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COGNITIVE EXERCISES FOR DESIGN THINKING

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ABSTRACT
Underlying design thinking process has been explained using visual thinking composed of seeing – imagining – drawing. In this way, interactive and iterative natures essential in design thinking can be better understood. The visual reasoning model that supports visual thinking with cognitive activities can be used to explain and guide cognitive processes in design thinking. It would be desirable to devise methods and tools to support design thinking using the visual reasoning model as a framework. This paper presents on-going research about cognitive exercises for design thinking with discussion on requirements in devising such exercises and future research issues.

Keywords: Design Thinking, Visual Reasoning Model, Activity Transformation, Design Cognition

1 INTRODUCTION

Design thinking is now recognized as a human-centered, possibility-focused and hypothesis-driven problem solving method [1, 2]. Design thinking process is often described with the process sequence of *Empathize – Define – Ideate – Prototype – Test* [3]. Many iterations of this design thinking process are conducted to solve a problem. Liedtka [4] described design thinking with four waves composed of *what is?*, *what if?*, *what wows?* and *what works?*, where what if? corresponding to Ideate is emphasized with the highest wave.

McKim (1972) described visual thinking process as iterative interactions of *seeing – imagining – drawing* [5]. The process would start from seeing as basic understanding of the design problem. Next the process moves to imagining where potential solution ideas are imagined while these are ambiguous. Drawing to help the imagination follows. Looking at the sketch, designers see if the imagination roughly sketched could be a solution to the problem understood with previous seeing processes. By seeing that some parts are OK but some other parts are deficient, improvements needed are identified in the next seeing. Imagining and drawing of solution improvements follow. Seeing the improvements are OK, understanding of the problem may be reinterpreted, then further imagining comes again. A simple prototype is built and the designers see the prototype to evaluate based on some evaluation criteria identified in previous seeing processes. Imagining continues with further improvements. Next improved prototypes are built. The next seeing process involving potential users for their feedback follows so that imagining of improved solutions can continue [6]. In this way, the design process makes progresses with visual thinking of seeing – imagining – drawing.

McKim [5] smoothly described the general designerly way of problem solving process through expressions easy and familiar to designers. This design process has been described later as seeing – moving – seeing [7]. Experienced designers smoothly combine the iterative process of seeing – imagining – drawing, and designers may seem to conduct imagining and drawing simultaneously. Designer capabilities in performing visual thinking smoothly and naturally with moving of imagining and drawing and reflection of seeing are critically important [8]. Visual reasoning capability has been identified as a critical element of design creativity [9]. A visual reasoning model [10] was developed to understand the cognitive process of design by describing the seeing – imagining – drawing visual thinking process with basic cognitive activities of *perception, analysis* and *interpretation* for seeing; *generation, transformation* and *maintenance* for imagining; and *internal* and *external representations* for drawing as shown in Figure 1. Interactions of these cognitive activities as well as designer's *knowledge* and *schema* on the object of designing constitute the visual reasoning process.

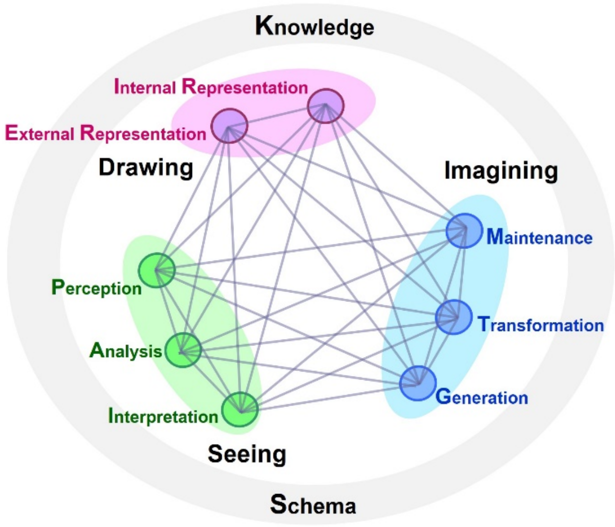


Figure 1. Visual Reasoning Model (from [10])

This reasoning model was developed to provide step by step guidances for visual reasoning processes for tasks like a missing view problem, where a third orthographic projection of a valid 3D solid object is to be sketched given two consistent orthographic projections [11]. Suwa and Tversky [12] proved that their *constructive perception* task, where many different interpretations are to be made for ambiguous drawings, was valuable in comparing visual reasoning ability between design experts and novices. Both capabilities on missing view problems and constructive perception tasks have been proven to be correlated with design capabilities [9].

Object of designing in service design is human activities as services are defined as activities done by human beings for others with some values [13]. Structured methods for imagining have been developed for service design and these methods have been characterized using the visual reasoning model [6]. Particularly, the structured *what if* method utilized the Context-Based Activity Modeling [14, 15] method of human activity description as the schema in associating the seeing part and the imagining part. It is critical to enhance the ability of imagining in close interaction with seeing and drawing in service design thinking. As CBAM would serve as a formal description language for human activities and would have an important potential to work as a framework for service design in the digital transformation era, exercises to enhance familiarities for CBAM would be desirable with the structured *what if* imagining method.

This paper presents on-going research about cognitive exercises for design thinking where interactive and iterative operations of those cognitive activities of the visual reasoning model are specifically orchestrated. The remainder of the paper is composed like the following. First, missing view problems and similar visual reasoning tasks are characterized with orthographic projection rules as schema. Constructive perception tasks are then discussed including the aspect of constructive perception that is not present in the missing view problem, which would be regarded as reframing or avoiding fixation. Thirdly, as a more comprehensive cognitive exercise for service design thinking, making stories exercises, that are newly developed, are explained so that exercises for cognitive elements of creativity [16] are combined with structured imagining method using CBAM. Finally, the paper will be concluded with discussions regarding potential frameworks for design thinking learning and education including future research issues.

2 COGNITIVE EXERCISES FOR SEEING – IMAGINING – DRAWING

Three cognitive exercises for design thinking process of seeing – imagining – drawing are now described as these can be used to address different level of difficulties and different emphases as well as interactivities. While the first two have been used before in some empirical research on design creativity, the third has been newly devised enhancing an existing exercise on cognitive elements of creativity.

2.1 Visual Reasoning Exercise

As the visual reasoning model was developed from the cognitive activities of the iterations of seeing – imagining – drawing, description of the cognitive process of a missing view problem like the one in Figure 2 would be straight forward. Note that a missing view problem is a typical visual reasoning so that a three dimensional solid is to be imagined by seeing the front view and top view projections through iterations of seeing – imagining – drawing. After *perceiving* top horizontal edge of the front view and the left rectangle of the top view and *analyzing* that these two entities match in their widths, it is hypothetically *interpreted* that these two would *generate* a long rectangular block based on the *schema* of orthographic projection. When this block is visually *represented internally*, it is confirmed that this block would be *analyzed* to satisfy the constraints imposed by the other entities. Then, that block may be sketched *externally*. For those who are good in their visual imaging, that block may not need to be externally represented. Next, the bottom edge of the front view and the big rectangle of the top view are *perceived* and their matching widths would be *analyzed*. Then the wider rectangle of the front view and the big rectangle of the top view would be hypothetically *interpreted* to *generate* a big bottom rectangular block in *internal representation* using the *schema* of orthographic projection. After confirming *analysis* that this block would satisfy the other constraints imposed by other entities, this base block can be visually *represented* or sketched. When these two blocks so far represented are considered together, the two rectangular faces matching the front co-linear edges of the top view can be *perceived* collectively. Then it can be *interpreted* that these two faces are co-planar. These in turn are *transformed* to be merged into a face in *internal representation*. Then the solid object is to be *perceived* and this would be *analyzed* to be inconsistent with the horizontal edge in the middle of the front view. Through further seeing, the horizontal top rectangular face of the upper block can be *transformed* to a slanted rectangular face with its front edge is lowered to the height of the middle horizontal edge of the front view using the *schema* of orthographic projection. Then finally the current 3-D solid object *represented* would satisfy both the front and top views. The solid is then *sketched externally*, ending the visual reasoning process. More of this kind of visual reasoning exercises are created with varying level of difficulties and different number of iterations required.

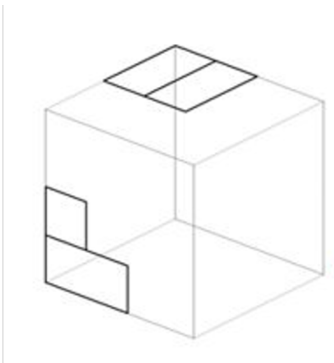


Figure 2. A Missing View Problem

2.2 Constructive Perception Exercise

In constructive perception, users are asked to give different interpretations as many as possible for a few ambiguous drawings shown in Figure 3. A typical process of constructive perception would start with *perception* of some visual features of the drawing. For example, round part in the bottom of Drawing 1 is *perceived* and round part in the upper portion is also *perceived*. Then these two round features are *analyzed* to be of the same width, making a matching bottom and top pair. Then what if hypothesis is made in *interpretation* like "what if these matching round features are hypothesized to be those of a hamburger" based on the *knowledge* of the user. Then, according to the hypothesized interpretation, some parts of the drawing would be *transformed*. For example, those small features at the right part of the upper round part could be removed in *imagining* with *internal* visual *representation*. With these transformed, further *analysis* with *knowledge* can be done and if this confirms the hypothesized hamburger what if, then the user would *say out externally* or *write down externally* "hamburger". This process can be depicted by visiting the basic cognitive activities of the visual reasoning model of Figure 1 and knowledge and schema if relevant as shown in Figure 4 with the reasoning sequence numbers.

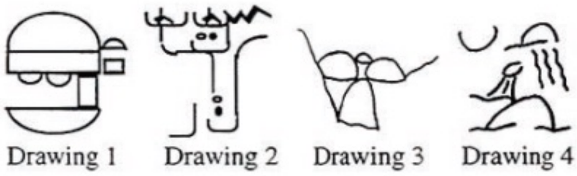


Figure 3. Ambiguous Drawings for Constructive Perception [12]

Perceiving and analyzing an ambiguous drawing, many different interpretations of the drawing are to be made. For this, a new interpretation is to be *imagined* hypothetically with support from previous *knowledge* of visual images, resisting fixation to previous interpretations. In *internal representation* of hypothesized *interpretation*, improved perception is to be confirmed by *analysis* with *knowledge* to result in the confirmed new *interpretation*. Then, the user would *represent* it *externally* by saying, for example, an espresso machine in this time. Note that, in this seeing – imagining – drawing iterations, the role of any specific *schema* is relatively weak unlike the missing view problems. On the other hand, *knowledge* plays an important role in making what if hypotheses repeatedly overcoming fixation.

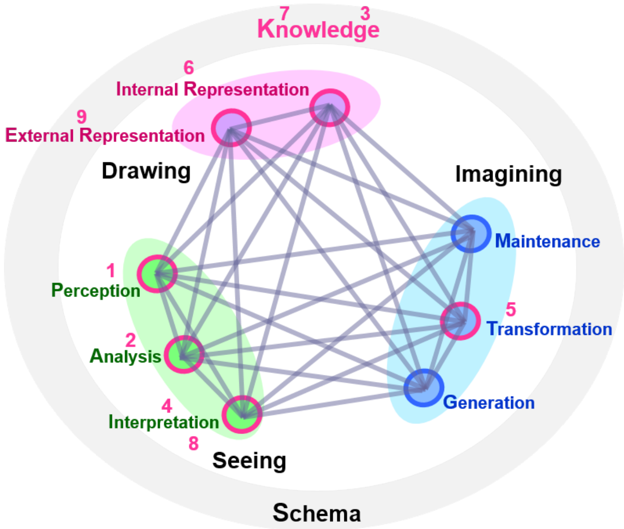


Figure 4. Visual Reasoning Model Process of a Constructive Perception Exercise
(1.perception – 2.analysis – 3.knowledge – 4.interpretation – 5.transformation –
6.internal representation – 7.knowledge – 8.interpretation – 9.external representation)

2.3 Structured Imagining (What If) Exercise

2.3.1 Making Stories

An exercise program for cognitive elements of creativity, such as *fluency*, *flexibility*, *originality*, *elaboration* and *problem sensitivity* [17, 18], has been devised to provide personalized support for creativity enhancement for design students [16]. The ‘making stories' exercise asks the students to produce different stories using three different photos by changing the order of them. This exercise involves human characters appearing in the photos to form important parts of the stories so that originality and elaboration elements are exercised where different stories are generated flexibly reflecting changes in the sequences of photos. The ‘making stories' exercise asks the students to produce different stories using three different pictures by changing the order of them. Therefore, this activity aims to improve the *flexibility*. The *elaboration* can also be developed through this activity by implying cause and effect of given pictures and specifying them. In addition, the *originality* can be enhanced through the effort to make unique and novel stories.

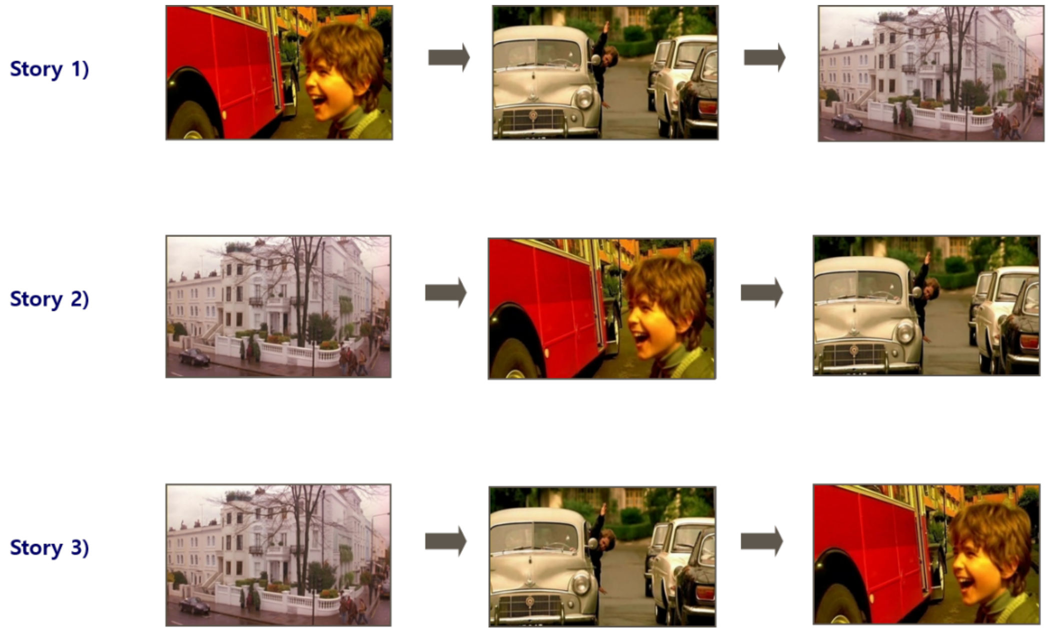


Figure 5. Make Stories Exercise [16]

As service design is all about human activity design, making stories exercise including photos of human characters have been enhanced to structured imagining exercises for service design thinking. As such exercises would require interactions and iterations of seeing – imagining – drawing together with schema and knowledge, the schema of CBAM would be used in describing human activities reflecting stories made from the photo sequences. Alternatively, human activity descriptions using CBAM can be first made from photos, and then stories can be constructed reflecting CBAM descriptions. Next in the section, CBAM is reviewed briefly and an exemplary exercise for structured imagining is to be explained.

2.3.2 Context-Based Activity Modeling

The activity description is centered around the *action verb*. The object of the action verb is specified as the *object* element of the activity. The *active actor* is the subject stakeholder of the activity who performs the action. In some cases, the *passive actor* and/or the *third-party actor* are specified as well. The *tool* of the activity is specified when a tool is used in the activity. Another element of the activity in CBAM is the *context*, which is in turn described by the following four context elements: The *goal context*, the *relevant structures*, the *physical context*, and the *psychological context*. The relevant structures are the entities associated with the object element in the action. The physical contexts such as location and time are specified. The psychological context such as emotional states and motivation level can be associated. In addition, whether the activity is public or private, and whether the activity is performed alone or with others can be specified as social context as a part of the psychological context. Through this rich description of activities as an underlying description, diverse experience issues can be addressed in human activity-centered experience design. That is, CBAM is regarded as a basic underlying schema in service activity design.

2.3.3 Structured Imagining Exercise

In the stories of the making stories exercise, activities of the main character should be modeled reflecting the photo scenes in describing the context based on the CBAM schema. Exercise tasks can be given as follows.

(1) For the photos given in the sequence of the story (1) in Figure 5, make a story where the main character is the boy of the first photo. Reflecting or seeing the story (1), make or generate a context-based activity modeling of an activity of the boy.

(2) For the photos given in the sequence of the story (2), make a story where the main character is the boy. Reflecting or seeing the story (2), transform the context-based activity modeling of the activity of the boy for story (1) to make a modified context-based activity modeling of an activity of the boy.

(3) For the photos given in the sequence of the story (3), transform the context-based activity modeling of the activity of the boy for story (1) or story (2) to make a modified context-based activity modeling of an activity of the boy. Reflecting the modified context-based activity modeling, make a story where the main character is the boy.

An example story (1) can be like the following: "The boy called the red bus to go home in a wide street near his school. He was happy as he finished today's school work and exciting as he was going home. The street was congested with a lot of cars until he reached his house". Reflecting this story, the boy's activity of *calling* the bus can be described using CBAM as shown in Figure 6 (a). The goal context is to go home. The relevant structures for the boy's activity of calling bus would be the wide street and other cars of various sizes in the street. The physical contexts are time and location of the street near school as well as the noisy and windy conditions of the street and clear weather condition. Exciting motivational state and happy emotional state of the boy actor are represented in the psychological contexts as well as social context of public activity and crowded occupant context.

Now the CBAM describing process of Figure 6 (a) is regarded using the visual reasoning model. The goal context would be coming from the story. The relevant structure of other cars of various sizes would be coming from the perception of a photo and the analysis that other cars would also be on the street as the bus is on. Then it can be hypothesized that calling, or waiving for, the bus would be influenced by other cars. Similarly, the wide street would be coming from the perception of a photo and from the knowledge that calling bus would be influenced by the width of the street. Some of the physical contexts are easily derived from perceiving on photos. The emotional and motivational state would be coming from the perceived image of the boy and the knowledge that students are on the streets on their way to school and on the way home. This emotional and motivational states were already constructed in story making. That is, the imagining of the story already utilized the interactive cognitive activities of perceiving, analyzing, interpreting, generating of happy emotion and exciting motivation, followed by confirmation using knowledge and the photo of the boy.

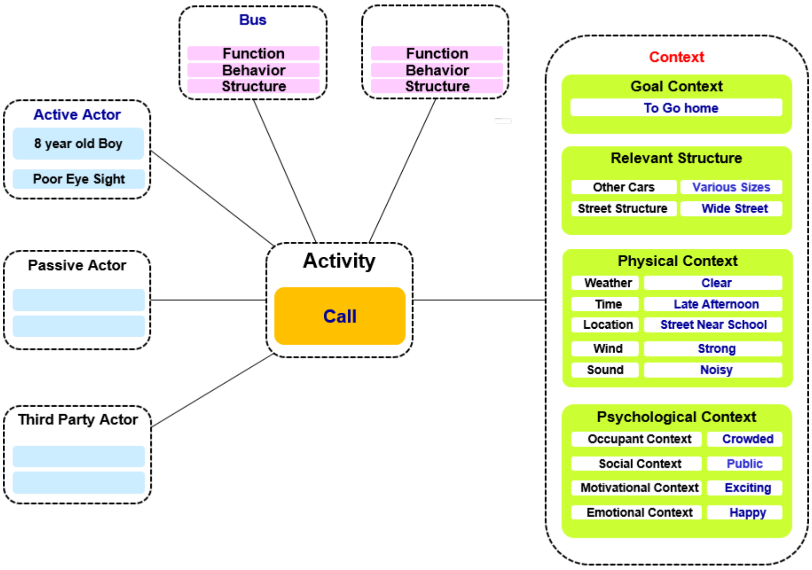
As asked in the task (3), a modified CBAM of the boy's activity can be made by transforming the object from Bus to Dad's Car as shown in Figure 6 (b). The action verb is also modified from *call* to *spot* (find among many cars). The activity of the boy in spotting Dad's car in spite of the big bus blocking his view can be modeled as shown in Figure 6 (b). Note that relevant structure has been modified to include the big Bus and Dad driving the car as the boy successfully spotted Dad's car in the context where a lot of cars of various sizes were in the street as well as a big Bus. Certainly, Daddy is relevant to the car he was driving. Physical contexts are directly copied, and so are psychological contexts. Then, from this new CBAM description, a new story can be made as the following; "The boy finally spotted dad's car and he was happy and exciting in spite of long waiting due to street congestion on dad's way from home to the school as daddy was making a big bodily gesture in the car so that the boy can easily spot his car".

This exercise is integrating making stories exercise of creativity and CBAM description exercise so that cognitive elements of creativity are mixed with cognitive activities of visual reasoning using CBAM as core schema.

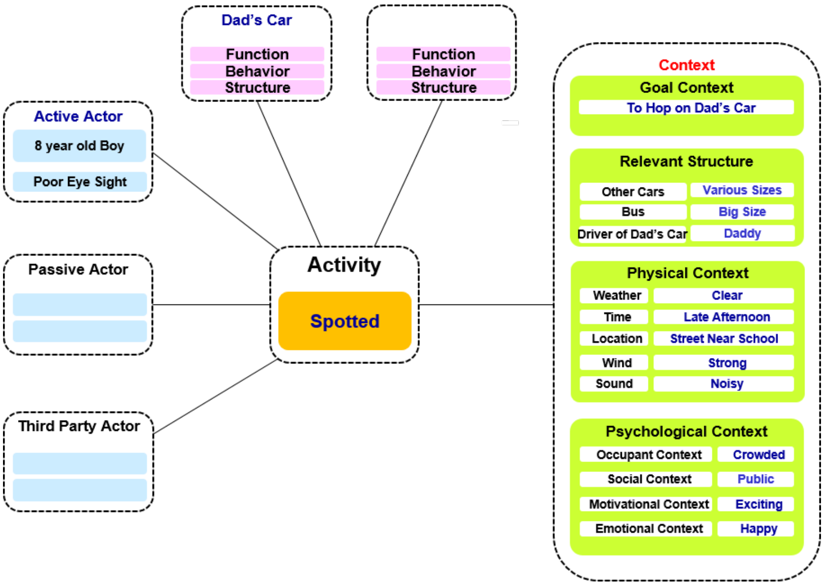
3 DISCUSSIONS

In this section, future research tasks are discussed together with issues and requirements in devising cognitive exercises for design thinking and related design learning efforts. These discussions can be enhanced towards those of a framework for design thinking learning and education.

Visual reasoning exercises can be varied in a diverse manner. Usually the more faces in solution solid objects can make the exercise more demanding as exercises would need more reasoning steps if there are larger number of faces. The types of faces can be varied including faces parallel to viewing planes, faces perpendicular to viewing planes, slanted faces and skewed faces. If many skewed faces are involved, missing view problems would become more difficult requiring complicated reasoning steps. While missing view problems are more structured, it may be easier to make alternative exercises with different levels of difficulty. Such levels can be evaluated also empirically based on performance results by many exercise participants.



(a)



(b)

Figure 6. Context-Based Activity Modeling Used in Structured Imagining Exercises

As mentioned in descriptions on visual reasoning exercises, this kind of exercises has strong dependency of schema. On the other hand, constructive perception exercises show less dependency on schema. Maybe some exercises can require more involvements of knowledge while others may not. Some exercises could require deep involvements of both schema and knowledge. Based on the required involvement of knowledge and schema, respectively and collective, design thinking exercises can be differentiated. Regarding the basic cognitive activities of seeing, imagining and drawing, natures of exercises could also be distinguished by levels of involvements of these cognitive activities. In other words, some exercises may require more analyses while other exercise may demand more critical interpretations. Some exercises may require more of internal representations, others need more of external representations while these could be also differently involved reflecting personal visualization ability differences. Maybe some problems may require more iterations in outer iterations of seeing – imagining – drawing, some others may require many of local level, or inner iterations of seeing – imagining – drawing.

As in the case of structured imagining exercise, cognitive exercises can be more complex requiring cognitive activities of seeing, imagining and drawing, and cognitive elements of creativity. Also exercises may require nice handling of transformations between different elements of exercises. As discussed, some dimensions of cognitive exercises of design thinking could be identified so that these will form the foundation for the framework of design thinking cognitive exercises. This is certainly an important future research task. In such a framework, various different design thinking exercises can be compared and classified, and such dimensions could guide how new exercises can be devised.

Future research tasks for design thinking exercises can include both prescriptive research and empirical research. Empirical research may involve novice design thinkers and more experienced design thinkers. Such research also includes identifying potential inter-relations among different cognitive aspects, for example, such as personal creativity modes [19] and learning styles [20]. Many future research tasks could be identified addressing these issues. As critical in design learning in general, more opportunities of learner reflection could be provided utilizing various tools [21]. As digital tools such as experience evaluation and experience engagement are being devised to support users to make their experience iterations of experience – evaluation – engagement in an accumulative and improving manner [22], research on design thinking learning and education should also address devising of similar tools. As more immediate future research task, some initial empirical research dealing with the three design thinking exercises explained in this paper, that is, visual reasoning, constrictive perception and structure imagining exercises, will be conducted.

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