Cognitive styles in design problem solving: Insights from network-based cognitive maps

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This study aims at understanding the cognitive styles of designers from the point of view of precedent utilization and idea generation. A protocol study was conducted with 24 masters students majoring in industrial design. To analyze verbal protocols, this study devised a new way of describing cognitive processes called 'cognitive map.' It supports intuitive interpretations of a cognitive process while visualizing its comprehensive structure with rich relationships among encoded items. Based on cognitive maps, three phases of the design process were identified, and the cognitive styles of each participant were derived through integrating the cognitive styles of each phase. As a result, four types of cognitive style − Focused probers, Treasure hunters, Selectors, and Explorers − were identified and described.

Keywords: cognitive styles, protocol analysis, design precedents, design behaviour, research methods

Prior knowledge and experience have been regarded as critical components of creative thinking processes aimed at the creation of the new (Hyman, 1961; Runco & Chand, 1995; Ward, 1995). In the design process, prior knowledge and experience play a pivotal role. Laxton (1969) mentions a reservoir of knowledge as a prerequisite for design ability. Suwa and Tversky (1997) found that background knowledge, especially the domain knowledge, makes a significant contribution to and has implications for designing.

In the field of design, domain knowledge has often been represented as precedents. As Goldschmidt (1998) stated, the role of precedents in design is quite different from precedents in the practice of law, which uses identical cases to adopt. The design precedents rather support the design activities as a reference which suggests ways to deal with design problems. Designers can refer to their pool of precedents in order to find problem solving elements which can be reused in a different design problem (Visser & Trousse, 1993). In addition to the solution generation phase, designers also utilize their episodic knowledge to understand the problem and evaluate its solutions (Visser, 1995).

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In Lawson's elaborated explanation of design expertise (2004a), precedents help designers to form their own schemata and are also utilized as gambits to recognize the design situation. Even in a group of students, the development of expertise changes the ways precedents are used, from geometric to symbolic referencing. This also suggests that precedents are actively engaged not only in the design process but also in the development of design expertise. As such, the level of dependency on prior knowledge and experience may vary depending on the designers' level of expertise. In addition, it may be different depending on the designers' own characteristics. The study by Kruger and Cross (2006) empirically shows that some designers often utilize their prior knowledge rather than other sources. In the case of these designers, the utilization of such knowledge has the potential to be developed into a design strategy (Kruger & Cross, 2006).

As many studies have expanded our understanding about the usage of prior knowledge and experience in designing, researchers engage in design activities in a variety of forms and ways. It seems likely that the engagement of these mental resources has a significant relationship with design ability. However, there have been limited attempts to elaborate the diverse characteristics in the usage of precedents, and its implications to designing. If the utilization of precedents is one of the most important aspects of the design problem solving process, how does it vary and differ depending on the designer? Is it possible to classify these variances into a limited number of cognitive styles that have distinctive features to each other? This research focused on these research questions, and attempted to investigate the design problem solving process of designers in terms of utilizing prior knowledge and experience. We viewed the design problem solving process as a cognitive process which progresses while utilizing various cognitive elements. In order to analyze a cognitive process, we conducted a protocol study, and devised a new graphical representation that visualizes cognitive elements and their relationships in order to support the analysis and interpretation of protocols. The new description method is also discussed thoroughly and compared to existing methods of interpreting protocols.

1 The known to the new – precedents in design

Previous studies in cognitive psychology indicate the significant role of prior knowledge and experience in creative thinking. Conceptual expansion, which was proposed by Ward, Smith, and Vaid (1997), is an example of how prior knowledge may influence the creative process. It refers to a cognitive activity whereby peoples' knowledge of familiar concepts is extended for creating, even to different domains. Other researchers have proposed conceptual combination and reorganization as a significant ability of human creativity (Baughman & Mumford, 1995; Mumford, Mobley, Reiter-Palmon, Uhlman, & Doares, 1991; G. M. Scott, Lonergan, & Mumford, 2005). These studies highlight the contribution of existing knowledge and experience in the creative process. However some studies have argued that prior experiences can inhibit the creative process. One experiment showed that people tend to create something that highly resembles the appearance of existing animals even though they were asked to design an alien creature (Ward, 1994). Similarly, it has been suggested that providing examples may constrain the novelty of ideas, although the number of generated ideas remained uninfluenced (Smith, Ward, & Schumacher, 1993).

In the design discipline, prior knowledge and experience have been frequently viewed as precedents which are defined as either whole or parts of past designs that designers are aware of (Lawson, 2004b; Pasman, 2003). Precedents provide relevant solutions or ways of designing that designers can refer to. For example, textile designers actively utilize previous designs as well as other sources of inspiration to generate new ideas and communicate with others (Eckert & Stacey, 2000). Architects have made extensive use of pattern books which contain accumulated knowledge related to architectural styles and details (Lawson, 2006). Industrial designers acquire and apply relevant knowledge from precedents while they are creating the form of a design concept (Muller & Pasman, 1996).

Through successive studies, Oxman (1990, 1994, 1999, 2004) has provided more structured descriptions of how prior knowledge is adapted in order to create a novel design, and presented a pedagogical framework based on them. On the basis of previous theoretical studies that viewed design as a form of knowledge, she described designing as a dynamic process of transforming prior experience into the form of design knowledge through generalization and typification (Oxman, 1990). Especially, the typification of precedents according to situations, constraints, and goals enables designers to embody the knowledge across different domains. It also enhances creativity as precedents are generalized and are interwoven with each other through a higher level of abstraction (Oxman, 1990). In order to understand the organization of knowledge constructed through generalization, a tripartite scheme of Issue-Concept-Form was proposed, and it was expanded by including Analogy and Metaphor, which support design processes (Oxman, 1994, 1999). The conceptual model of knowledge organization and utilization suggests that designing is highly related to obtaining the precedents and re-using them while accommodating their utility in present issues. A recent study of Oxman (2004) supported the pedagogical benefits of knowledge-based systems in terms of encouraging independent and collaborative knowledge construction and modification.

The utilization of prior knowledge is used in the design processes in relation to design outcomes as well. The description of Lawson (2004b) demonstrated how precedents influence various aspects of design based on the model of design constraints. The frequent use of historical styles and reference to their aesthetical details may constrain the formal aspect of design, and may at times also constrain the symbolic aspect. In terms of a design problem generator which may define constraints, a designer can constrain his or her design by himself/herself when s/he tries to construct his/her signature style throughout every designed entity. Lawson's explanation indicates another possible effect of precedent utilization, which may reduce the novelty or innovativeness of an idea. Jansson and Smith (1991) found that even professional mechanical engineers appeared to become 'fixated' on an existing solution provided in advance. Successive studies conducted by a group of researchers (A. T. Purcell, Williams, Gero, & Colbron, 1993; A. T. Purcell & Gero, 1992, 1996) reported the fixation in both mechanical designers and industrial designers, though the degree of fixation was different across the disciplines. On the other hand, the study of Viswanathan and Linsey (2013) argued that the degree of fixation may be affected by the modality of solution examples. The results of their study showed that a physical example can cause a higher degree of fixation compared to a pictorial one, but can also facilitate generation of nonredundant ideas (Viswanathan & Linsey, 2013). Contrary to these results, one of the most recent studies suggested that the usage of precedents may not influence the novelty of design, but instead reduces the diversity of design solutions (Doboli & Umbarkar, 2014). Although the influence of the precedents is yet to be fully discovered, it seems likely that knowledge from precedents is embodied in the newly created knowledge to a certain degree.

As such, these results of previous research suggest an extensive engagement of precedents in designing and its diverse influence on the design outcomes. There could be a variety of explanations for these differences – the types of design problem, the level of expertise, and the professional field. In this research, we focused on personal differences which have hardly been explored in other studies. We hypothesized that there are personal differences in the way of utilizing precedents, and the ways of using them may be clustered into a limited number of cognitive styles. Also, we assumed that the differences have a relationship with the design outcomes – generated ideas – in terms of diversity and details.

There have been attempts to investigate and define the cognitive styles of designers. Nigel Cross (1985) viewed the design process as a learning process, and suggested cognitive styles of designing based on the learning strategies which were proposed by Pask & Scott (1972). He introduced the notion of serialistic and holistic cognitive styles and described them while relating them to the neurological abilities of the two hemispheres of the brain (Cross, 1985). The more recent study of Kvan and Jia (2005) explored a similar topic which tried to correlate the learning styles of students with their performance in an architectural design studio. They identified the learning styles of students using an inventory named Kolb-LSI, and assessed the performance of students. The results indicated that convergers showed lower achievement compared to assimilators (Kvan & Jia, 2005). The research conducted by Bar-Eli (2013) examined design behaviour from the perspective of sketching. The author identified individual characteristics related to use of sketches, and proposed several profiles in the two different phases of design (Bar-Eli, 2013).

As previous studies discussed, the understanding of designers' cognitive style has significant implications for both design education and practice (Bar-Eli, 2013; Basadur, Graen, & Wakabayashi, 1990; Cross, 1985; Kvan & Jia, 2005). This embraces the issues of understanding cognitive styles of students and teachers, and even the characteristics of design tasks. Although much knowledge related to this topic has been accumulated, various aspects have yet to be explored. Especially, there have been few studies which investigate design activities directly in order to identify cognitive styles. In this regard, this research investigated the cognitive styles of designers in terms of utilizing precedents and idea generation during the design problem solving process.

2 How to understand a cognitive process – ways of describing protocols

2.1 Representing the cognitive process of protocols

Understanding the cognitive process of designers is a popular topic which has been investigated constantly (Chai & Xiao, 2012). Related to this topic, protocol studies have been employed frequently in order to examine cognitive processes which are hard to measure and observe (Cross, 2001). Previous protocol studies utilized various methods to analyze and present the encoding results, and these methods could be classified into several types. Providing an excerpt of a protocol is a straightforward and direct way to share the raw data and the framework of encoding. Some researchers provided extracts of protocols, and explained how a segment is encoded and the meaning of the encoded behaviours (Eastman, 1968; Goldschmidt, 1991; Schon & Wiggins, 1992; Suwa, Purcell, & Gero, 1998; Valkenburg & Dorst, 1998; Visser, 1995). This method provides a transparent view of cognitive processes without manipulating the protocols, and also helps readers to engage in the analysis of the cognitive process by themselves. Thus this method is broadly found in many protocol studies due to its fundamental function to present the data and its results. Another basic method is displaying the frequencies of encoded items using tables and/or charts. Both qualitative and quantitative studies include frequencies in the results, and it has become the starting point of analysis especially in the case of quantitative research which uses statistical analysis (Kruger & Cross, 2006; Stempfle & Badke-Schaub, 2002; Tang, Lee, & Gero, 2011). A graph which displays frequencies is a good method for summarizing the encoded results, and provides a concise way to explore the entire process. When it is combined with qualitative discussions, the frequency graph often serves as a tool for analyzing and representing the encoded protocols. Depending on the visualization methods, frequency charts reveal different characteristics of the data. They can reveal repetitive trends of design activities (Akin & Lin, 1995), and can also help to display relationships between two or more actions (Suwa et al., 1998). Although the frequency data can be transformed into a variety of types of graphs and charts, sometimes it can become a record of design activities which barely provides insights and further interpretation of the process (Dorst & Dijkhuis, 1995).

2.2 Representing the relationships among cognitive elements

There were other types of description which focused on the interactivity among design activities and their relationships. The study of Akin and Lin (1995) concentrated on the simultaneity of several design actions, and portrayed the frequency of multiple design actions using a graph. Instead of tracing individual design activities, the authors investigated the activities taking place together and explored the combination of activities which affected the novel design decisions. The research of Valkenburg and Dorst (1998) was a case in which a totally new way of describing protocols was developed and employed in order to investigate the design activities of teams. They utilized different shapes of figures to represent design activities, and also described the relationships between activities using arrows and boxes. The new description method supported rich explanations of protocols and aided discussions related to the interpretation of design activities. It was good at providing specific information about the cognitive process, and made it easier to recognize different types of activities. However, the method was less effective as a means of understanding the entire process of design, and for comparing one process with others intuitively.

Another method which has been actively utilized and co-developed by several researchers is Linkography, proposed by Goldschmidt (Goldschmidt, 1990, 1995; Kan & Gero, 2008; Van der Lugt, 2003). In this method, a design process is represented by a combination of sequential 'design moves', and links between them. Through constructing the linkograph of a designer or a design team, it is possible to interpret the design process in terms of its critical moves and designing reasoning (Goldschmidt, 1995; Dorst, 2004). Similarly to the graphical representation that Valkenburg and Dorst (1998) proposed, a linkograph describes the relationship among activities, and it additionally supports an interpretation of its structure to identify critical design moves. However, it is difficult to analyze a design process with linkograph, because the representation method of links is constrained and moves are connected to each other with a single type of relation.

2.3 A new way of representing multifaceted relationships among cognitive elements

Although many methods have been used to interpret and present the results of encoding, the description methods have some limitations in terms of their structure and in their viewpoint. A protocol is rich and complex data which contains the verbal expressions of cognitive process. In most cases, protocols are too complicated to analyze and to find meaningful insights even after they are encoded. Thus a good description method is required which is good at both summarizing and revealing the meaningful patterns of cognitive processes. While doing so, it should maintain the richness of verbal protocols and support comparisons among different cognitive processes. However, it is hard to find a method which satisfies all of these needs and requirements to manage and interpret the protocol data. In this regard, this study employed a new way to visualize the cognitive process which supports analysis and interpretation of protocols. We brought the perspective of a network to perceive the encoded protocols, and aimed at representing the comprehensive structure of a cognitive process while describing the relationships and think flows. There have been attempts to visualize a cognitive structure or a reasoning process by adopting the concept of a network (Ruiz-Primo & Shavelson, 1996; Sowa, 2006). Although they provide a richer description of relationships among different concepts, most of them were applied to understand a static structure rather than a dynamic process. In this regard, in order to provide valuable insights and an intuitive way of interpreting cognitive processes, we focused on representing the dynamic process of designing through visualizing the multifaceted relationships among cognitive elements. The details of our method, which originated from network analysis, will be discussed later along with a comparison of previous applications. Through developing and adopting this method, it is expected that we can suggest a novel and distinctive way to make the meaning of protocols and also the cognitive processes explicit.

The following section begins with a detailed account of experimental design and procedure, including the coding strategy and the coding scheme used in this study. Next, the visualization method adopting the concept of a network is explained with the cognitive maps generated by a Social Network Analysis (SNA) tool. The results section is composed of two parts. In the first, the benefits of the new description method – cognitive maps – are discussed based on a comparison with the existing methods. The second section presents findings from the cognitive maps which suggest different cognitive styles in the design problem solving process. This paper concludes with a discussion of implications and relevant issues for further studies.

3 Data collection and analysis

3.1 Participants

A total of 24 masters students in the industrial design field participated in the experiment. All of them had studied in an industrial design department or a product design department for their undergraduate degree. Thirteen participants were female and eleven were male. The average age of the participants was 24.8; ages ranged from 22 to 29.

3.2 Design brief

Each participant received a design brief in written form. The brief used in this study was related to an ordinary product which has simple functionality – a folding chair. A chair was intentionally chosen because it is an item which is universally known. This could facilitate utilization of prior knowledge and experience to generate and develop design ideas.

Instead of giving the same brief to all participants, two slightly different design briefs were utilized as listed below.

Design brief 1: Design a folding chair.
Design brief 2: Design a folding chair for the 20–30s age range who live alone in a small size flat.

Two different design briefs were devised based on the results of previous studies which discussed the role and influence of constraints on cognitive processes (Bonnardel, 2000; Chandrasekaran, 1990; Gero, 1990; Gross, Ervin, Anderson, & Fleisher, 1988; Toye, Cutkosky, Leifer, Tenenbaum, & Glicksman, 1994). Constraints were described as an important part of the design process which inhibit or promote creativity (Chandrasekaran, 1990; Noguchi, 1999; Smith et al., 1993). Thus it was expected that differing levels of constraints would affect the cognitive process of designers. However this paper will not concentrate on investigating the effect of constraints because it aims at identifying different cognitive styles through a new method of describing and analyzing the cognitive process itself. Besides, the post-hoc analysis revealed that the distribution of the four cognitive styles had no relationship with the type of design brief that the participants used.

Both design briefs were open-ended and had no specific requirements related to the output of the design exercise. Such freedom was given in order to observe the natural and intrinsic cognitive styles of participants while they generated ideas and developed them. Participants were allowed to generate solutions which satisfy the design brief based on their understanding. The number of ideas and the level of detail of any final outputs were not specified either.

3.3 Experimental procedure

The experiment was conducted individually in a closed room equipped with a video recording device to record the participants' sketching activities and all of the verbal data. A3 papers, pencils, and pens were provided for the participants' use. Figure 1 shows the setting of the experimental room.

The design brief was provided as a written document on which was also written an explanation of the purpose and the procedure of this experiment. Half of the participants worked on design brief 1 (fewer constraints), and the other

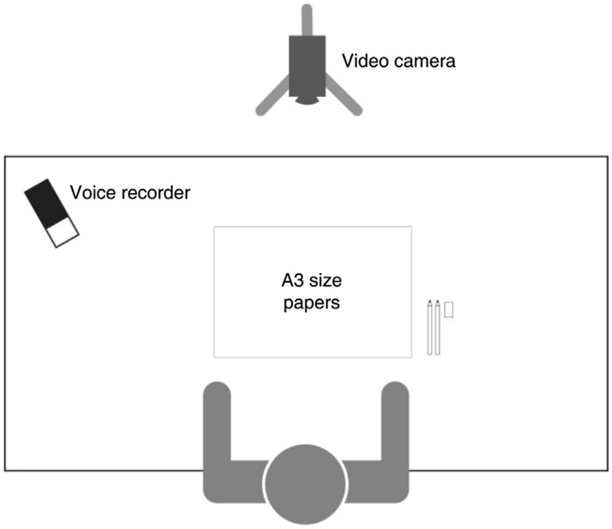


Figure 1 Experimental setting

half worked on design brief 2 (more constraints). While working on the design task, participants were asked to think out loud. Think-aloud is a method to gather data about thinking through concurrent verbalization (Fonteyn, Kuipers, & Grobe, 1993; Someren, Barnard, & Sandberg, 1994). Before entering the main experiment, a short think-aloud exercise was performed (Ericsson & Simon, 1998; Someren et al., 1994). This exercise helped participants to become accustomed to the think-aloud method. While working on the task for one and a half hours, participants were not allowed to use external sources to obtain information or knowledge which they did not already have or could not retrieve, since this experiment was investigating how people utilize memorized information, and its implication for the cognitive process.

3.4 Data analysis

The verbal data from the think-aloud method was first transcribed into text. 24 protocols were obtained through this process. While transcribing, the protocols were segmented based on verbal pauses and the linguistic structure of verbal statements. These protocols were utilized as a main source of the analysis while they were supplemented by the sketches of each participant.

3.4.1 Identifying a think flow

A cognitive act may correspond to several verbal segments rather than a single segment (Someren et al., 1994). In order to understand the flow of a cognitive process, verbal segments were combined into a think flow, which is defined as a consecutive thinking process with a single topic or a coherent perspective. In this research, a topic or a perspective was usually dealt with at the product level of which participants generated conceptual ideas. Hence the granularity of a cognitive act that we concentrate on is larger than that of other studies which focused on features of a product (Dorst & Dijkhuis, 1995; Goldschmidt, 1991; Kavakli & Gero, 2002). For instance, the concept of a 'design move' that Goldschmidt (1995) devised is related to beginnings and endings of coherent utterances which indicate a small step or an act which transforms the design situation. In terms of granularity, a think flow rather has a similar structure with the design story that Oxman (1994) suggested. She proposed a definition of design story in order to parse the design knowledge, and it was described as conceptual design content which is composed of design issues, concepts, and related forms. A design issue refers to a particular point or a situation in a design problem. A concept is a solution which addresses an issue. It is realized as a specific artifact with a form. A design story is materialized while elaborating the linkages among these components. As a design story comprises not only the situation of a design problem but also the detailed realization of a concept, it is much closer to the concept of a think flow, which embraces successive cognitive acts to understand the design problem and develop a solution with a coherent perspective.

3.4.2 Coding scheme

The coding scheme of this study was drafted based on previous studies related to precedent utilization and idea generation (Jones, 1963; Tulving, 1991; Visser, 1995). Then, it was refined and confirmed through an iterative coding procedure. The detailed coding procedure will be described in the next section. In order to capture the interactions among cognitive elements, we tried to identify not only the elements of a design problem solving process, but also the relationships among these elements. Table 1 provides a brief explanation of each coding category.

An *Idea* is defined as a design concept which was generated to satisfy the design brief, and has at least one determined feature related to the product itself such as shape, functionality, or material. Depending on its novelty and the level of detail, an idea can be classified into one of two subcategories. A design concept which is novel in overall aspects was considered as an *initial idea*. As an idea is developed with additional features and/or details, it was classified into the category *developed ideas*.

In this research, the word *Precedents* represents prior knowledge and experience regardless of the domain that the knowledge was retrieved from. The precedents were classified depending on their memory types – episodic or semantic memories. The definition of episodic and semantic precedents was adopted from a theory of psychology which argues for the interdependency between episodic and semantic memories (Dix, 2004; Tulving, 1991).

Episodic precedents represent things retrieved from episodic memory systems, which have specific contexts and a direct relationship with personal experience. When a participant retrieved a specific artifact, or a situation from personal

Table 1 Five coding categories which represent cognitive elements of a design problem solving process

Coding category		*Definition*
Ideas	Initial ideas	An initial design concept which is novel in overall aspects, and also satisfies the design brief.
	Developed ideas	A design concept which has more details or additional features compared to an initial idea.
Precedents	Episodic precedents	Episodic memories which are related to direct and personal experiences
	Semantic precedents	Semantic memories which are obtained through learning and/or inference based on episodic memories
Interpreters		A highly conceptual theme which affects the interpretation of the design problem

events, it was regarded as an episodic precedent. Figure 2 is an excerpt of a protocol which contains an episodic precedent about a product that a participant saw in her grandmother's house.

Semantic precedents are composed of two different types of semantic memory. Some semantic memories come from theoretical knowledge that participants have learnt or studied. The other part of semantic memories is created through inference and generalizations of episodic knowledge. In the case of generalizations, participants produce knowledge by themselves through combining several personal experiences and/or reflecting theoretical knowledge upon their personal experiences. Figure 3 shows an example of the latter type of semantic precedent which is related to a prototype of a chair.

During the primary analysis of protocols, another type of cognitive element was identified which participated greatly in the design problem solving process. This element was a conceptual theme which was too generalized to be categorized as a precedent. This category was named *Interpreters*, because it helps to interpret the meaning of the design brief, and engages in manipulating the problem space. Figure 4 shows an example of interpreters from a protocol. As shown in the excerpt, the participant suddenly perceived a new meaning of a folding chair which was different from the understanding that she had employed. There have been several studies which support the participation and contribution of interpreters in the design process. Lawson (2005) argued that a design problem can be subjectively perceived and interpreted due to its innate nature. An experiment which required participants to design a restaurant for birdlike creatures showed that the design direction and

> In my grandma's house, there is a chair… without legs. No legs, only a seat pad and a backrest. My grandma uses this while watching a TV… Sitting on the floor..

Figure 2 Example of episodic precedents from the protocol of participant O-F4

Usually, chairs have legs.. legs… and a chair means… A chair can be defined as something with a backrest, a seat pad, and legs…

Figure 3 Example of semantic precedents from the protocol of participant X-M3

Well.. Ah..! I was really biased. A folding which folds the chair…No. If I fold papers, and utilize them as a module... Then build a chair. This kind of chair… could be a folding chair. Yeah maybe..? So, not folding the chair itself, but a chair made with folded modules. Fold, fold, fold, and combine them.

Figure 4 Example of interpreters from the protocol of participant X-F6

outcomes depended on the interpretation of the design task (Sifonis, 1995). Dorst and Cross (2001) also reported an interpreting behaviour of designers which includes redefining the design problem based on the understanding of their own resources and capabilities (Dorst & Cross, 2001). Based on the previous studies and the evidence from the protocols of this research, *Interpreters* were defined as a category of the final coding scheme.

After identifying think flows and encoding different types of elements, the relationships among encoded elements were defined. There were two types of relationship and each encoded item had one or both relationship with the other items. The first one is a directional relationship which represented the order of retrieval and utilization. These sequential relationships supported the analysis of the encoding results from the perspective of a procedural activity. The other relationship was related to each item's contribution to idea generation. Among the precedents and interpreters which were mentioned during the entire design exercise, some items were involved in the idea generation process, but some were not. Any precedent or any interpreter which played a role in idea creation had a linkage with the idea that it contributed to.

Overall, the entire coding scheme aims at elaborating the categories of cognitive elements involved in the design problem solving process, and clarifying relationships among them. According to previous studies, it seems likely that episodic and semantic precedents participate differently in cognitive processes (Sowa, 2006; Visser, 1995). It is expected that expanding the concept of precedents will promote a better understanding of designing and its knowledge construction. In the case of idea categories, this study devised definitions of three different levels of ideas which could appear during the design process. Due to the differences in granularity and specifications, it was hard to compare two ideas from different categories. In order to better understand the role and contribution of each level of ideas, the way of classifying ideas should be investigated further from the perspective of development and maturation of an idea. The coding scheme that we devised could be described as a relational coding scheme since we attempted to define the relationships among cognitive elements. Although we only utilized two types of relationships, the relationships among cognitive elements can be defined as anything depending on the purpose of the research. Thus, a relational coding scheme could be utilized in other studies to investigate and reveal rich interactions among cognitive elements.

3.4.3 Coding procedure

While encoding, it is important to make the process as objective as possible. Based on the encoding procedure of a previous study (Gero & Mc Neill, 1998), this study focused on defining each coding category precisely, and obtaining reliability through iterative encodings and arbitration.

The overall coding procedure is summarized in Figure 5. Primary encoding was done with the transcripts of six participants. At first, a theory-driven coding scheme was utilized which was developed based on previous research (Jones, 1963; Tulving, 1991; Visser, 1995). During the primary encoding process, a new category evolved, the definition of each category was refined, and the final coding scheme was developed.

With the final coding scheme, which was explained in the previous section, the protocols of 24 participants were encoded twice. Only one of the researchers was involved in the entire encoding process. There was at least a month between the first encoding and the second encoding. This time gap was intended to help the coder avoid becoming fixated on the first encoded result. It also helped to look over the definition of each category and enhance the test-retest reliability. After finishing the second encoding, the first and the second encoded protocols were compared to identify disagreements between them. These disagreements were arbitrated and adjusted based on the discussions of the two researchers, and the final protocol was obtained. With the final protocols, the Cohen's kappa coefficients across the coding categories were calculated. Though episodic and semantic precedents categories showed more discrepancies between the protocols than the others, the level of agreement throughout all categories was above 0.80, which indicates an acceptable level of agreement (Lombard, Snyder-Duch, & Bracken, 2002). Table 2 shows the Cohen's kappa coefficients calculated based on the final protocols.

4 Visualization of cognitive process

4.1 Conversion of a cognitive process to a network – cognitive map

As discussed in the earlier section, previous methods of describing protocols have limitations in illustrating the interrelatedness of a cognitive process

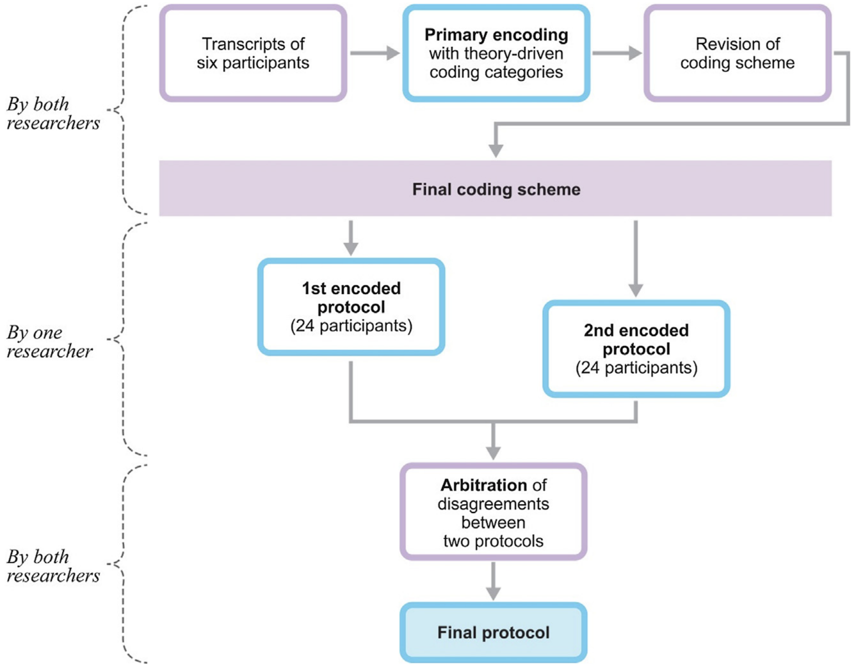


Figure 5 Coding procedure

Table 2 Level of agreements between two protocols

Coding category	*Ideas*	*Episodic precedents*	*Semantic precedents*	*Interpreters*
Cohen's kappa	0.93	0.89	0.86	0.94

without impairing the contents of protocols and the encoding results. Instead of using existing methods, this research devised a new way of describing protocols which can be easily constructed based on encoding results while supporting an intuitive interpretation of the cognitive process. This description method was called a 'cognitive map', because it provides a view of the entire structure of the cognitive elements in a design process. The basis of a cognitive map was developed from the concept of a network. A network is defined as a composition of nodes and linkages which indicate the relationships among nodes (Wasserman, 1994). There have been studies which made attempts to employ the concept of a network in order to represent cognitive processes and/or structures. Semantic networks (Sowa, 1992, 2006) and concept maps (Ruiz-Primo & Shavelson, 1996) are representative examples. Both methods are based on the concept of a network which is composed of nodes and links, and have been used to represent knowledge structures in several disciplines such as linguistics and psychology (Fisher, 1990; Ruiz-Primo & Shavelson, 1996; Sowa, 2006). Semantic networks can be categorized into six types depending on the properties of links and information that nodes hold (Sowa, 2006). Hence, a type of semantic network usually reflects a single aspect of a knowledge structure instead of describing it comprehensively. On the other hand, concept maps are networks with nodes that are connected directionally by links of various relations, and are intended to organize the entire cognitive structure (Novak & Cañas, 2008).

Compared to semantic networks and concept maps, the cognitive map that we devised is focused on representing the dynamic process through which prior knowledge is utilized to develop new concepts. It means that the links in our method show active engagement with a concept in a creative process rather than representing the density of conceptual relations with other nodes. Furthermore, the cognitive map provides multiple layers of links which contain different definitions and properties. Hence two nodes in a cognitive map can be connected to each other several times with different types of links. Through this, a cognitive map supports the representation of a multifaceted cognitive process. In this regard, cognitive maps suggest an expanded way of describing and analyzing cognitive processes that previous studies have not yet contributed.

In order to construct cognitive maps of each participant, the encoded protocols were converted into compositions of nodes and links. Table 3 summarizes how the encoding results were converted into network data. Each encoded item from the five coding categories was defined as an entity in a network in which attributes were assigned according to the coding categories. Then two types of relationships between entities were defined. The first one is about the sequential order of entities which were utilized for designing. The second one is about the relationship with an idea, and whether an entity contributes to the generation of an idea or not. Every entity has a sequential relationship and some of them have the second type of relationship related to an idea.

We constructed 24 cognitive maps using protocols which were converted to network data. Figure 6 shows a cognitive map of participant F3 which was hand-drawn by researchers. In the cognitive map, each encoded item was represented as a different type of figure depending on its coding category. The sequential order between two items was represented as a grey arrow, and items related to the generation of an idea were clustered into a package, colored purple. A cognitive map − this new way of describing a protocol − focuses on visualizing relationships among cognitive elements which were involved in the design problem solving process, and provides a comprehensive representation of its structure.

4.2 Utilization of a social network analysis (SNA) tool

Although individual cognitive maps were hand-drawn for each participant, we decided to construct them again using a social network analysis (SNA) tool in order to automate the visualization process and increase the objectivity of its

Table 3 Conversion of encoded protocols into network data

Elements of a network	*Definition*	*Encoding categories*	*Converted data*
Entity	Each encoded item of five coding categories	Initial ideas	Entity which has an attribute value of Initial idea
		Developed ideas	Entity which has an attribute value of Developed idea
		Episodic precedents	Entity which has an attribute value of Episodic precedent
		Semantic precedents	Entity which has an attribute value of Semantic precedent
		Interpreters	Entity which has an attribute value of Interpreters
Relationship	Relationship between two encoded items	The order of utilization	Sequential relationship
		Contributed to an idea	Mutual relationship

outcome. A variety of SNA tools were made and developed in order to support social network analysis, which seeks understanding of social networks while focusing on the social actors and the relationships among them (Serrat, 2009). SNA originated from sociology, and has been utilized in studies of

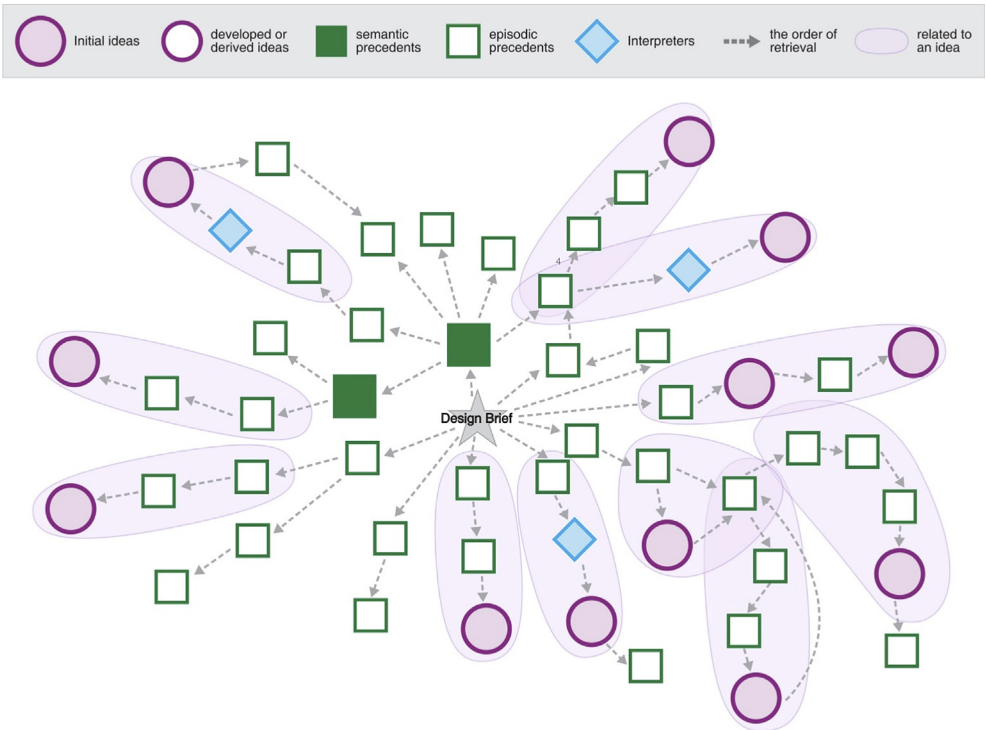


Figure 6 Hand-drawn cognitive map of participant F3 with a legend

community structure, international trade exploitation, and collaborative research networks (J. Scott, 1988). One of the key properties of social network analysis is that it heavily depends on graphical modeling to display and reveal the pattern of networks (Freeman, 2004). Hence social network analysis has been developed using scientific and mathematical theories to enable visualization, and most social network analysis tools provide diverse ways of describing networks according to the research aims and topics. Due to these characteristics of social network analysis, it is expected that the usage of an SNA tool supports generating an objective and scientific description of cognitive processes and investigation of properties of the entire process.

In this study, a social network tool named NetMiner10 was utilized to re-visualize the cognitive process based on encoding results. Similarly to the process of drawing a cognitive map, the encoding results were recognized as network data. In the case of NetMiner10, the program used the terms 'node' and 'link data' instead of network entity and relationship, respectively. As with the hand-drawn cognitive maps, the concept of node corresponds to the encoded item of a protocol in this study. Each encoded item was defined as a node, and assigned a value according to its coding category.

Link data which informs the linkage between nodes corresponds to the relationship between encoded items in this study. As mentioned in the previous section, two different types of relationships were defined in this study. Figure 7 shows a partial cognitive map in order to display two different relationships. The first relationship is a directional linkage depending on the order of utilization in the cognitive process. This kind of relationship is defined as a target-source relationship (Huisman & Van Duijn, 2005; J. Scott, 1988). For example, item A, which is utilized prior to another item, B, has a target-source relationship in which A becomes a target, and B is defined as a source. Every item belongs to both target and source, except items which are located at the end of a think flow, which indicates the discontinuity of a thought. The second type of relationship represents a link between an idea and a cognitive element which contributes to the idea, and it is defined as non-directional link data (Huisman & Van Duijn, 2005). Due to the complexity, in a hand-drawn cognitive map, the second type of relationship was visualized by clustering related elements together into a package. However, the computer-aided cognitive maps connect every entity related to an idea, and this representation implies the interaction of several concepts to create an idea.

4.3 Cognitive maps – visualized cognitive process

In order to construct cognitive maps using an SNA tool, one of the spring embedded algorithms, Kamada-Kawai, was selected and used. This algorithm seeks optimal positions where there is minimum stress on the linkages between nodes (Freeman, 2000; Kamada & Kawai, 1989). It enables us to understand the adjacency between nodes intuitively (Kamada & Kawai, 1989). Figure 8

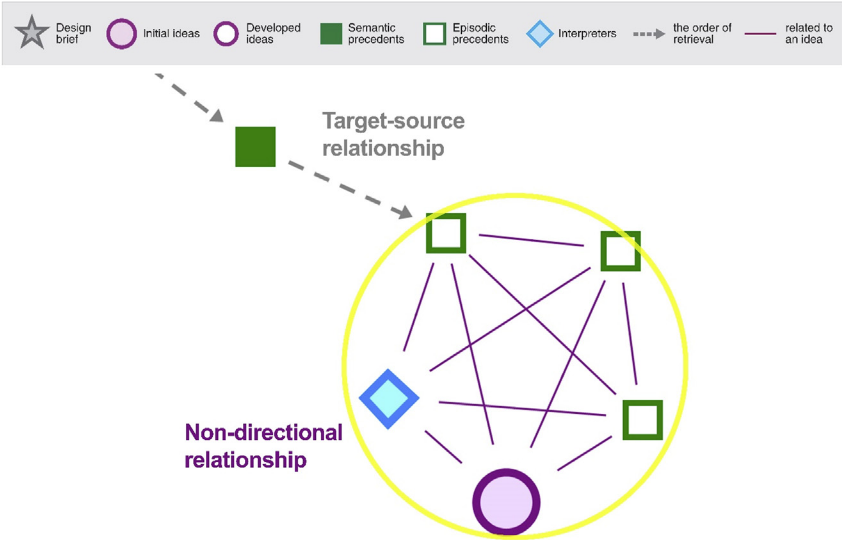


Figure 7 Partial cognitive map generated by SNA software

shows six cognitive maps as examples of visualization output. Every encoded item from five different types of encoding categories – initial ideas, developed ideas, episodic precedents, semantic precedents, and interpreters – were represented as a single figure depending on their category. The sequential relationships were visualized as arrows, and ideas and items involved in the idea generation were connected together and clustered into a package.

5 Advantages of cognitive maps

5.1 Representation of a comprehensive structure of cognitive processes

Cognitive maps have several noticeable benefits compared to previous methods of visualizing cognitive processes based on encoding results. First of all, the cognitive maps display the comprehensive structure of a cognitive process through describing the relationships among encoded items. There have been several attempts to visualize not only encoded items but also their relationships (Kan & Gero, 2008; Valkenburg & Dorst, 1998). These previous attempts have a limitation in describing the entire structure of items with multiple relationships. Most visualization methods have represented the cognitive process as a sequential procedure. Although some researchers tried to describe transitions and relationships between activities, the representation was usually limited to connecting the adjacent activities. Hence the description often lost the complexity and richness of the cognitive process. However, cognitive maps which adopt the concept of a network enable visualization of a cognitive process without compromising the multifaceted properties of the encoded

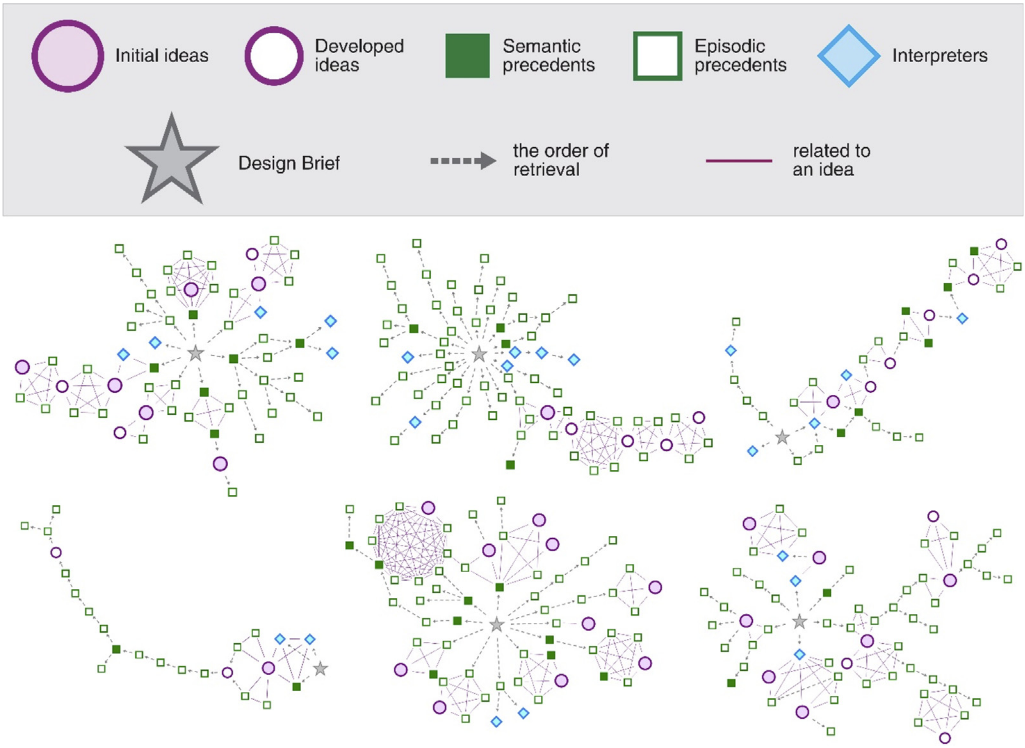


Figure 8 Cognitive maps of six participants — F8, F12, M9, F4, M4, M6

data. Figure 9 provides a comparison of two different description methods — one follows the traditional paradigm of describing the cognitive process and the other is a cognitive map. They were generated based on the encoding results of participant F2 and participant M9.

The conventional graph (Figure 9 left), which portrays the process as a sequence, summarizes the encoding results well and helps to compare the two different processes. However, the cognitive maps (Figure 9 right) provide a more lucid representation to understand the characteristics of each process and identify the differences intuitively. It describes the diversity and the depth of the entire cognitive process as well.

The cognitive maps also support the qualitative investigation of cognitive processes that a quantitative analysis cannot reveal. Table 4 and Figure 10 are

Table 4 Quantitative data of participant F11 and M5 from encoding

Number of	*Think flows*	*Initial Ideas*	*Developed ideas*	*Precedents*	*Interpreters*
F11	25	1	5	54	2
M5	17	1	3	44	3

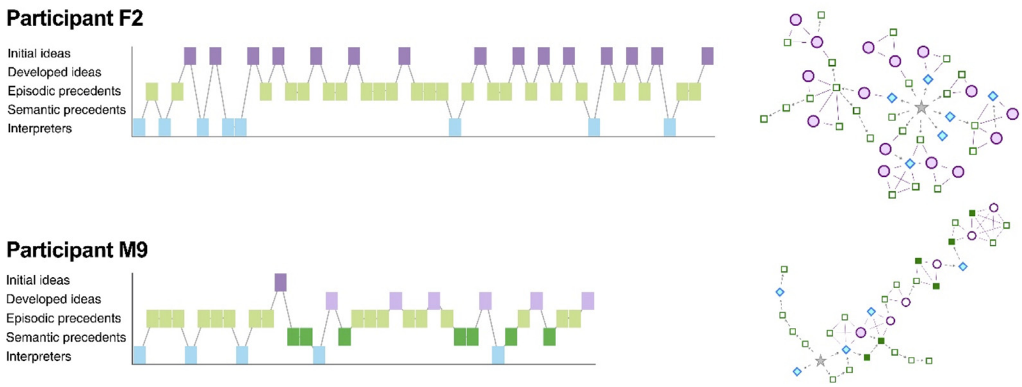


Figure 9 Comparison of two different visualization methods

examples from two participants who look quantitatively similar but are readily distinguishable in their cognitive maps.

The quantitative data shows that participants F11 and M5 are not significantly different in terms of the frequency distribution of coded items as the result of the Chi-square test indicated (χ^2 (4) = 0.93, p = .920). The cognitive maps, however, suggest a significant difference in their cognitive processes (Figure 10). Participant F11 (left) explored a variety of topics while generating a developed solution. The expanded shape of the cognitive map describes the divergent thinking process which consists of several independent think flows. On the other hand, the cognitive map of participant M5 (right) shows a directional and focused process compared to the one on the left. Even though the participant retrieved various precedents, they were highly interrelated with each other and contributed to the progress of a limited range of thoughts.

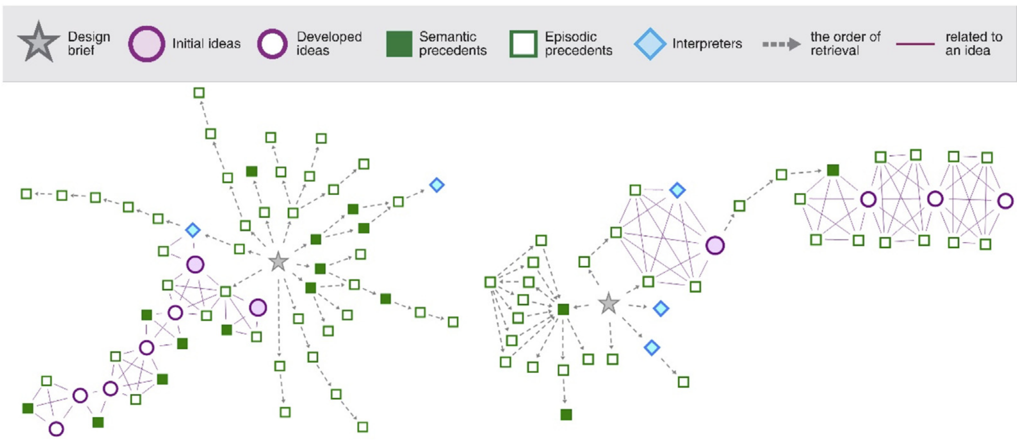


Figure 10 Cognitive maps of participant F11 (left) and M5 (right)

5.2 Flexible application to various coding schemes

The concept of cognitive maps is applicable to any other coding schemes which can clarify the relationships between encoded items. Most previous description methods were devised especially for specific coding schemes. Hence it was markedly difficult to utilize the same description with other coding categories or paradigms. However, the concept of cognitive maps allows flexible alteration and adaptation regardless of the coding scheme. For example, the coding scheme of Valkenburg and Dorst (1998) has four cognitive activities – naming, framing, moving, and reflecting – and the researchers made an attempt to visualize the design process. In their visualization method, the framing activity is represented as a box which embraces other related activities. Using a cognitive map, the four types of activities could be represented as four different figures, and their relationship could be visualized by links among them. Figure 11 provides the application of the concept of a cognitive map while comparing it with the original visualization method of other researchers.

5.3 Quantitative metrics to describe and compare cognitive maps

Network analysis has its own metrics to describe the properties of networks. Many of them are developed based on graph theory in order to define and quantify the attributes of a network and the nodes in it (Scott, 1988; Serrat, 2009). Compared to the other methods that have been devised for protocol analysis, a cognitive map has a wide range of predefined metrics which can be easily employed to investigate its properties. For instance, the average degree and the diameter are metrics which describe the properties of a network (Scott, 1988). Average degree represents the average number of links that the nodes of a network have. A network which shows a higher value of average degree indicates that nodes are connected to each other more frequently than

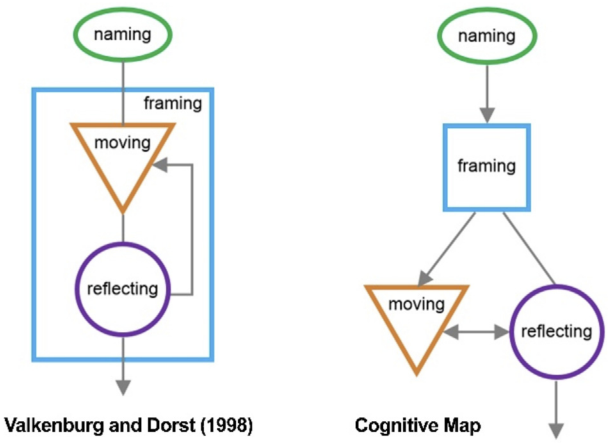


Figure 11 Application of the concept of a cognitive map (right) to a different coding scheme (left)

the other network. The link index of a linkograph, which is defined as the ratio between the number of links and the number of moves, is quite similar with the concept of average degree in that it describes the density of linkages among nodes (Kan & Gero, 2005b). According to the argument of Kan and Gero (2005a), it is expected that a network with a higher average degree may have less opportunity to create quality and novel outcomes because it is already too saturated to develop new linkages among nodes. The diameter means the longest distance among all the calculated shortest paths between nodes in a network. Hence a large diameter indicates the deep structure of a network, and relatively low connectivity among nodes. The depth of a linkograph that El-Khouly and Penn (2013) utilized is a similar metric to diameter which is also based on the distance between one node and the others. They used this metric as part of their analysis in order to identify the emergence of insights, and a low mean depth indicates the incremental emergence of insights (El-Khouly & Penn, 2012, 2013). In this study, a lager diameter could be interpreted as a focused development of ideas within a limited range of alternatives.

Centrality is one of the most frequently used metrics in network analysis; it identifies the relative importance of each node in a network (Scott, 1988). Unlike previous metrics — average degree and diameter — which measure properties of a network, the centrality matrices offer comparison among nodes inside of a network. There are a variety of centrality types depending on the attribute that characterizes an important node. Degree centrality is based on the number of links that are directed to and/or from a node. A higher degree centrality refers to a node that has more connections with other nodes, and is more likely to be powerful in the network. The concept of degree centrality resembles critical moves in linkography, and there are similarities between a critical move and a node with higher degree centrality (Goldschmidt, 2014). Critical moves are often defined as moves with a particularly high number of links which include both forth links and back links. Hence critical moves are regarded as structural anchors which enable understanding of how an issue is treated and concluded within a design process (Goldschmidt, 2014). Contrary to a linkograph, a cognitive map is often composed of multiple types of nodes, hence the meaning and implication of higher degree centrality should be interpreted again from the perspective of characteristics of the node.

The proportion of links is also utilized as a measure of productivity. As a higher portion of links follow the critical direction of design thinking, it is assumed that the designers demonstrate higher productivity (Kan & Gero, 2005a, 2005b). In the case of network analysis, the productivity could be measured in a different way depending on the organization of links and nodes defined by the researchers. In this study, the proportion of nodes that connect to an idea could be considered as the productivity of the design process. However, employment and interpretation of network-based metrics require a considerable amount of thought and examination based on the nature of the cognitive process and the logic behind the metrics. The same metric can imply different meanings depending on the aim of the research, devised coding scheme, etc. In this regard, we include only the measure of diameter in our analysis in order to compare the cognitive maps of the participants. The potential of other metrics should be investigated further in future studies in order to complementarily support the findings from qualitative analysis.

6 Cognitive styles in the utilization of precedents for design problem solving

In this paper, we concentrated on the procedural characteristics of the design problem solving process based on the qualitative interpretation of cognitive maps. A cognitive map enables us to look over the comprehensive structure and configuration of a cognitive process. This contrasts with the quantitative analysis of encoding results which have been commonly utilized. Based on the interpretation of the cognitive maps, three phases of the cognitive process were identified – exploration, generation, and development. For each phase, the encoded results were examined much more thoroughly to investigate the cognitive characteristics of the designers. Finally, the cognitive characteristics of each phase were aggregated and interpreted to form a comprehensive picture of the cognitive style of a participant.

6.1 Phases of the creative process

The cognitive maps of participants showed that there were three different types of think flows. The first one is a think flow which is solely composed of precedents or interpreters. It means that this think flow does not contribute to formulating an idea. A second one is a think flow which has a relationship with an initial idea. It suggests that precedents in the think flow were utilized for generating an initial concept. The last one is a think flow related to a developed idea, which shows the process of refining an idea. Figure 12 highlights the three different types of think flows in a cognitive map.

These three types of think flows suggest the existence of three different phases of the design problem solving process – exploration, generation, and development. Each phase consists of distinguishable mental activities in terms of its utilization of prior knowledge and idea generation, and they randomly and iteratively occur in an entire process to support design problem solving.

The first phase that every participant showed is the exploration phase, which includes the retrieval of prior knowledge from memory and searching for associations between the design problem and retrieved knowledge. All participants had at least one think flow which is composed of precedents but does not contribute to idea formation. This indicates that exploration is a distinctive part of cognitive processes. During this phase, designers continuously explore precedents to find possible associations with the problem, and it is expected that knowledge structure models that previous studies suggested

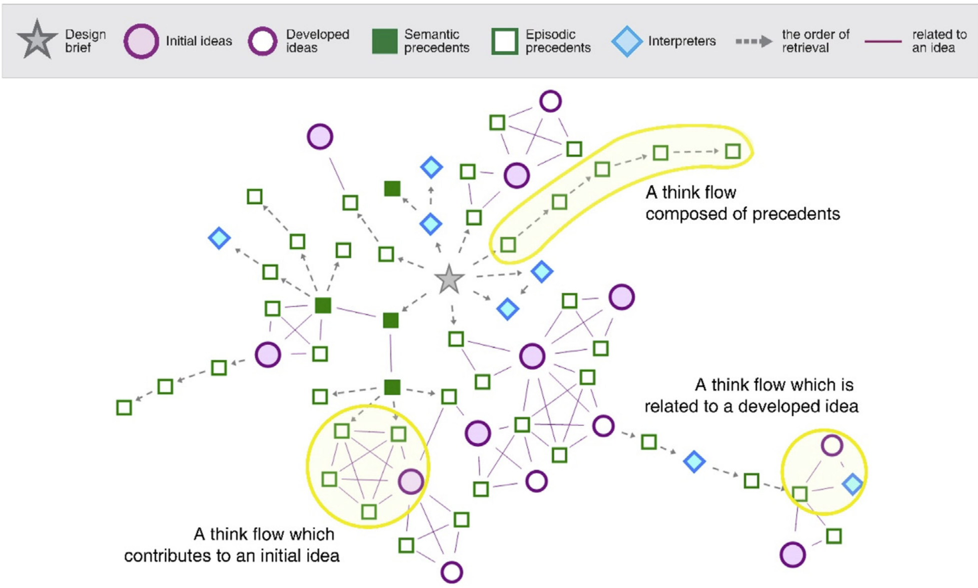


Figure 12 Three types of think flows in a cognitive map

(Oxman, 1990, 1994, 1999) have a strong influence on the productivity of this phase.

The second phase is a generation phase, where novel and/or discrete design concepts are formulated. Among precedents which were explored during the first phase, only some of them were utilized in this phase. Think flows related to an initial idea show the generation process that a participant experienced. Although all participants had this phase, the cognitive style and its outcome varied immensely.

The last phase is a development phase in which an initial design concept is improved in terms of its details. Think flows of this phase begin with an idea which is generated in advance. Designers started with an initial design concept, and tried to elaborate it while utilizing their prior knowledge and experience. This phase can also be described as a period when the form of a concept is tested and confirmed in terms of its morphological, functional, and aesthetical value. Hence there were many participants who retrieved multiple precedents to find a relevant form for his/her new concept. Unlike the previous two phases – exploration and generation – the development phase was not observed from all participants.

The significant insight of this division is the distinction between the retrieval of prior knowledge and the generation of new ideas. Although various models of the creative process have been suggested, they regarded the process of exploring relevant knowledge as a part of the generation phase, or a preparatory step for it. In the case of the Geneplore model suggested by Ward, Smith, and Finke (1999), the retrieval of prior knowledge is described as one of the elements which contributes to the generation phase. The four-stage model is a classical description of the creative process which has been reviewed and revised by many researchers (Busse & Mansfield, 1980; Cagle, 1985; Lubart, 2001; Patrick, 1937; Wallas, 1926). The first stage is the preparation stage, which includes the analysis and defining of a problem. In the preparation stage, the exploration and retrieval of relevant knowledge is described as an activity which could be done. The model devised by Bassadur et al. (2000) gave more emphasis to the exploration of knowledge by regarding it as one of eight steps. Although several studies have suggested a distinction between idea generation and retrieval of relevant knowledge, there have been few attempts to investigate the different cognitive aspects of the two phases (Amabile, 1996; Getzels & Csikszentmihalyi, 1976). The protocols of this study proposed a clear distinction between the exploration and the generation as well as a change of cognitive styles across the two phases. In this regard, the identification of three phases – exploration, generation, and development – provides a means to examine the creative process and the cognitive styles.

6.2 Identification of cognitive types in each phase

In order to identify the cognitive type of each participant for each phase, the structures of the cognitive maps were investigated while reviewing the quantitative data of encoded results. Table 5 summarizes the definition of cognitive types in each phase, and data that was utilized to identify the type of each participant. Each phase has three types, which are numbered 1 to 3 from the most convergent type to the most divergent one respectively. Although quantitative data were reviewed together, judgments to determine the type of each participant were made by researchers qualitatively.

To identify the cognitive type of the exploration phase, the entire shape of the cognitive maps and the number of think flows were examined. The number of think flows represents the diversity of precedents retrieved from the memory system, and every precedent which was mentioned in the protocol was considered as an explored concept while seeking its contribution to idea generation. Hence the number of think flows increases as more diverse topics are retrieved and explored. Indeed, participants showed differences during the exploration phase. Some participants retrieved a variety of topics and precedents related to the design situation while others rather focused on a limited number of topics. The diversity also affects the shape of a cognitive map. As more topics are mentioned, the cognitive map appears more expanded and dispersed. Table 6 shows the results of clustering participants into three categories depending on their cognitive types in the exploration phase. The average number of thinks flows was calculated by taking the mean number of think flows that participants of each type had. A Kruskal–Wallis H test showed that there was a

Table 5 Definition of cognitive styles in each phase and factors related to them

	Exploration phase	*Generation phase*	*Development phase*
Cognitive style	The level of divergence in explored topics	The diversity of generated ideas	The extent of developing ideas
Features of Cognitive maps	Spreadness of the entire map	Distribution of initial ideas	Progression of think flows
Quantitative data from encoding results	Number of think flows	Number of initial ideas	Number of developed ideas

Table 6 Numerical description of each cluster in the exploration phase

Cognitive style in Exploration	*Type 1*	*Type 2*	*Type 3*
	Limited exploration	*Moderate exploration*	*Divergent exploration*
Number of participants	6	13	5
Average number of think flows	13.17	19.54	32.40

statistically significant difference in the number of think flows among the three types, χ^2 (2) = 9.99, $p < .05$.

In the case of the generation phase, we focused on the number of initial ideas which were relatively novel and original in order to identify the cognitive types. While generating solutions, each participant showed different cognitive types. Some participants preferred to generate various concepts while referring to a variety of topics. Contrary to this, others rather preferred to generate a limited number of ideas within constrained topics. Hence the number of initial ideas and their distribution in a cognitive map were utilized to identify the cognitive types in the generation phase. Table 7 shows summarized information of the three different types in the generation phase. As suggested by the results of the Kruskal–Wallis H test, these three types are different from each other in terms of the number of initial ideas, χ^2 (2) = 27.60, $p < .05$.

In the case of the development phase, sixteen out of 24 participants developed ideas which were refined from initial ideas with more details. The other eight participants did not generate any developed ideas. Thus these eight participants were classified together into a cognitive type with no development. While investigating the data of the remaining sixteen participants, we found that the cognitive maps provided a more intuitive and profound understanding of the development phase. Table 8 shows the number of developed ideas of two participants with their cognitive maps. They generated a similar number of developed ideas. In the cognitive maps, however, the level of development of their ideas is significantly different. In the case of participant M1, a number of developed ideas were generated from a single initial idea in a continuous manner. Thus the cognitive map has a long think flow which represents progressive development of an idea. Contrary to participant M1, the developed ideas of

Table 7 Numerical description of each cluster in the generation phase

Cognitive style in Generation	*Type 1*	*Type 2*	*Type 3*
	Limited generation	*Moderate generation*	*Divergent generation*
Number of participants	10	12	2
Average number of initial ideas	1.70	9.58	16.00

F6 were generated from three different initial ideas. Hence the cognitive map of F6 looks evenly distributed without a distinctively long think flow. It indicates that the development of initial ideas was not markedly progressive and/or advanced.

In conclusion, three different cognitive types were identified in the development phase based on the number of ideas and the structure of cognitive maps. The first type showed a progressive development with iterative refinements and improvements. The second one showed a preliminary level of development, while the third one showed no development phase as explained before. Table 9 summarizes the results as identified in the development phase.

Although the judgment about the level of development was made qualitatively based on the cognitive maps, a Mann–Whitney U test revealed that types 1 and 2 showed a statistically significant difference in terms of the average number of developed ideas, Mann–Whitney $U = 667.00$, $p < .05$.

6.3 Cognitive styles in the design problem solving process

In this study, we viewed a cognitive style as a combination of cognitive types over three phases. We integrated the types that a participant showed for each phase, and the integrated combination was defined as that participant's cognitive style of the entire design problem solving process. Hence the judgement of a cognitive style was naturally driven by the types of the three phases that were identified by researchers qualitatively in the previous stages. As a result, we

Table 8 Number of developed ideas of participants M1 and F6

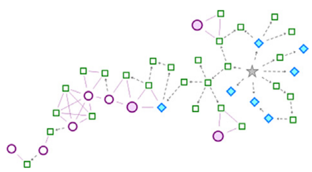
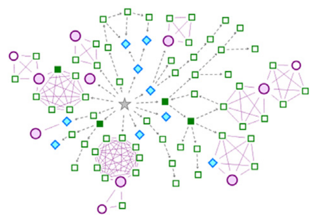
	M1	F6
Number of developed ideas	5	3
Cognitive map		

Table 9 Numerical description of each cluster in the development phase

Cognitive style in Development	*Type 1*	*Type 2*	*Type 3*
	Progressive development	*Preliminary development*	*No development*
Number of participants	9	7	8
Average number of developed ideas	4.75	3.43	0

found four different combinations of types of three phases, and these represent four cognitive styles in the design problem solving process. Table 10 shows the integrated cognitive styles of 24 participants with their types for all three phases. The name of each cognitive style was decided as follows in order to intuitively deliver the key features of each style: *Focused Probers*, *Treasure Hunters*, *Selectors*, and *Explorers*.

Table 10 Cognitive styles of 24 participants

Participants	*Types of Cognitive Styles in Each phase*			*Integrated Cognitive Styles*
	Exploration 1 – limited 2 – moderate 3 – divergent	*Generation* 1 – limited 2 – moderate 3 – divergent	*Development* 1 – progressive 2 – preliminary 3 – none	
M1	2	1	2	Treasure Hunter
M2	1	1	1	Focused Prober
M3	2	2	3	Explorer
M4	2	2	3	Explorer
M5	1	1	1	Focused Prober
M6	2	2	2	Selector
M7	3	2	2	Selector
M8	2	2	3	Explorer
M9	1	1	1	Focused Prober
M10	2	2	2	Selector
M11	1	1	1	Focused Prober
F1	2	3	3	Explorer
F2	3	3	3	Explorer
F3	2	2	3	Explorer
F4	1	1	1	Focused Prober
F5	2	1	1	Treasure Hunter
F6	3	2	2	Selector
F7	1	1	1	Focused Prober
F8	2	2	3	Explorer
F9	2	2	2	Selector
F10	2	2	3	Explorer
F11	3	1	1	Treasure Hunter
F12	3	1	1	Treasure Hunter
F13	2	2	3	Explorer

Table 11 Cognitive characteristics of four cognitive styles and the average number of initial ideas

	Focused Probers	*Treasure Hunters*	*Selectors*	*Explorers*
Number of participants	6	4	5	9
Average # of think flows	13.17	24.00	24.80	21.78
Average # of initial ideas	1.17	2.25	9.20	11.33
Average # of developed ideas	4.83	5.00	2.40	0
Average diameter	29.2	19	10.2	8.56
The degree of divergence in the exploration phase	limited	moderate ∼ divergent	moderate ∼ divergent	moderate ∼ divergent
The diversity of generated ideas	limited	limited	moderate ∼ divergent	moderate ∼ divergent
The extent of developing ideas	highly progressive	preliminary ∼ progressive	preliminary	none

Table 11 describes the characteristics of each cognitive style through the number of participants and the average number of initial ideas. In order to verify the differences among cognitive styles, the average diameter was calculated as well. As described in section 5.3, a large diameter of a network indicates a deep structure with low connectivity among various topics. Hence, it could be considered as a representation of a focused cognitive process within a few topics. The average diameter shows that *Explorers* have the smallest diameter whereas *Focused probers* demonstrate the largest.

The '*Focused Probers*' includes six participants who showed a limited and focused cognitive process while solving the given design problem. They retrieved a limited number of topics in the exploration phase, and generated fewer ideas – on average 1.17. Instead of creating more design concepts, they developed each idea deeply with a great amount of detail.

The second cognitive style is labeled '*Treasure Hunters*', which is characterized by a relatively small number of initial ideas compared to the explored precedents. Four participants belong to this group. Although the divergence level of exploration was moderate or high, the participants generated only 2.25 ideas on average. They all showed the cognitive phase of developing initial ideas, though the level of development differs within the group of participants. Except for the number of think flows, *Focused Probers* and *Treasure Hunters* are quite similar in terms of generated ideas. However, they showed different levels of diversity in the exploration phase, which is clearly demonstrated by the cognitive maps (Figure 13).

The '*Selectors*' and the '*Explorers*' share similar characteristics in the exploration and generation phases. Their cognitive styles showed a moderate or

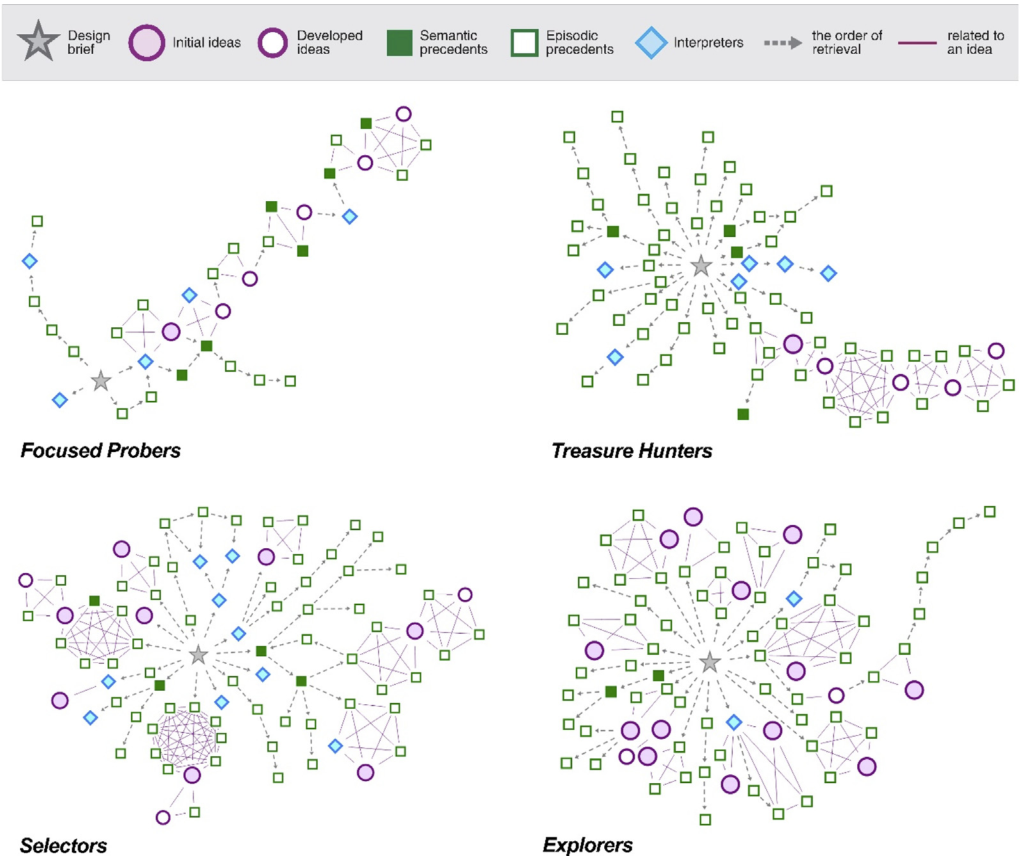


Figure 13 Cognitive maps of four cognitive styles

diverse exploration of precedents and generation of ideas. However the *Selectors* generated slightly fewer ideas compared to the *Explorers*. The significant difference between these two styles is located in the development phase. The five *Selectors* had the *development phase* with primary development. In contrast, the nine *Explorers* didn't make any development for their ideas. Figure 13 shows four cognitive maps which represent each cognitive style.

6.4 Cognitive styles in relation to design abilities

In fact, this study is not the first attempt to classify the cognitive styles of the creative process. Although a limited number of studies have been done in the design discipline, there have been various studies focused upon cognitive styles in psychology and the creativity research field (Brophy, 2001; Cross, 1985; Khandwalla, 1993; Kvan & Jia, 2005; Martinsen, 1995; Riding & Cheema, 1991). However this study is unique and significant because it provides a more elaborated explanation of cognitive styles through integrating the types of three different phases in the creative process. Compared to the description of previous studies which divide design thinking into convergent and divergent

(Cross, 1985; Tovey, 1984), the four different cognitive styles defined in this study suggest a richer explanation of convergent and divergent behaviours depending on the design phase. *Focused probers* were people who kept thinking in convergent ways, and *Treasure hunters* divergently explored idea sources, but became convergent in the idea generation and development phases. *Selectors* showed a similar pattern of thinking with *Treasure hunters*, but the depth of convergent thinking in the idea development phase was shallower than *Treasure hunters*. Contrary to the others, *Explorers* exhibited divergent thinking throughout the entire design process.

Although the result of this study extends previous studies that investigated cognitive styles, it also suggests a possible relationship between the level of expertise and the cognitive variances among participants. Cross (2004) compared the design behaviours of novice and expert designers and summarized that experts are ill-behaved and solution-focused designers who are readily attached to a limited number of early concepts instead of generating a wide range of alternatives. The study of Ahmed, Wallace, and Blessing (2003) provides a similar description that experienced designers tend to have their own approach to a particular problem while novices repeat the pattern of trial and error without a distinctive strategy. In this regard, it seems likely that the cognitive behaviours of *Focused Probers* and *Treasure Hunters* fit the characteristics of experts whereas the *Explorer* shows behaviours of novice designers. However, a divergent way of thinking which indicates the ability to develop multiple alternatives has also been regarded as an important part of design thinking, and it has been promoted to nurture experienced designers (Atman, Chimka, Bursic, & Nachtmann, 1999; Cross, 2004). It is hard to conclude that fluency of divergent thinking conflicts with the level of expertise that a designer has. In this study, we did not require a definite form of the final outcome and let them mange the entire process by themselves. This experimental setting was intended to make participants be liberal in the way they dealt with the design problem. Thus we think that the cognitive process of participants may be driven by their personal and preferred way of thinking rather than their competitive expertise. However, further study is needed to examine the details of cognitive style and its relationship with the abilities of designers. Especially it is necessary to measure the quality of design outcomes to compare the competencies of each cognitive style with respect to design abilities and expertise. This is a limitation of this study and also an important issue for further research in relation to developing an appropriate measurement of design outcomes.

This study also tried to provide a more reliable description of the cognitive styles of designers who usually deal with complex and multifaceted problems. Some of the previous studies utilized a pre-developed scale or an inventory to assess the cognitive styles of participants (Basadur et al., 1990; Brophy, 2006; Kirton, 1987; Kvan & Jia, 2005; Martinsen, 1993). Most of those scales took the form of questionnaires, yet these were far removed from the general design problems and hardly reflected the cognitive behaviours in the design process. Thus this study investigated the utilization of various cognitive elements as an indicator of a cognitive style to understand the characteristics of personal design processes that previous studies had limitations in explaining.

The cognitive styles identified in this study support the work of other researchers which indicate cognitive style as a critical factor in the application of experiential and tacit knowledge employed during design practice (Brophy, 2001; Cross, 1985; Self, Evans, & Dalke, 2014; Tovey, 1984). Differences in the cognitive style imply differences in perceiving, interpreting, and solving design problems. This research has shown that each cognitive style can be varied in its creative outcomes which are related to the diversity of ideas and the degree of development. In this regard, understanding the cognitive styles of designers may have more practical implications for both design education and design practice.

7 Conclusions and implications

This study conducted a protocol study in order to investigate the cognitive styles of designers in relation to the utilization of precedents and idea generation. 24 masters students majoring in product or industrial design participated in a one and a half hour design exercise, and verbalized their cognitive process while they were solving a given design problem. The verbal protocols from the experiment were firstly segmented into units of a discrete think flow. Then the segmented protocols were encoded based on coding categories which consisted of ideas, precedents and interpreters.

In order to describe and support the analysis of encoded protocols, a new graphical representation was devised adopting the concept of a network. This is called a '*cognitive map*', and is composed of encoded items and relationships among them. Compared to existing description methods, a cognitive map is good at providing a comprehensive structure of cognitive processes based on the encoded results. It also supports a rich and diverse interpretation of protocols which quantitative data has difficulty in indicating. The concept of cognitive maps is flexible enough to be applied to other coding schemes while securing its objectivity when it is supported by an SNA tool.

Through analyzing the cognitive maps of 24 participants, three different phases of the creative process were identified: the *Exploration*, *Generation*, and *Development* phases. The cognitive types of each phase were determined by researchers while referring to the quantitative data and the structure of cognitive maps. Then four cognitive styles were identified through integrating the cognitive types of these phases: *Focused probers*, *Treasure hunters*, *Selectors*, and *Explorers*. These four styles showed noticeable differences in exploration of precedents, and generation and development of ideas. The cognitive maps of each participant described the characteristics of cognitive styles without compromising the richness and complexity of the protocols.

As previous studies have argued (Bar-Eli, 2013; Brophy, 2006; Cross, 1990; Tovey, 1984), the results of this research indicate the importance of understanding the cognitive styles of designers. Design education is required to provide appropriate educational programs for each student in order to promote students' expertise and distinctive abilities. However, this study did not make any attempt to measure and evaluate the quality of outcomes and the abilities of each participant. In this regard, further studies are required to investigate the relationship between cognitive styles and the quality of design outcomes in relation to design expertise. Cross (1990) argued that design ability can be developed and improved to the mature level through design education. If a design student naturally has a cognitive style that prefers a certain type of thinking in a certain phase, the education should be different from that received by others who have another cognitive style. The education should be able to identify the cognitive style of each student, and nurture a competitive expertise while managing the strengths and deficiencies of their cognitive style.

In conclusion, this study has implications for the way of describing and analyzing protocols as well as the understanding of cognitive styles in the idea generation process. In terms of its methodology — cognitive maps — further studies are required to test its applicability toward a variety of coding schemes and to understand the implications of network-based metrics upon cognitive studies. The nature of each cognitive style and its relationship with design expertise are also interesting issues which should be studied further. It can provide a profound understanding of each cognitive style in order to identify styles and promote their usage in design education.

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