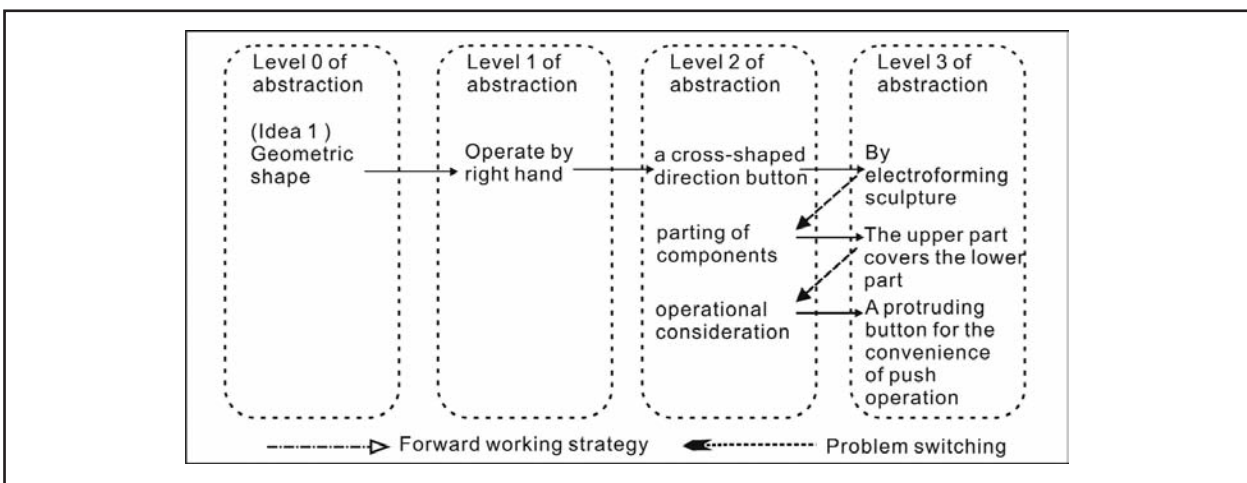
Figure 7. The procedure of the design strategy making of Designer A

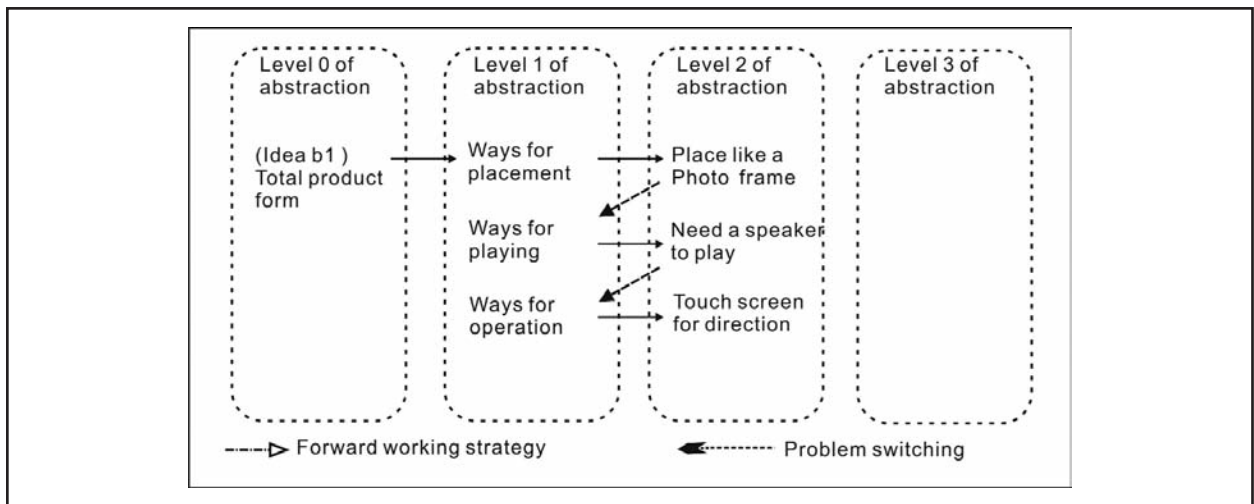# Comparison of Designer's Design Thinking Modes in Digital and Traditional Sketches

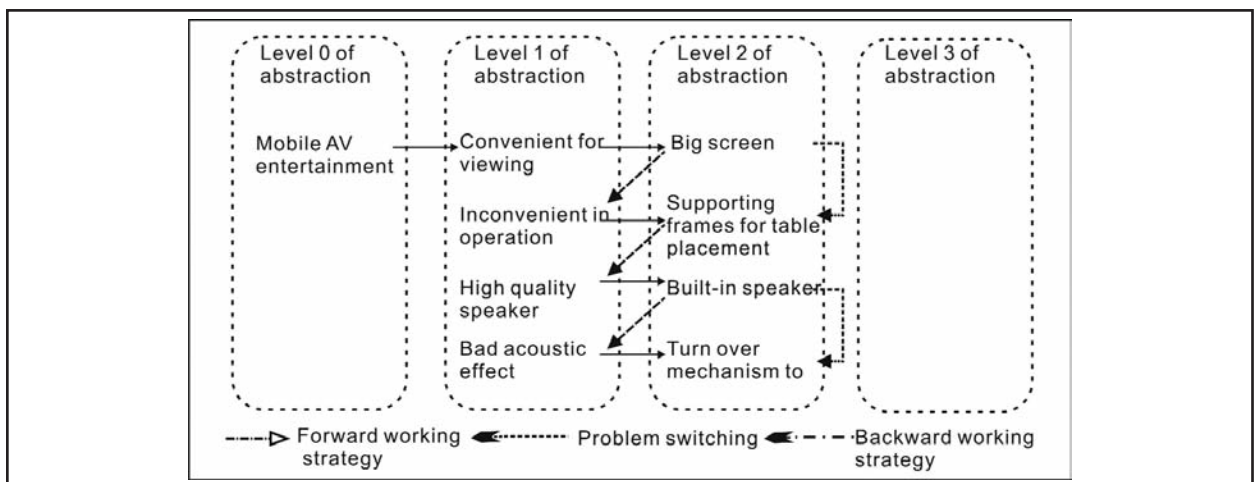*Figure 8. The procedure of the design strategy making of Designer B*

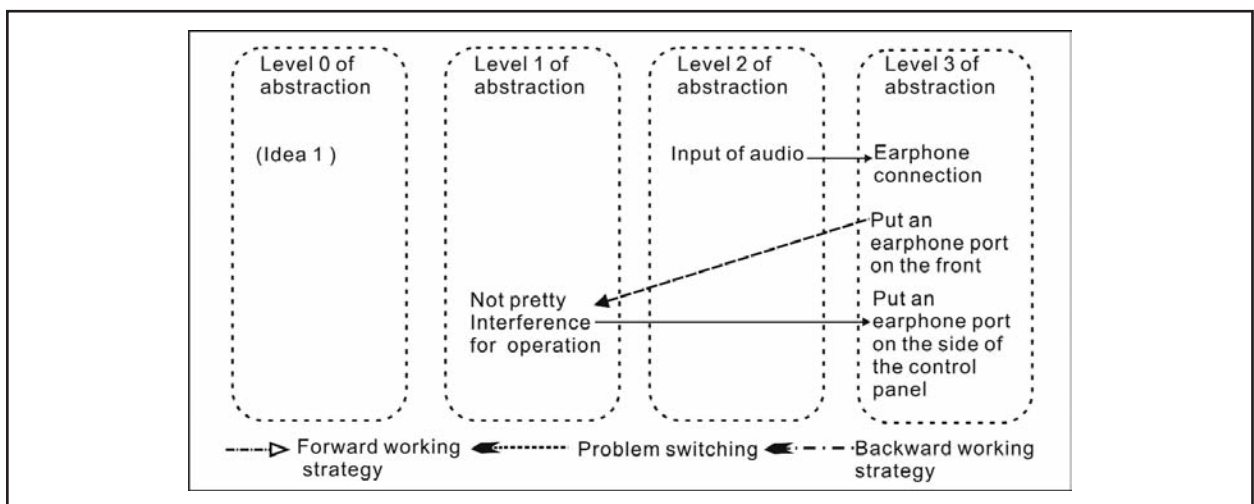*Figure 9. The procedure of the design strategy making of Designer C*

Figure 10. The procedure of the design strategy making of Designer D

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processed immediately at the same moment. One thing special for Designer B is that he first started his ideas from level 0, then developed into details on level 1 and level 2. Obviously, Designer B didn't reach the abstraction level 3 in defining the sub-problems. Therefore, he switched between two abstraction levels, level 1 and level 2 for the solutions to sub-problems (figure 8). The protocol analysis revealed that in most situations, Designer B adopted the forward searching policy for idea development; the backward policy was seen only in the reassessment of ideas while viewing his ideas. This may be due to the reason that some parts of the design problems were not clearly defined in the beginning, thus causing the backward searching policy to happen.

Designer C's searching policy in design thinking

Before idea development, Designer C was concerned about the AV problems, portability, and other functional conditions, which are design strategies of design breadth in higher priority. In developing the first idea, Designer C started from the previously set conditions but an evident phenomenon of Bw strategy could be found in his further development. For example, the original specification of big screen was taken into second thought due to the inconvenience in hand-holding operation and finally a support frame was added to set the MP3 on the desk (figure 9). Such kinds of conditions not set previously appeared and brought forth the backward working strategy for reconsideration, modification, or evaluation. This phenomenon may be partly due to the fact that Designer C's major was furniture design and the task was a project of 3C product design. Though Designer C had no problems in dealing with conceptual sketches and digital graphic tools, the subject was unable to subtly take into consideration the whole problem and other related design conditions because of limited techniques and know-how knowledge regarding the experiment, resulting in the frequently seen Bw thinking mode in making conceptual sketches.

The design thinking mode for designers in the traditional medium group

The thinking mode of Designer D was basically based upon the Fw design strategy. After the core concept was generated, his ideas started from level 0 or level 1 in degrees of abstraction on the basis of key technique and concept set on his own; then the design of details on level 2 and level 3 deployed. The situation of Bw design strategy happened only when Designer D was working on Idea 2 for the earphone port connection device (figure 10).

After Designer D finished three ideas, it could be seen that all ideas were put on the desk for the evaluation of strengths and weaknesses. Such kind of synthetic evaluation and revisions was not seen in digital tool group. After this, the detail design, form modification, auxiliary graphics and descriptions of Designer D showed many Bw design strategies. In these steps, the conditions were not previously set but refining of the ideas and supplementary details with sophisticated design methods. It can be seen a strategy to add the related design conditions.

Discussions
Design thinking modes for designers in digital medium group

(1) The protocol analyses and results of the study reveal that the building of a framework for the design problem is key to the effective development of design problems. Moreover, designer's familiarity with the critical technology and knowledge regarding the design project is essential to the effective framework of design problems. It is therefore easily to find that Designer A and Designer B could control the project in a more efficient way. With a more complete framework of design problems, they could organise their sketches in a more detailed and efficient way in developing ideas.

(2) With higher degrees of familiarity with critical technology and knowledge, Designer A and Designer B were evident in their forward working strategy. Backward working strategy, backing to lower abstraction level 0 or level 1, were rarely seen in these two designers. Relative to Designer A and Designer B, Designer C showed a much lower familiarity with the design problem due to his design profession domain and property of the design project. Without the support of technology and knowledge, a lot more backward working situations were found and Designer C repeated in considering, revising and evaluating the design concepts to accomplish his product characteristics.

Comparisons of designer's thinking modes in digital and traditional media
Similarities between designers of digital and traditional media

Compared with the traditional pen and paper environment, digital tools do not have a critical or more evident influence in the speed of idea generation and the control of solutions in concept development.

(1) As far as the searching policy of design problems is concerned, four designers are common in their strategy procedure as seen in figure 11. Though their design profession and media are different, they applied the same policy to search for the design problem. It can be inferred that experienced designers

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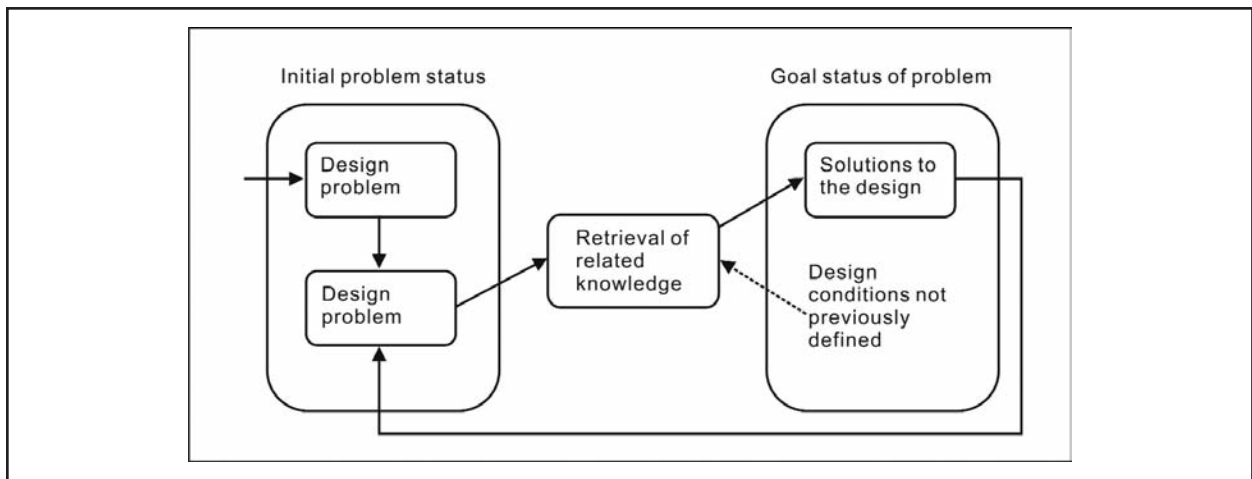

Figure 11. Strategic procedures for designers to search for design problems

have specific strategic procedures in dealing with design problems. Based upon the design problem, definitions rendered from their own knowledge and technical know-ow, designers can offer suitable solutions to the design problem.

(2) The priority order of problems designers adopt in design projects depends upon the critical technology and knowledge designers as well as the design characteristics they subjectively set for the new product. In other words, they will first try to solve the problems they fully understand or those that will have come out with special characteristics in their opinions. If designers have a better understanding of the design problem, the procedure of problem solution will be smoother. Accordingly, if they cannot have a good control of the critical technology and knowledge, they may find it troublesome if they insist to solve the design problems that will generate special characteristics. Without the assistance of corresponding technology and knowledge, a lot of backward working strategies will come out during the development of new product ideas, causing it more difficult for designers to deploy their idea development.

Differences between designers of traditional and digital media

Compared with the traditional pen and paper environment, However the differences in tool features cause apparent discrepancy in the detail development and consideration. Their differences are discussed from the function provided by media, transformation modes of concept development, and detail manipulation.

(1) Function provided by media: The digitalised environment can offer more integral function commands than does the traditional pen and paper environment. Therefore, in the procedure of sketches, digital tools can offer visual ambiguity other than lines, helping designers to find more possibilities in concept development. In addition, the "undo" and "redo" function helps a lot for designers to switch between different levels of abstraction.

(2) Transformation modes of concept development: Because of the features of media tools, designers under the digitalised environment are able to take advantage of the concepts of layer and duplication. They can compare the concepts on the semi-transparent upper and lower layers for a further extension of their concepts. On the other hand, designers in the traditional pen and paper environment will compare their ideas in an over view way in a big space to extend their concepts.

(3) Detail manipulation: Because there are no duplication or zoom in – out tools in traditional pen and paper environment, for the manipulation of details, designers need to redraw the detailed parts. On the paper, designers can compare and contrast ideas on different levels of abstraction. For designers in the digitalised environment, they can include all details in their ideas with the functional commands in the system, presenting a better completeness of design proposals.

From these discussions mentioned above, it is clear that though there exist differences between two media tools, they can offer different advantages for designers in idea development. Currently, the digital environment is getting mature and designers can choose to use pen and paper or digital tools for their idea sketches according to their characteristics and habits in concept development.

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Conclusions and suggestions
The design thinking modes of designers in applying digital medium

(1) The contents and delicacy of pen touches of three designers in digital tool group are similar to those in traditional pen and paper environment. It is, therefore, inferred that the digitalised environment can simulate the sketching procedure in traditional manual tools.

(2) In concept development, three designers in digital media group primarily adopt the forward working mode in searching for solutions to the design problem. Whether it is in a development mode with the priority of depth or of width of the design problem, designers build up their design problem structure by their technique and know-how as well as the design characteristics set by their subjective points of view. If designers can control the key technique and know-how, then they are more likely to adopt the Fw design strategy for the concept development; otherwise, if they are not sufficient enough in the control of the key technique and knowledge, it is more often to see the Bw design strategy during the concept development.

(3) The commands offered in digitalised environment can make it possible for designers to have in-depth consideration of the product details.

Comparison of designer's design thinking mode in using digital and traditional media

(1) It has been found in this study that designers have similar searching procedure in searching design strategy in applying digital and traditional media. The reason is probably that designers with years of experience have the same problem solving procedure in their design activity. No remarkable differences are found between different design tools or between design professions.

(2) With traditional design tools, designers cannot push their thinking of design problem to a higher degree of abstraction. In other words, because of the limited space on paper and no redo or modification of the pen touch, the sketches look messy. Moreover, designers who use traditional pen and paper cannot make the detailed design as efficiently as designers in digital tool group.

(3) Designers can process the comparison of ideas on different levels of abstraction due to the real-time over view feature in traditional sketches. Designers, therefore, can advantage of this feature on the synthetic transformation of concepts and idea

modification. In digital tool environment, such kind of feature is restricted due to the limit of system and equipment.

Suggestions

In this study, the differences of design thinking modes experienced designers have in using different media are explored. Whether the application of different tools has an impact on designer's creativity is not covered. However, the designer's creativity will indeed influence the problem solving and self-evaluation of the design problem. In addition, for the design thinking mode of designers, only searching strategy and decomposition strategy for design problem domain are explored in this study. In the future, the structural reorganisation of design problem and recombination of related design problems in design thinking can be further explored in the future.

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maxwu@hfu.edu.tw
fansichy@gmail.com
luckyguychen@gmail.com

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