Behaviors of Novice and Expert Designers in the Design Process: *From Discovery to Design*

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It is generally known that expert and novice designers work in different ways and also engage in different behavior during the design process. In order to have a better understanding of how they behave during the design process, the objective of this paper is to explore the differences between experts and novice behavior. A protocol method was adopted to examine the sequence of the design phases and design activities, along with the amount of time spent, the number and frequencies of occurrence, and also the frequencies of transition between phases. The results were revealed using a protocol analysis with sequence maps and quantitative data. We found different and similar design behaviors of experts and novices in the entire design process. No significant differences were found between the experts and the novices in terms of the general sequence and the total time spent on each phase during the design process. However, we did find differences in the early stage of the process which made an impact on the subsequent design behavior and performance. At the later stage of the process, the experts tended to stay in the design phase. On the other hand, more frequent transitions among the three phases were observed in novices during the later stage of the process which could be a result of needing to compensate the incompleteness in the previous phases. The outcomes of this paper provide insights for not only designers themselves but also for educators.

Keywords – Design Process, Design Behavior, Expert, Novice, Protocol Analysis.

Relevance to Design Practice – Studying the behavior that takes place in the design process can help designers better understand the interaction between themselves and the design. This can also lead to more efficient communication, cooperation, and educational strategies.

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Introduction

Design is a sequence of processes and the design elements are intended to meet the needs of the clients and provide company benefits. Browning (2018) mentioned that people who thoroughly understand the design process have advantages that increase their competitive edge. Thus, it is valuable for people to focus on the design process.

The earliest use of the term *design process* originated from the construction of battleships. After World War II, people found that the design process in engineering could be applied to other fields, so they tried to combine different models and theories. For example, Wynn and Clarkson (2005) combined the design process in the engineering field, using the creative design process to develop a complete model. The theories proposed by various researchers have been different. Love (2000), Bender et al. (2002) and Dorst (2008) all suggested that models are not comprehensive enough. They suggested that the design process should help people understand the design situation thoroughly and should be combined with commercial activity. Therefore, Green et al. (2014) proposed an interim design ontology in their research. They established the hierarchy of the design process, clearly describing the phases and hierarchy, so that the designer or executor could study specific content.

Many studies have pointed out that there are differences between novices and experts, including efficiency, output, strategies, and methods. Experts are often better than novices in their professional fields (Chi et al., 2013). Cross (2004) pointed out that designers with good design performance tend to repeat their design behavior, but the actual situation still requires further exploration. Furthermore, a designer's implementation of the design process may vary based on experience and ability. Understanding the design process and design behavior may help distinguish the differences between novices and the experts.

The Development of the Design Process

Design is considered an indispensable element in the creative industry and in new product development (Jerrard & Husband, 1999; Von Stamm, 2008). The design process determines the quality of a product. If designers want to improve a product, they also need to improve their design process because the better the design process is, the better the product will be (Chapman, 2006). There are many similarities between different design processes

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(Howard et al., 2008) However, Blessing and Chakrabarti (2009), and Dorst (2008) pointed out that the current design process lacks comprehensiveness. Therefore, Green et al. (2014) proposed several principles based on a revision of Wang and Ilhan's theory (2009). They proposed the interim design ontology based on the above principles and visualized it, as shown in Figure 1.

In the interim design ontology, the design process is divided into five phases: Discovery, Definition, Design, Develop, and Deliver, which is called the 5D model and has been summarized by Dubberly (2005). Compared with the widely used 4D model proposed by the Design Council (2015), the 5D model has an independent design phase that is included as a clearly identifiable activity, such as sketching, form design, etc. All the phases in the 5D model can be defined and differentiated from one another. This design process model was proposed clearly and comprehensively.

In many studies, it has been established that design is not a simple linear process. For example, design behavior involves repeated back-and-forth transitions between divergent and convergent thinking that occurs in all design processes (Green et al., 2014; Lewrick et al., 2018). Cross (2008) also proposed that design is a process of evaluation and communication, which is an iterative process.

In this study, the first three phases of the interim design ontology: Discovery, Definition, and Design were used as the experimental model to evaluate a designer's design behavior in terms of Path and Design Activity. The first reason for that was that this model may help students better understand how the design process works (Green et al., 2014). In this model, *Path* refers to the way that designers executed these five phases. *Design behavior* refers to the actions taken in the design process, so the *design behavior* includes all the behaviors taking place during the interim design ontology process. In addition, this study examines the short-term design behavior, rather than a long-term research plan. Similar to other design models, the Develop phase and Deliver phase in the 5D model have to be implemented over a long time frame, which often involves manufacturing and commercial activities. Thus, these two phases were beyond the scope of our research. With the exception of these two phases, this model included the Design phase and therefore was appropriate for observing a short-term design task. This was the second reason for applying the 5D model in this study.

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Expert and Novice Designers

Experts are individuals who have acquired knowledge in a specific professional field through long-term experience or training (Chi et al., 1981). Macnamara and Maitra (2019) believe that experts need to invest in their professional fields for at least 10 years. Chi et al. (1981) mentioned that novices and experts have different problem-solving abilities. Because the ability of the problem solvers is different, the problem-solving process is also different (Smith, 1991). It can thus be inferred that the solution process of experts and novices may also be different. In terms of dealing with well-defined problems, such as those in the fields of physics and geometry, studies (Anderson et al., 2013; Larkin, 1981) have indicated that novices tend to adopt working-backward and depth-first search strategies, while experts prefer to use working-forward and breadth-first search strategies for problem-solving. However, when dealing with ill-defined or difficult problems, such as design issues, a mixture of working both forward and backward occur more often. (Ho, 2001; Mitchell, 1990)

In the early stages of the design process, the behavior of experts and novices is already different. Christiaans and Dorst (1992) reported that both junior and senior industrial design students get stuck in the information gathering process; however, the junior students generally gathered less information and were aware of fewer potential criteria and difficulties that might be encountered. Compared to the group of senior students, who gathered lots of information, another group of seniors requested less information, formulated the structure of the problem early, and consciously obtained better solutions in terms of creativity (Cross et al., 1994). Atman et al. (1999) also pointed out that junior engineering students typically spent a large proportion of their time defining the problem, but the quality of their final designs was insufficient. In contrast, the senior engineering students paid more attention to the scope of problems by collecting more information, considering more possible solutions, and transferring more frequently between design steps and activities before progressing into the final design stage, in turn achieving significantly better design results. Although some studies (Atman, 2019; Atman et al., 2007; Brand-Gruwel et al., 2005) reported that experts spend more time on information gathering and defining problems. They emphasized that defining the scope of problems and information gathering are major differences between experts and novices.

The above-mentioned findings were echoed in other studies. Experts prefer to represent the structure of a problem in their own way at the beginning of a task, while novices tend to eliminate problems that they cannot deal with (Ho, 2001). Schön (1988) said "In order to formulate a design problem to be solved, the designer must frame a problematic design situation: set its

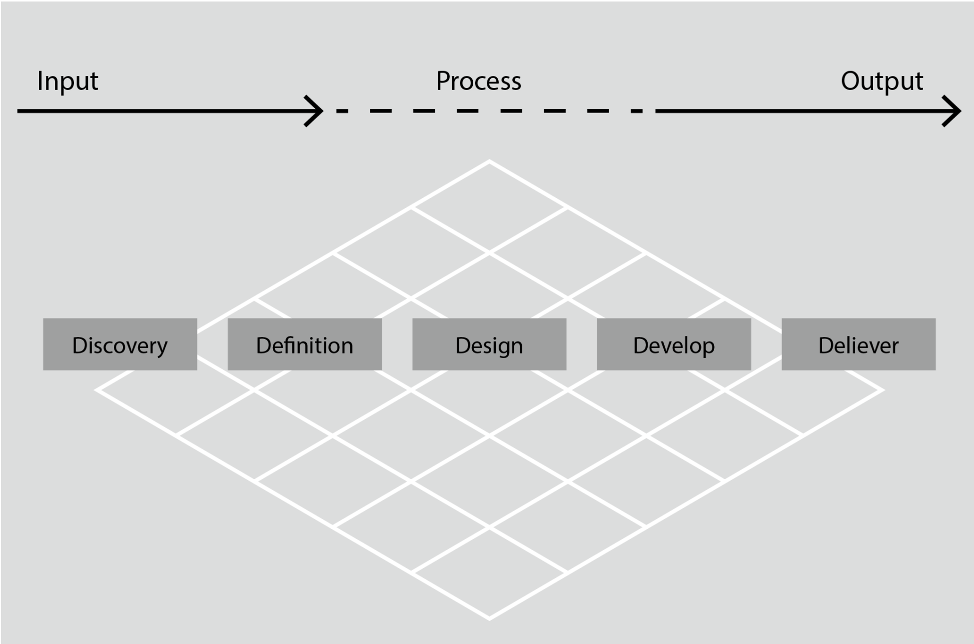

Figure 1. Visualization of the interim design ontology (Green et al., 2014; redrawn and simplified by the authors.)

boundaries, select particular things and relations for attention, and impose on the situation a coherence that guides subsequent moves" (pp. 181-190). In addition, the activities involved in *problem structuring* play an important role not only at the beginning of the design process, but also occur periodically throughout the entire design process (Goel & Pirolli, 1992; Schön, 1988). Cross (2004) concluded that "successful design behaviour is based not on extensive problem analysis, but on adequate 'problem scoping' and on a focused or directed approach to gathering problem information and prioritising criteria" (pp. 427-441). Therefore, one of the key characteristics of expert designers may not be how much time they spent on information-gathering, problem-analysis, or problem-defining, but how they deal with problems.

The other strategy worth noting used by expert designers for problem-solving is that they rapidly generate and evaluate solutions at the beginning of the design process. Lloyd and Scott (1994) reported that, in order to approach a design task, more experienced designers tend to adopt generative reasoning and propose solution predictions in the very early stages of the design process based on their prior specific experiences. They then combine these solution predictions together with other design activities in order to discover, define, and generate final designs. Ahmed et al. (2003) also indicated similar results when comparing novice and experienced designers in the field of engineering. They found that novices prefer to adopt a *trial and error approach* to carry out the design process. That is, they generate, implement, and evaluate one solution, then generate another, and iterate this process again and again. In contrast, experienced designers make a preliminary evaluation earlier in their initial decision-making process before proceeding to subsequent stages, such as implementation and final evaluations.

The literature above have all indicated differences between experts and novices when they deal with an ill-defined problem. However, there are still issues on both sides worth discussing, such as activities sequences, and different and similar patterns of behavior that take place during the design process. The research objectives of this study were to explore the behavioral differences between novices and experts in the implementation of the design process and to summarize their behavioral patterns. Therefore, we focused on less/more experienced designers and attempted to answer the following research questions (RQ):

- RQ1. How do designers execute the different phases of design and activities in sequence?
- RQ2. What is their level of performance and investment in each phase of a design?
- RQ3. What are the differences in the behavior of novices and experts in the design process?

In order to explore these research questions, the following three types of indicators are discussed to compare the path of designers and to understand the actual behavior and the focuses of designers: (1) the sequence of phases and activities, (2) the occurrence and the frequency of transition between phases, (3) the occurrence, frequency, and time spent during the phases and various activities. In this study, the term of occurrences is defined as how many times each phase, activity, and transition between phases occurred in the entire design process. Time spent refers to the length of time for each phase and activity. Transition between phases refers to the switching of phases, i.e., from discovery phase to definition phase or from definition back to discovery. We posit that the first and second type of indicators corresponding to the RQ1 and the RQ2 are affected by the third indicator.

Methodology

The thinking-aloud method was adopted for the experiment, and the data were examined separately using qualitative and quantitative analyses.

Participant Recruitment

Initially five experts and five novices were recruited. However, one of the experts had become a senior product manager and was no longer involved in such things as drawing and 3D modeling of designs. Because of his very different background in professional design, we decided to remove his data for the subsequent analysis in this study (Table 1). To be enrolled in the study, experts were required to have more than ten years of working experience in the product design field. The novices were third-year college students majoring in product design who had completed more than four design projects or had finished their internship.

Experiment Design

Experiment Procedure

The experiment was divided into three steps:

- Step 1: Warm-up practice. This step allowed the participants to understand and familiarize themselves with the Think-aloud method to reduce the gap between expression and thought. The project in this step was to design a USB flash drive for office workers.
- Step 2: Formal Think-aloud experiment. The participants were asked to complete a task with the Think-aloud method. The experiment was conducted in a laboratory to ensure that there were no interruptions. The topic of the task was an alarm design for hearing-impaired People. This product was aimed at a specific target group, so the requirements for the research were clear and the participants could clearly understand the goal of the task. Thus, they could not skip the discovery and definition phases. In addition, because an alarm is a common item that most people are familiar with, extreme variations in the design could be avoided due to misunderstandings. The experiment lasted around sixty minutes, but was limited to no more than one hundred minutes or less than forty minutes.
- Step 3: Retrospective interview. In terms of the gap between expression and thought, which is a limitation of the Think-aloud method, the interview could help make up for any possible issues. This method also helped the researcher gain a better understanding of the reasons behind the behavior.

Experimental Tools

The experiment was conducted with two cameras and one voice recorder to record the videos, images, and verbal data. This set of tools was the same as that used in previous research (Kim & Ryu, 2014). A computer, white drawing paper, and drawing utensils were provided for the participants during the experiment. The experimental setting is shown in Figure 2.

In this study we observed the design behavior in the first three phases in the 5D model, and the protocol analysis was conducted using three coding schemes. For the purpose of precisely observing and evaluating the details for each phase, the coding scheme for the discovery phase followed that used by Gero and Neill (1998) ; Kim and Ryu (2014)'s scheme was followed for the definition phase, and the coding scheme from Chen and You (2006) and Suwa and Tversky (1997) was followed for the design phase, as shown in Table 2.

In this research, the data collection and protocol analysis were conducted independently by the two coders who were experienced in design research. In order to check the inter-reliability of the coding for each participant, Cohen's Kappa was used to test the consistency between the two coders. The results of Cohen's Kappa for all participants were higher than 0.8. To a large extent, the inter-reliability between the two coders was consistent. The different coding between them was discussed and checked, and then the differences were combined for subsequent analysis.

Table 1. Participant Characteristics.

	Gender	Age	Experience	Career
Expert 1 (E1)	M	37	13 years	product designer
Expert 2 (E2)	M	37	15 years	
Expert 3 (E3)	F	33	10 years	
Expert 4 (E4)	M	38	14 years	
Novice 1 (N1)	F	22	3 years	junior student
Novice 2 (N2)	M	23	3 years	
Novice 3 (N3)	M	22	3 years	
Novice 4 (N4)	M	21	3 years	
Novice5 (N5)	F	23	3 years	

Figure 2. Experimental setting: (a) front view; (b) second view from a camera.

Table 2. Coding scheme of phases and activities.

Code	Phase	Code	Activity	Example
Dc	Discovery (Gero & Mc Neill, 1998)	Ap	Analyzing the problem	"What is the system going to need to do…."
		Cp	Consulting information about the problem	"The brief says it has to be light and…."
		Ep	Evaluating the problem	"That's an important requirement…."
		Pp	Postponing analysis of the problem	"I don't think I can do it now, I will find it later."
Df	Definition (Kim & Ryu, 2014)	Re	Retrieval of functional description	"This function should be applied to…."
		Rf	Retrieval of form description	"I want the surface to look simple and soft…."
		Rs	Retrieval of semantic description	"The product should be delightful, convenient and…."
		Aa	Analogy	"It is just like the chair designed by…."
Ds	Design (Chen & You, 2006; Suwa & Tversky, 1997)	Cr	Creating and revising figure	"I am now sketching the upper lid…."
		Sw	Creating symbols and words	"So I write down the features of this product…."
		Ms	Moving the same object	"I will keep drawing to make this look better until…."

Table 3. Example of protocols coded for Expert 1.

Start time	End time	Transcript	Remark	Design phase	Activity
00:00	05:53	When I receive a design project, I usually first create an overall picture for myself as soon as possible. This picture helps me to organize the following design steps and strategies.	thinking and notes making	Dc	Ap
05:53	06:48	I am not familiar with hearing-impaired people. I have to find some important information in internet.	information collecting	Dc	Cp
06:48	10:45	I am still trying to understand and analyze the design goal.	thinking and notes making	Dc	Ap

In addition to the protocol analysis, because of the very small sample size, the Mann-Whitney U Test was used to test the differences between the experts and novices as a supplement to the results of the qualitative research. In the statistical test, experts and novices were the two factors for the Mann-Whitney U Test, and the independent variables included three categories: occurrences, time spent, and transfer between phases. Occurrences refers to how many times each phase and activity occurred in the entire design process. The variables included the number and frequency of events during each phase and activity. Time spent represented the length of time for each phase and activity. The variables included the time spent in seconds for each phase and activity and as a percentage of the whole design process. Transition between phases referred to the switching of phases. When the phase switch followed the general sequence of the design process, i.e., discovery, definition, and then design, it was marked as a forward transition. On the contrary, when the switch went inversely, e.g., went from definition back to discovery, it was considered to be a backward transition. The variables included the number of switches and the frequency of forward and back transitions.

Results

Sequence of Phases in the Design Process

The first research question in this research involved exploring the differences in the order of execution on the part of novices and experts in the design process. Figure 3 shows this sequence in the execution of the discovery phase (Dc), definition phase (Df), and design phase (Ds). The vertical axis in the chart represents the three phases, and the horizontal axis is time. It was found that regardless of whether it was an expert or a novice, the entire process started from the discovery phase, followed by the definition and the design phase. The difference between the novices and the experts is that the experts finished the design process within a certain length of time in the design phase. As shown in Figure 3, most of the design phases for both the experts and the novices were not continuous, but the experts could maintain a longer period of constant design activities (green line in Figure 3) toward the end of the entire process. This finding was identical with the results of the Mann-Whitney U Test (Table 4). In the design phase, the longest duration of the constant design activity (green line in Figure 3) of the experts (976 sec.) was significantly longer than the novices (446 sec.).

With the exception of E1, the other experts had entered the design phase in the first half of the entire design process. On the contrary, most novices started the design phase in or after the

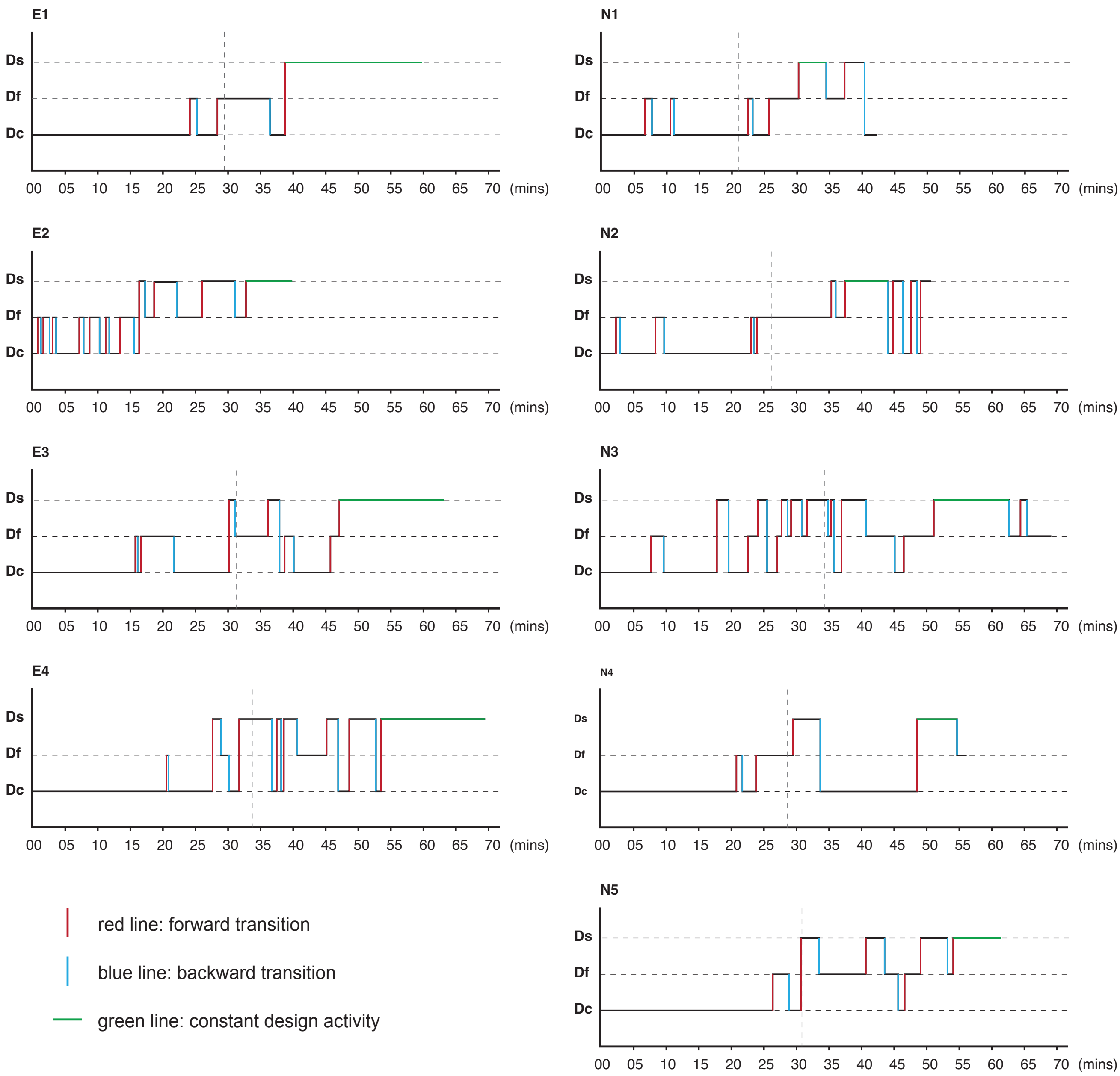

Figure 3. Sequence of phases by experts (left) **and novices** (right)**.**

middle of the entire design process except N3. Compared to the other participants, E2, E3, E4, and N3 arrived at the design phase relatively earlier and performed phases transitions between design and the other two phases in the first half of the design process. E2 moved a few times between the design phase and the definition phase while sketching, and arrived at clearer definitions of the product at the same time. N3 persistently changed multiple times among all three phases, and finally ended with the definition phase. In terms of the sequential performance of the phases, although both groups had repetitions, the time points at which repetitions occurred and the phases they occurred in were different.

The transition between phases is also shown in Figure 3. For example, E1 transferred forward (red line in Figure 3) from the discovery phase to the definition phase two times, from the discovery phase to the design phase once, and backward (blue line in Figure 3) from the definition phase to the discovery phase two times. The results of the Mann-Whitney U Test for the transition between phases are shown in Table 5. Two outcomes are worth noting for further discussion. First, the difference between the experts and novices in the frequency of backward transitions in the first half of the entire design process was nearly significant ($p = 0.06$), where experts (57%) exhibited a higher frequency than novices (35%). Similarly, before the constant design activity in the design phase occurred (before reaching the green line in Figure 3), the difference between the experts and novices in the frequency of backward transitions was also nearly significant ($p = 0.06$). The experts (100%) exhibited a higher transition frequency than the novices (74%). In other words, when the constant design activity occurred, the experts longer transited backward to the other phases.

Table 4. Result of Mann-Whitney U Test for the duration of the constant design activity in design phase.

	Experts (N = 4)		Novices (N = 5)		U	z	p
	M	SD	M	SD			
Duration of the constant design activity (min:sec)	976.00 (16:16)	342.23	446.00 (7:26)	155.99	1	-2.21	0.03

Table 5. Results of Mann-Whitney U Test for transitions between phases.

			Experts (N = 4)		Novices (N = 5)		U	z	p
			M	SD	M	SD			
Forward-transition	Total forward-transition times		7.25	3.30	7.60	3.50	10.00	0	1
	Discovery to Definition	Times	3.50	2.65	3.20	1.10	9.50	-0.13	0.91
		Frequency	50%	.25	45%	.15	7.50	-0.62	0.56
	Definition to Design	Times	1.50	1.29	3.00	2.35	6.00	-1.01	0.41
		Frequency	17%	.14	37%	.15	4.00	-1.47	0.19
	Discovery to Design	Times	2.25	2.50	1.40	1.14	9.00	-0.27	0.91
		Frequency	33%	.30	18%	.12	8.50	-0.37	0.73
Backward-transition	Total backward-transition times		6.25	3.51	6.20	3.03	10.00	0	1
	Definition back to Discovery	Times	3.50	2.38	2.20	0.84	7.00	-0.78	0.56
		Frequency	64%	0.31	39%	0.15	4.50	-1.35	0.19
	Design back to Definition	Times	1.50	1.29	2.40	2.19	8.00	-0.51	0.73
		Frequency	19%	0.13	36%	0.21	5.50	-1.11	0.29
	Design back to Discovery	Times	1.25	1.89	1.60	1.34	8.00	-0.51	0.73
		Frequency	18%	0.24	25%	0.16	7.50	-0.63	0.56
	In the first half of the entire design process	Times	3.75	2.99	2.40	1.67	7.00	-0.76	0.56
		Frequency	57%	0.18	35%	0.09	2.00	-1.96	0.06
	Before the constant design activity	Times	6.25	3.50	4.60	2.70	7.00	-0.74	0.56
		Frequency	100%	0.00	74%	0.17	2.00	-2.15	0.06

Investment in the Design Process

In order to determine the investment in each design phase, occurrences and time spent were used as indicators. The results of the Mann-Whitney U test are shown in Table 6 and Table 7. However, none of the analyses revealed significance in terms of occurrence and time spent.

Generally speaking, in the entire design process, the average occurrence times in all phases were higher on the part of the novices (16.2 times) as compared to the experts (14.5 times, see Table 6). The average occurrence times in the discovery phase were 5.75 times for the experts and 4.8 times for the novices (Table 6). Both the experts and novices spent nearly half of their time in this phase (Table 7). In the definition phase, the amount of time spent by the novices was higher than that spent by the experts. In terms of the design phase, the number of the average occurrence times from the novices was higher than the experts (Table 6), but the experts spent more time in this phase than the novices (Table 7).

Detailed Activities in Each Phase

In this section, a more in-depth discussion on the design behavior in each phase is provided. Figure 4 and Figure 5 respectively show the design activities carried out by the experts and novices in the different design phases. These activities were used to observe the behavior of the participants in each phase.

As Figure 4 shows, all of the experts started the entire design process from the discovery phase. In this phase, apart from E4, the design activities of the other three experts started with analyzing the problem (Ap). In the first half of the discovery phase, it was observed that most of the experts were repeatedly analyzing the problem, consulting information about the problem (Cp), and evaluating the problem (Ep). When they reached one-third of the design process, they returned to consulting information about the problem. When looking at the novices in Figure 5, we see that they, similar to the experts, started by analyzing the problem in the discovery phase. However, only two novices (N3 & N5) started to evaluate the problem at the beginning of the design process. N2 and N4 evaluated the problem relatively late, and N1 did not evaluate the problem at all. N3 and N5 went back and forth between consulting information about the problem and evaluating the problem repeatedly early after starting the design process, but the experts changed between analyzing the problem and consulting information about the problem more often. It is worth noting that the duration of the constant design activity in design phase from N3 and N5 were longer than the other novices. In addition, when there was a need to postpone analysis of the problem (Pp), E2 and E4 did so for a short time early in the process and not in a disorganized manner, while N4 started postponing analysis of the problem in the middle or much later, which also took a long and continuous amount of time.

Table 6. Results of the Mann-Whitney U Test for occurrences in all phases.

		Experts (*N* = 4)		Novices (*N* = 5)		*U*	*z*	*p*
		M	*SD*	*M*	*SD*			
Total occurrence times		14.50	6.76	16.20	5.36	9.50	-0.12	0.91
Discovery phase (Dc)	Times	5.75	2.22	4.80	1.79	7.00	-0.75	0.56
	Frequency	47%	0.08	43%	0.08	6.00	-0.98	0.41
Definition phase (Df)	Times	5.00	3.56	5.60	2.61	7.50	-0.65	0.56
	Frequency	30%	0.13	36%	0.06	7.00	-0.74	0.56
Design phase (Ds)	Times	3.75	2.50	4.40	2.88	8.50	-0.37	0.73
	Frequency	23%	0.08	21%	0.07	8.50	-0.37	0.73

Table 7. Results of the Mann-Whitney U Test for time spent in all phases.

		Experts (*N* = 4)		Novices (*N* = 5)		*U*	*z*	*p*
		M	*SD*	*M*	*SD*			
Total time spent (min:sec)		3433.75 (57:13)	838.19	3362.80 (56:02)	599.10	8.00	-0.49	0.73
Discovery phase (Dc)	Time spent (sec.) (min:sec)	1574.25 (26:14)	607.11	1682.80 (28:02)	361.94	9.00	-0.25	0.91
	Percentage	44%	0.10	51%	0.13	5.00	-1.23	0.29
Definition phase (Df)	Time spent (sec.) (min:sec)	555.00 (9:15)	162.64	799.80 (13:19)	285.24	4.00	-1.47	0.19
	Percentage	18%	0.11	24%	0.06	7.00	-0.74	0.56
Design phase (Ds)	Time spent (sec.) (min:sec)	1304.50 (21:44)	451.11	880.20 (14:40)	463.48	4.00	-1.47	0.19
	Percentage	38%	0.06	25%	0.09	3.00	-1.72	0.11

In the definition phase, the experts and novices exhibited similar activities. Most of the participants—three experts and four novices—first defined the semantics (Rs), then defined the functionality (Re), and finally defined the form of the product (Rf); moreover, the participants did not necessarily make an analogy (Aa) during the process. In addition, it is clear from Figure 4 and Figure 5 that compared to the novices, when the experts made their first definition, the time spent was usually short and not continuous.

Figure 4. Sequence of design activities by the four experts.

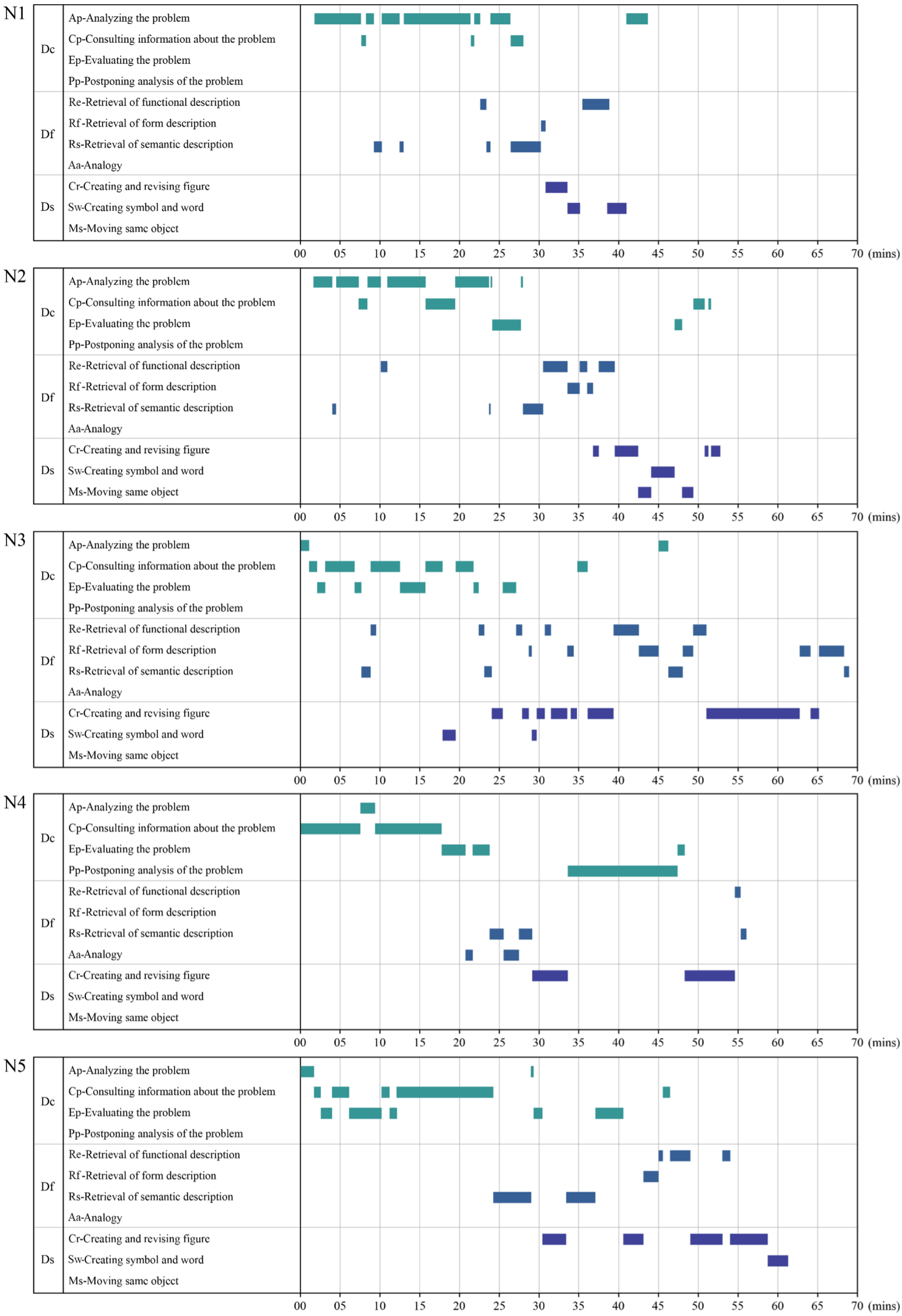

Figure 5. Sequence of design activities by the five novices.

In the design phase, as Figure 4 and Figure 5 show, all participants spent the most time on creating and revising the figure (Cr). After finishing most of the sketching, three of the experts spent additional time on the “moving same object” (Ms) activity, but only N2 carried out this activity. While most of the four experts ended their design process with creating and revising the figure (Cr) in the design phase, only one novice finished the design process in the design phase. The other four novices moved back to the other phases and ended the whole design process with different activities, such as analyzing the problem (Ap), consulting information about the problem (Cp) in the discovery phase, and retrieving semantic description (Rs) in the definition phase. The novices tended to iterate repeatedly in the design phase, and they could not maintain constant and long-term design activities.

Summary of the Results

All the research findings are summarized in Table 8. We found similarities and differences between the experts and the novices during the entire design process. Regardless of the experience level—experts or novices—their sequence in the design process was very similar. Nevertheless, slightly different behaviors were observed in the three phases.

First, according to the nearly significant result from the Mann-Whitney U Test for the backward transitions between phases, with the experts showing a higher frequency than the novices in the first half of the entire design process before entering the constant design activity. Second, in the discovery phase we found differences between the experts and the novices in handling problems such as

Table 8. Summary of the results.

		Experts	Novices
Entire	Sequence of phases	1. Discovery phase, 2. Definition phase, and 3. Design phase	
	Entire process end	With the design phase	With the different phases and activities
Discovery Phase (Dc)	Begin with	Analyzing the problem (3 experts and 4 novices)	
	Key activities	The following behaviors repeatedly occurred: analyzing the problem (ap), consulting information about the problem (cp), and evaluating the problem (ep)	
	Analyzing the problem (ap)	Persistently intertwined with consulting information about the problem (cp) before half of the entire process	Stopped later and did this in a relatively disorganized manner
	Evaluating the problem (ep)	Occurred upon reaching one-third of the entire design process	• N3 and n5 began evaluating the problem (ep) very early and went back and forth between consulting information (cp) about the problem and evaluating the problem (ep) • N2 and n4 evaluated the problem (ep) late and n1 never did it
		The duration of constant design activity from the participants (n3, n5, and all experts) who did ep earlier was longer than the other participants (n1, n2, and n4)	
	Postponing analysis of the problem (pp)	Short but earlier	Long, continuous time and later (only n4)
Definition Phase (Df)	Sequence in definition phase (df)	1. Retrieval of semantic description, 2. Retrieval of functional description, and 3. Retrieval of form description	
	First time-spent for definition	Shorter	Longer
Design Phase (Ds)	Key activities	Creating and revising the figure	
	Begin	Before the middle of the entire process (3 experts)	On/after the middle of the entire process (4 novices)
	Patterns	Maintained constant and long-term activities	Iterated with other phases repeatedly
	After the constant design activity	No longer transferred back to other phases	Transferred between phases continually
	Activity at the end	Creating and revising the figure (3 experts)	Different phases and activities
Mann-Whitney U Test	Overall	Most results were not significant.	
	Constant design activity	Significantly longer: 976 sec. (16:16)	Significantly shorter:446 sec. (7:26)
	In the first half of the design process (nearly significant)	Higher frequency of backward transition between phases (57%)	Lower frequency of backward transition between phases (35%)
	Before the constant design activity occurred (nearly significant)	Higher frequency of backward transition between phases (100%)	Lower frequency of backward transition between phases (74%)

the methods used in analyzing (Ap) and evaluating (Ep) the problem. It is noteworthy that evaluating the problem is most likely an important activity for the design phase, because the participants who evaluated the problem early also had a longer duration of constant design activity. Finally, the differences between the two groups were particularly significant in the design phase, especially toward the end of the entire design process. In comparison to the novices, the experts started the design phase early, maintained constant and long-period activities, had no frequent transitions back to the other phases after their constant design activity began, spent longer time on constant design activities, and ended the whole process with the design phase.

Discussion

In this study, we found few differences between the four experts and five novices using only the indicators proposed at the end of the literature review section. Consequently, it is inappropriate to conclude on the results by merely considering the occurrences, frequencies, and time spent on the three phases and design activities. Different studies have also shown conflicts regarding the time spent on different phases. Some studies have indicated that novices spend more time on discovery and definition (Atman et al., 1999; Cross et al., 1994), while others have opposite findings (Atman et al., 2007; Brand-Gruwel et al., 2005). This study has shown that a more comprehensive consideration of the three indicators and the frequencies of transitions between phases may provide a more in-depth exploration of the design behaviors between experts and novices.

Similar Sequence and Investment in Design Phases

The general sequence of design phases in the design process was similar for both the four experts and five novices. They more or less followed the general design process—to discover, define, and finally design. Furthermore, based on the results of the Mann-Whitney U Test, no differences were found between the two groups for the following variables: occurrence, frequency, and time spent on phases, meaning that their time investment on the phases was similar. This trend can also be seen in Figures 4 and 5. To verify this further, we combined the data from all participants and used paired t-tests to determine whether there was a different investment between phases. The results were significant (Table 9). With respect to the frequency of occurrence between phases, the phase that least frequently occurred was the design phase. Regarding the time spent, all participants spent the most time in the discovery phase, significantly more often than in the other two phases, with the time spent in both the definition phase and design phase being the same. These findings answered our research questions RQ1 and RQ2 mentioned above.

These results reveal that regardless of expertise, the discovery phase consumed the most time for all participants in this study. Accordingly, it is reasonable to conclude that all participants highly valued the discovery phase. Being the fundamental phase in the entire design process, the other design phases are established based on the discovery phase. Therefore, all participants invested considerable effort in the discovery phase, with the experts and novices having consistent performances. It is noteworthy that although all participants recognized the importance of discovery, they went on a different path from this phase on.

Regarding the differences between the experts and the novices in the design process, we have divided the findings roughly into two parts for discussion. In the first part, preparations in the early stage of the design development process are considered. In this regard, most of our findings echo those of prior studies. In the second part, performances in the later stage design development are discussed. The following discussion answers the research question RQ3 mentioned above in this study.

Table 9. Results of the pair t-test for the comparison between phases (N = 9).

		Phase	*M*	*SD*	*df*	*t*	*p*
Frequency of occurrences	Pair 1	Discovery	0.44	0.08	8	1.99	.080
		Definition	0.34	0.10			
	Pair 2	Definition	0.34	0.10	8	2.34	.047
		Design	0.22	0.07			
	Pair 3	Discovery	0.44	0.08	8	6.09	.000
		Design	0.22	0.07			
Time spent (in percentage)	Pair 1	Discovery	0.48	0.12	8	4.59	.002
		Definition	0.21	0.08			
	Pair 2	Definition	0.21	0.08	8	-2.02	.078
		Design	0.31	0.10			
	Pair 3	Discovery	0.48	0.12	8	2.66	.029
		Design	0.31	0.10			

Preparations in the Early Stage for the Design Development

There is clear evidence of different behaviors between experts and novices in the early stages of the entire design process. Previous studies have indicated that experienced designers are more sufficiently effective in the information gathering and the problem formulation phases (Atman, 2019; Atman et al., 2007; Atman et al., 1999; Brand-Gruwel et al., 2005; Christiaans & Dorst, 1992; Cross, 2004; Cross et al., 1994), which is echoed similarly in our findings,wherein the four experts intensively analyzed the problem at the beginning of the entire design process. In addition, most of the four experts evaluated the problem at the beginning of the design process; however, only N3 and N5 of the five novices began to evaluate the problem early on. The experts systematically evaluated the problems based on their domain knowledge. For example, Expert 4 evaluated the problem as follows: "I am looking at what key points this product should have. This function is not required by the hearing-impaired. We need to think about users, the market, and timeline at the same time." By contrast, Novice 4 said, "Like iPhone headsets that control sleep time, I think my alarm clock can do the same. In addition, I saw a light that could slide back and forth. I want to use this form in my design." When the experts evaluated a problem, they made decisions by considering multiple factors that might affect the product. However, novices tended to use existing cases to evaluate problems, which was similar to the finding of Ball et al. (2004), in which they reported that compared with novices, expert designers demonstrate more schema-driven than case-driven analogizing behaviors. Because of their incomprehensive consideration, novices are more likely to fall into endless cases of analogies, have no clear direction, or are apprehensive about jumping to conclusions before they had figured out the problem. However, experts could confidently decide and analyze the direction of the product more quickly because of their large domain knowledge base that could support them in solving the given problem (Ericsson & Staszewski, 1989). In terms of postponing the problem analysis, the experts had their own way of scoping the problem as early as possible, for instance, because they knew what would take too much time to explore. They understood that not all of the tasks would be completed in this experiment; thus, they chose to explore the possibility of postponing the problem analysis. For example, when Expert 5 postponed the problem analysis, he said, "I have to know the accurate size of the electronic parts for the design; otherwise, such a form cannot be accepted by customers. But because it will take a lot of time to find specifications, I will not do it now." Because the experts knew that there were problems that could not be solved immediately, they eliminated them first, and then clarified the problems that could be addressed at the present to achieve constant behavior in the design phase. Ho (2001) indicated that experts prefer to represent the structure of a problem in their own way at the beginning of a task, while novices tend to eliminate problems that they cannot deal with. The results in our research showed that both the experts and novices could eliminate or postpone problems that they cannot deal with. The difference between them was how soon they realized these kinds of problems. Again, we could see that the experts were aware and reacted to the problems earlier than the novices.

It is obvious that the phases transitions are essential activities in the entire design process. To a large extent, the phases transitions, particularly the backward transitions, are similar to the concept of iteration, i.e., the back and forth transitions between all of the activities in the design process, such as information gathering, problem definition, solutions evaluation, and so on. To iterate in the design process is a useful way to evaluate the proposed solutions (Guindon, 1990) as well as a tool for linking the problem definition to solution concept (Dorst & Cross, 2001). Previous studies have mentioned that compared to novices, experienced designers spend more attention and time to iterate between design steps in order to allow for better scoping of problems and solution developing (Adams et al., 2003; Atman et al., 2007; Crismond & Adams, 2012). From another point of view, in the design process designers tend to move to and fro between the problem space and solution space (Dorst & Cross, 2001; Drew, 2019). According to earlier studies (Dorst & Cross, 2001; Maher & Tang, 2003), this kind of transition concurrently enhances the quality of activities both in the problem and solution spaces, as well as helping the designers find satisfying solution concepts. The findings in this research partially echoed the above-mentioned studies. There was a more intertwined and iterated performance of the design activities in the case of the experts in the first half of the entire design process as well before the constant design activity. The experts were accustomed to searching for information while defining problems or solutions. Only after the experts found a reasonable design concept and felt satisfied with it did they proceed to the design phase. By contrast, phases transitions occurred more frequently in the latter half of the process in the case of the novices, especially during the design phase. These results are consistent with those of Cross (2004), indicating that "Expert designers appear to be 'ill-behaved' problem solvers, especially in terms of the time and attention they spend on defining the problem."(p. 439) Our findings show that regardless of expertise, all of the participants iterated between different activities in the three phases and moved repeatedly between the problem and solution spaces, inferring that all participants valued the phases transitions (or iteration). However, the difference between the two groups was the purpose, function, and timing of when the phases transitions were executed. The experts transferred between phases early to establish a good frame and setting, and to prepare for the upcoming design steps; whereas the late iteration by the novices seemed only motivated to compensate for the incompleteness in the previous phases.

To generate and evaluate solutions at the beginning of the design process is a strategy often used by expert designers in the design process. This is also known as conjectures for solutions. Experienced designers tend to combine these early conjectures together with other design activities because this is an approach to understand the problem, to define the design goal, as well as to evaluate the constraints of solutions (Ahmed et al., 2003; Lloyd

& Scott, 1994). This design pattern of experts was also revealed in our findings. Most of the four experts started the design phase early, before the middle of the entire process, and continually transferred between the design phase and the other two phases. On the contrary, most of the five novices started the design phase after half way through the design process. Although early conjectures for solutions seems to be a good approach in the design process, some studies have observed that experienced designers are accustomed to concentrating on a single certain solution and show less comprehensive consideration for alternative ideas (Ball & Ormerod, 1995; Rowe, 1991; Ullman et al., 1988). In many cases, even though the experienced designers had already become aware that their early conjectures for solutions were constrained and insufficient, they still tend to fix and improve them rather give them up and go for the better alternative (Ball et al., 1994; Cross, 2004; Rowe, 1991; Ullman et al., 1988). However, this study did not focus on the selection of ideas and further development, nevertheless, the pattern of preferences toward early ideas can be partially identified by the constant design activities in the design phase.

Performances by the Design Development in the Late Stage

The significant differences between both groups in this study were all mostly related to the design phase. Compared to the novices, the experts maintained constant and long period design activities, had significantly longer constant design activities, and ended the whole process with the design phase. Overall, the experts paid more attention and concentrated more on the design activities, particularly at the very end of the design process. In the following we interpret these findings from three aspects. First, as mentioned above, during the selection of alternative ideas and development the experts probably relied on the ideas that were generated in the early stage of the process, and then devoted effort to maintain and modify these early ideas. Consequently, they focused unconsciously more on the idea development in the design phase. It is worth noting that, regardless of the quality of outcome, the experts were very likely constrained in this kind of single idea and had fewer chances to reach other but better solutions. On the contrary, although the performances of the novices at the end of the design process differed in a number of ways, the possibilities to obtain better alternative solutions still existed. The second aspect highlights the participants' self-confidence in the design process. Because the novices lacked sufficient experience and knowledge, as such, they might have been vaguely executing the design phase. Furthermore, they also lacked self-confidence in their design ability and often doubted themselves; thus, even in the later phase of the entire design process, they still had to clarify problems by executing the previous phases. One of the novices said, "I do not know if this shape is right or not. It does not seem reasonable, and there is no way to solve the problem, but forget it, I do not know where the problem is, I will think about it later." Even after finishing the product proposal, because the novices did not have faith in their decisions, they went back to redefine or even explore the problem again, thus ending the entire design process without being able to convince themselves. In the retrospective interview, the results were the same as those in a previous study, that is, compared with experts' high satisfaction and trust in themselves, novices had lower self-confidence and were not satisfied with their performance (Ahmed et al., 2003). The third aspect looks at the influences from the participants' prior design activities. Although a small part of the activities related to the design phase had already begun early in the whole process, the design phase was generally the last step. That meant, most activities related to the design phase were driven by the prior activities and their results. For instance, it could be observed that all of the experts repeatedly analyzed the problem and consulted information about the problem. When the experts determined that there was sufficient information and analysis of the problems, they proceeded to evaluate the problems. Moreover, the experts defined the product function and form in the first half of the design process. These observations revealed the experts' ability to evaluate the time point for making the next decision. Before implementing the final design and evaluation phase, the experts had already made a feasible decision (Ahmed et al., 2003; Lloyd & Scott, 1994). In comparison, when the novices were defining the problems in the first half of the design process, they still did not know what the issues were. and continued to find definitions that needed to be refined or completed until they were in the design phase. This could be why in the second half of the design process the novices persistently intertwined the design phase with the other two phases. The differences in terms of early analyzing and evaluating of problems, early and persistent phases transitions, and early combination of conjectures for solutions with the other design phases have all been demonstrated and discussed in previous studies. We believe that these early patterns in design activities certainly lead to the different ways in which the experts and the novices executed the design phase at the end of the whole design process.

Finally, in the following we discuss the issue of design patterns. In terms of dealing with well-defined problems, studies (Anderson et al., 2013; Larkin, 1981) have indicated that novices prefer the working-backward and depth-first search strategies, while experts prefer the working-forward and breadth-first search strategies. However, when dealing with ill-defined problems a mixture of working both forward and backward occur often (Ho, 2001; Mitchell, 1990). In this study, similar to previous literatures, many patterns in the design phases as shown by the experts were identified, as demonstrated and explained in the above paragraphs. However, in the research conducted by Smith (1991), some novices (students) use the same strategies as the experts (experienced teachers) for problem-solving. This seems to be echoed by N3 and N5 in our study. Like the experts, both of them started to evaluate the problems early, and began the design phase before the middle of the design process; moreover, N5 also ended the design process with the design phase. In addition, although N3 and N5 had a shorter duration of constant design activities compared to the experts, this was still longer than the other three novices. Therefore, we argue that a design process can only be identified as more expert-like or less expert-like from the patterns in design phases. In other words, it is probably inappropriate to categorize designers through their design activities into experts or novices.

Learning from the Experts' Design Behavior

Finally, the following discusses potential applications of our findings, especially in the field of design education. In this study, we have illustrated how the experts and novices behaved during the design process, from which we infer that the novices could be more efficient in understanding the design process if they familiarize themselves with the design industry. However, studying their design behaviors throughout the design process helped them better understand how they interact and perform given the design objectives. As for the experts, the design process may well be a working template for them to reach a consensus, but it might also be seen as a mere formality. The experts had to adjust the design process to deal with various realities; as such, there might not be a design process that could adequately cope with all situations. However, we can learn from the details of their design behaviors. From the experimental results, the novices could understand how they differ from the experts regarding their design behaviors, and further realize how their own thoughts and approaches affected their design process. Nonetheless, further research is needed to confirm whether learning from the experts' design behaviors could help novices identify blind spots and difficulties in the implementation of the design process.

In the previous study of Kavakli and Gero (2002), even though they indicated that different structures of cognitive actions existed between expert and novice designers, they could not establish whether the performance in the design process was governed by structured and organized acts. Furthermore, Smith (1991) also pointed out that some novices could also solve problems with the methods used by experts, thus, distinguishing designers into experts and novices by their problem solving patterns was not considered appropriate. Instead, Smith suggested that looking at whether their behaviors were perfomed successfully or unsuccessfully was more appropriate. In the field of design education, scholars (Beckman & Barry, 2007; Dzombak & Beckman, 2020) embedded the design process into a model of experiential learning, which was initially proposed by Kolb (A. Kolb & Kolb, 2005; D. Kolb, 2015). Running a design process could be considered a learning journey in which the learner or designer must experience the four steps of diverging (observe and notice), assimilating (frame and reframe), converging (imagine and design), and accommodating (make and experiment) between the horizontal poles of reflective observation and active experimentation, and the vertical poles of abstract conceptualization and concerted experience. In this model, the learner is just acquiring the knowledge and skills in the different steps, and different learners could be good in different phases of the design process. Consequently, successful and unsuccessful performances could be processes that they must go through to develop themselves. In other words, it may have seemed impracticable and problematic that the novices were asked to learn or apply expert methods to solve problems when they had insufficient domain knowledge.

Nevertheless, the study by Dow et al. (2011) for novice graphic designers showed that compared with prototyping in serial conditions, prototyping in parallel conditions leads to better design results. In their research, parallel conditions referred to the feedback from the prototypes being given in two rounds, while serial conditions referred to the feedback being given individually. We believe that parallel conditions are closer to the ways of experts in handling problems, because such conditions could offer the participants more comprehensive and productive suggestions to help them evaluate their ideas. We are of the opinion that this result could serve as evidence that novices achieve better performance in the design process when they adopted the experts' methods. In brief, more studies are needed to understand in which design phases the educator should help or suggest that the novices learn from the experts' design behavior.

Conclusion

This study attempted to clarify the design behaviors of novices and experts in the design process. We conducted an experiment in which four expert and five novice designers completed a design task. The results were obtained by protocol analysis together with sequence maps and quantitative data. We found that the experts and novices showed different and similar design behaviors in the entire design process.

First, we believe that to understand the design behavior of experts and novices, it is insufficient to consider only the occurrences and time span of the design phases and activities. Whether or not these indicators show significant results, most of the differences in behaviors were observed from the timing of executing the phases and activities and the transitions between them.

In terms of similarity in the design process, the general sequence of the design phases and time investment therein were not significantly different between the experts and the novices. In addition, among the three design phases, all participants spent most of their time on the discovery phase, and then started the design phase, placing high value on this phase, but differences in the behaviors between the two groups were observed from thereon, which impacted their subsequent design behaviors and performances.

As for differences between the two groups, we conclude that compared with the novices, the experts conducted early and intensive analysis and evaluation of the problems, persistently transitioned between phases, and combined conjectures for solutions with the other design phases in the first half of the entire process. These results are consistent with those of many previous studies. However, we further found that because of their solid preparations during the design development phase, the experts could maintain a constant design phase with very few transitions back to the discovery and definition phases, had long constant design activities, and ended the design process with the design phase. By contrast, because of their unclear problem scoping and definition, the performances of the novices at the end of the design process were more incoherent. In addition, we argue that the different performances in the late stage of the design process could be related to the preparations carried out during the design development phase in the early stage.

Limitations and Suggestions for Future Study

This study has some limitations. First, we focused on the design process for product design, industrial design, and other related fields. Other fields were excluded. Second, this research adopted a single specific design process model as the experimental model; as such, other models were not discussed. In addition, we used the thinking-aloud protocol as the method of data collection, but this method has its limitations and does not completely allow observation or recording of all the participants' design behaviors. Furthermore, due to time limitations, this study only covered the discovery, definition, and design phases for a short-term rapid design to evaluate the participants' design behaviors, instead of a long-term project. Therefore, there may be some differences between the experimental results and actual design situations.

Although this study found trends in the differences between the experts and the novices, it is undeniable that differences existed between the individuals within each group. The working patterns of each expert and each novice were also different. Moreover, to a certain extent, the designers may also have differed in their design behaviors and design activities according to their positions and responsibilities in their companies (e.g., Expert 3 in our study). This can be further explored in future studies. Therefore, more participants are needed to obtain higher precision in behavior patterns or types.

Finally, although we expected that the experts' behavioral patterns could provide the novices some guidance, the novices might not behave as professionally as the experts, even if they follow the same design behavioral patterns in the design process. Previous scholars (Beckman & Barry, 2007; Dzombak & Beckman, 2020) have indicated that the design process could be well linked with the experiential learning model. Thus, there is still a process of transformation from the stages of understanding to learning and implementation. Future researchers may be able to determine the differences between the understanding and implementation phases from this research and then build a bridge between the two so that design educators can turn this gap into an opportunity for learning, thereby helping novices know when, how, and what they could learn from experts.

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