RELATIONS BETWEEN COGNITIVE ABILITY AND CREATIVE DESIGN QUALITY

Yin, Yuan;
Childs, Peter

Dyson School of Design Engieering, Imperial College London

ABSTRACT

The study aims to identify the relations between creative design quality and content of the memorising precedents, association, and combination of information processes in a design context. 71 participants were recruited to finish a creative design task. Think aloud and interview were conducted during and after the creative design task to understand the content of the memorising precedents, association, and combination of information processes. The 71 creative designs were then assessed by five experts in creative design. The results from this study revealed that participants who generated high-creativity design tend to memorize various topic-related precedents, associate items based on topic-related information, and combine topic-related information with products. Participants who generated low-creativity design tend to memorize characteristics of a specific space of the design topic, associate items based on specific topic-related information, and add the topic-related pattern to a product.

Keywords: Creativity, Design cognition, Design process

Contact:
YIN, Yuan
Imperial College London
United Kingdom
y.yin19@ic.ac.uk

ICED23

1 INTRODUCTION

Design relates to humans highest cognitive abilities such as creativity (Hu et al., 2019). Although designers have various design strategies, most of the strategies included divergent thinking and convergent thinking processes (Childs et al., 2022). Divergent thinking processes allow designers to generate various ideas while convergent thinking processes allow designers to select the best ideas (Dubberly, 2012). Some researchers tried to integrate convergent and divergent phase of creative design processes (Houzangbe et al., 2022); While the others tended to understand the relations between convergent and divergent phase as iteration and considered the iteration of design processes is a divergent and convergent thinking iteration process (Cross, 2021). Divergent thinking mainly happens in the idea generation process under design areas (Shah et al., 2012). This idea-generation process is related to cognitive memorising precedents (Kim & Kim, 2015), association (Liu et al., 2020), and combination of information (Liu et al., 2020; Luo et al., 2021).

In an idea-generation process, designers need to seek inspiration from external examples or internal design experience and knowledge (Xue et al., 2020). Memorising precedents can be divided into two conditions (Tulving, 1984). The first condition is memorising semantic precedents which are related to facts and concepts constructed by data or organized knowledge (Tulving, 1984). The other condition is memorising episodic precedents which are related to events and specific perceptible experiences (Tulving, 1984). Researchers have revealed that in an idea-generation process memorising episodic precedents can help designers generate more initial ideas while memorising semantic precedents allow designers to develop the ideas in a more comprehensive way (Chrysikou et al., 2016; Mertens et al., 2020; Xue et al., 2020).

The ability of cognitive association of information is defined as the linking of two or more elements and defining the relations. It can be divided into remote association, (the ability to linking of two or more irrelated elements) and common association (the ability to linking of two or more related elements) (Yin et al., 2022). Remote association is considered one of the methods to generate creative ideas (Beda et al., 2020).

Combination is also considered an essential process for generating creative ideas in divergent thinking processes (Wan & Chiu, 2002; Beda et al., 2020). If the concepts used to combine are ordinary, the results of conceptual combination may be ordinary too. To increase the variety of conceptual combination, designers need to combine different elements, which is also called remote combination (Wilkenfeld & Ward, 2001).

Although researchers have identified the relations between the creative results and cognitive memorising precedents, association, or combination of information processes, this identification is mainly based on separate research. Also, studies are mainly related to detecting how the ability on memorising precedents, association, or combination of information affects the idea generation process instead of the creative design processes. This loss of context is one of the reasons why existing studies cannot identify how these abilities on memorising precedents, association, or combination of information processes affected the creative design quality. Therefore, this study aims to identify how the ability on memorising precedents, association, or combination of information affects the creative design processes, especially the creative design quality.

2 METHODOLOGY

To achieve the research aim, think aloud and interview were conducted to identify the performance of cognitive abilities (memorising precedents, association, or combination of information) in a creative design process. Then, the creative design generated from think aloud process were assessed.

2.1 Data collection study

2.1.1 Participants

Seventy-one design-background participants (23 male, 48 female; aged from 20-29) were recruited. All participants have experience in using think aloud method in research and can use hand-drawing methods to express their ideas.

2.1.2 Method

In the study, participants were asked to finish a creative design task. During the task, participants were asked to use think-aloud method to report their cognitive processes. After the design task, participants were asked to conduct an interview, where they need to detailed explain which information they have memorized, associated and combined.

2.1.3 Creative design task

The creative task (*designing a product using the provocation of the word 'fish' within one hour*) that the participants need to finish is selected from the 2019 China design-major graduate-student admission exam tasks. The reason why this creative design task is selected is out of the consideration that the task is a common topic and participants do not have barriers to understanding the task. Also, the results of the creative task will be assessed by experts in creative design areas. The creative task, thus, should be a common task that can be assessed by general experts in creative design areas.

THINK ALOUD

Think aloud is a common method used in reporting mental processes of participants (Lewis, 1982; Peskin & Ellenbogen, 2019). In this creative task process, think-aloud method is used to collect participants' cognitive process on memorising precedents, association, and combination of information. In the think-aloud process, participants were first explained what is memorising precedents, association, and combination of information. *Memorising precedents* is explained as memorising previous experience, concepts, or facts. *Association* is explained as associating two or more related or irrelated concepts. *Combination* is explained as two or more concepts being mentally synthesised. Then, participants were asked to report the three processes during their creative design processes. The instruction of think-aloud method used in this study can be seen in Figure 1. Although participants may have different visualization skills, they have been announced that their outputs will not be justified by the visualization skills; instead, their design will be assessed based on the creativity quality levels.

2.1.4 Interview

Think aloud can report participants' cognitive thinking process in real time. However, sometimes researchers may expect a deeper explanation of cognitive thinking processes. Interrupting participants in a creative design process may also interrupt participants thinking processes. Therefore, after the think-aloud, an interview was conducted as a supplement to understand which information has been memorised, associated, and combined by participants during creative design processes. The questions asked in interview are included in Figure 1.

2.1.5 Protocol

Figure 1 is an overview of the protocol. Before the study, participants were sent the information sheet and the consent form. They can ask any questions they have. If there are no questions, they need to sign the consent form. At the beginning of the study, participants were asked to complete an online questionnaire which was built up by Qualtrics. This questionnaire collected participants basic information such as educational background and design experience. The online questionnaire was sent through email. Participants need around 5 minutes to fill out the questionnaire.

Then, participants were introduced the think-aloud method and the cognitive processes that they need to report. After participants were ensured they understand how to conduct a think aloud in a creative design and what they need to report, participants were asked to design a product using the provocation of the word 'fish' in one hour and report the cognitive process through the think-aloud method.

Participants need to draw one product as their final solution on A4 paper, but they were open to sketching anything they want on the paper too. Participants were also announced that they were free to draw their ideas in a colorful or black-and-white form. They will not be justified by whether their ideas are colorful or not.

As soon as the creative design task was finishes, participants were asked to conduct the interview to deeply explain what they have memorised, associated, and combined. Participants can access their designs as a reminder to recall their cognitive processes. After the interview, participants need to identify whether they have expressed their solutions clearly. Participants were allowed to add annotations to explain their ideas but were not allowed to change what they have drawn. The think-aloud and interview processes were recorded by audio with the permission of participants.
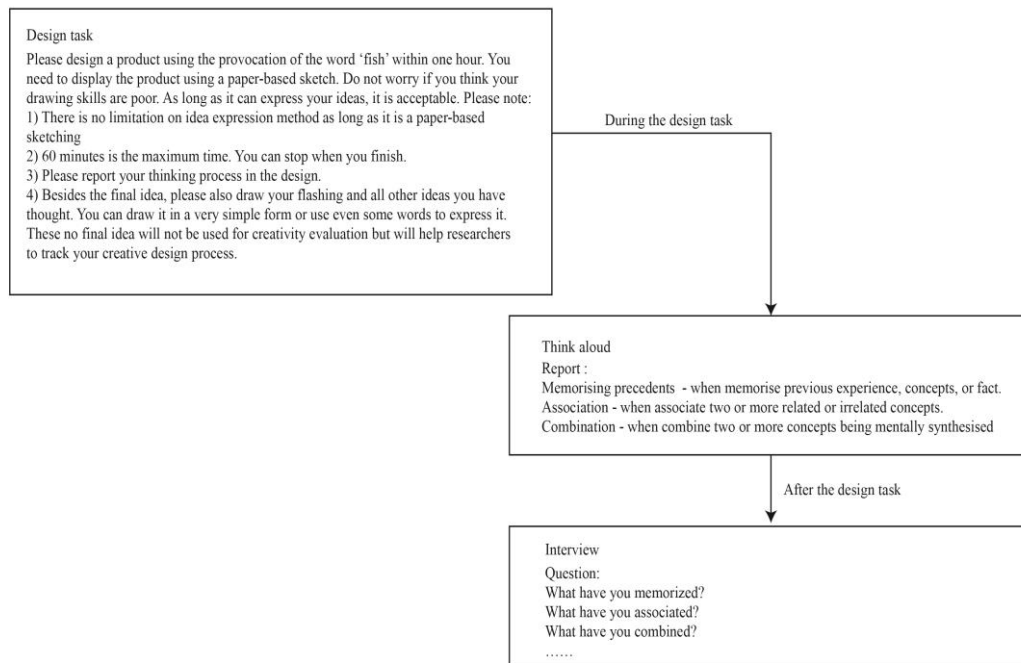

Figure 1. An overview about the data collection study protocol

2.2 Data assessment study

After the data collection study, the creative design quality of the solutions generated from participants needs to be assessed.

2.2.1 Participants

Five experts (3 females and 2 males, aged 31 - 40), who have more than 10-year experience in creative design, were selected as judges (Baer et al., 2004). Also, the judges should have experience in assessing creative design sketching in the past year.

2.2.2 Method

Judges were asked to assess the 71 creative design outputs using Consensual Assessment Technique (CAT; (Amabile, 1982). CAT (Amabile, 1982) is a no-criteria assessment method. This method recommends that judgers should be experts who are familiar with the relative domain areas. It commonly asks judgers to give a creativity score from 1 to 5 based on their understanding of creativity without explaining why they give this score. CAT has been widely used and verified (Christiaans, 2002). Its inter-rater reliabilities are usually more than 0.70 (Amabile, 2018, Baer et al., 2004). However, one limitation of CAT is that the assessment relies on experts in relative domains. If the creative tasks involve several different domains (such as poems, designs, and stories), the conditions will be complex and hard to recruit raters (Kaufman et al., 2008, Baer, 1991).

Considering the judges were all from China, where the grading levels are mainly divided into six levels, the CAT was adapted into six levels correspondingly. Also, the explanation on each assessment level was displayed to judgers at the beginning of the assessment (Table 1).

Table 1. The explanation on adjusted CAT method.

Level	Explanation on the creative quality of the creative design
A	The creative design is not creative
B	The creative design is creative but just in a very low level
C	The creative design is creative but just in slightly low level
D	The creative design is creative
E	The creative design is in a high creative level
F	The creative design is in an excellent creative level

2.2.3 Protocol

Before the study, participants were sent the information sheet and the consent form. They can ask any questions they have. If there are no questions, they need to sign the consent form. At the beginning of the study, judges were asked to complete an online questionnaire which was built up by Qualtrics. This questionnaire collected judges basic information such as educational background and design assessment experience. The online questionnaire was sent through email. Judges need around 5 minutes to fill out the questionnaire. Only the judges who have more than 10-year experience in creative and have experience in assessing creative design sketches during the past year can move the assessment task.

Judges who satisfied the selection requirement were then sent the assessment task questionnaire which was also built up by Qualtrics. In this questionnaire, participants were first introduced to how to assess the creative design using CAT. To be specific, participants were asked to select one level from A to F to represent the creativity quality level of each creative design. Also, they were asked that their assessment should base on the ideas instead of the visualization skills. Then, participants were introduced that these creative design were generated from the creative design task "design a product using the provocation of the word 'fish' in one hour". Participants have seven days to finish the assessment. They were suggested to pause the assessment when they felt bored or tired, but they need to ensure that their justification was fair for the 71 creative designs.

3   RESULTS

To identify how the ability on memorising precedents, association, or combination of information affects the creative design quality, the content of memorising precedents, association, or combination of information processes and the creative design quality was identified. Then, the two datasets were combined to answer the research questions.

3.1 Content of memorising precedents, association, or combination of information processes

Thematic analysis was used to analyse the content of the memorising precedents, association, or combination of information processes. Nvivo (Version 12), a software developed for qualitative data analysis (Phillips & Lu, 2018), was applied to assist the thematic analysis processes. Thematic analysis results were shown in Table 2. Four themes, 12 second codes, and 28 third codes were summarized.

Table 2. Thematic analysis results

Themes	Second Code	Third Code
Memorising precedents	Content of memorising precedents	Design topic related
		Intuitive
		Not related to design topic
		Product
		Same with aim

Association	Association form	Based on a few items
		Based on one item
		Common association
		Intuitive association
		Refuse distractive
		Remote association
		Subjective association
		Suddenly association
	Contextual details	Limited things
		Not-related to design topic
		Product related
		Related to design topic
Combination	Combination form	Common combination
		No combination
		Random combination
		Remote combination
	Contextual details	Design-topic related
		Non-design topic related
		Product related
Relations between association and memorising precedents	Association based on memorising precedents	
	Association related to memorising precedents	
	Association triggers more memorising precedents	
	Different	More ideas in association
		Based on memorising precedents to associate more
		The broad frame
		Memorising precedents was fundamental
	Exist at same time	
	Not different	
	Memorising precedents is the pre-step of association	
	Two round cycles	

3.2 Creative design quality

Creative design quality in this study was reflected by the creativity quality of the creative design. Level A was assigned Score 6; Level B was assigned Score 5; Level C was assigned Score 4; Level D was assigned Score 3; Level E was assigned Score 2; Level 6 was assigned Score 1. Minimum values, maximum values, mean values, and standard deviation (SD) of creative outputs assessment data were first calculated (Table 3). Coefficient alpha for the results was 0.708 (95% CI = 0.585–0.803), which indicated a reliable level internal consistency.

The average score of five judges for a specific design was used to represent the creative design quality of this design. Subjectively, if the creative design quality ranged between Score 3 to Score 6 (including Score 3), the corresponding creative design was considered a high-creativity design. If the creative design quality ranged between Score 1 to Score 3 (not including Score 3), the corresponding creative design was considered a low-creativity design. Based on this grouping method, 42 designs were grouped as high-creativity design while 29 designs were grouped as low-creativity design. The examples of high-creativity and low-creativity designs are shown in Table 4.

Table 3. Descriptive statistics (minimum values, maximum values, mean values, and SD) of each expert's CAT and CPSS results

Items	Minimum	Maximum	Mean	SD
Expert 1	1.0	6.0	3.514	1.3336
Expert 2	1.0	6.0	3.148	1.4076
Expert 3	1.0	5.0	3.282	.9663
Expert 4	3.0	6.0	4.444	.8347
Expert 5	1.0	6.0	3.732	1.1302

Table 4. Results on the relations between creative design quality and content of memorising precedents, association, or combination of information processes

	Participants who generated high-creativity design	Participants who generated low-creativity design
Memorising precedents	Memorize various topic-related precedents	Memorize characteristics of a specific space of fish (design topic)
	Memorize various products which may have the potential to be the source of ideas within and without topic-related areas	Memorize topic-related products within topic-related products areas.
Information association	Associate based on fish-related (topic-related) information	Associate different kinds of fish and fish-related biology
	Results related to topic information related to products	Results related to topic information
Information combination	Combine topic-related information with the products	Add the topic-related pattern to a product
Figure example		

4 DISCUSSION

This session combined the results from creative design quality and content of memorising precedents, association, or combination of information processes. Table 4 is an overview of the combined results.

4.1 Relations between content of memorising precedents and creative design quality

Most of the participants (65) memorizing precedents at the beginning of a creative design process, which indicated that memorising precedents is a necessary process in design. Precedents related to the design topic and precedents related to products were the two kinds of precedents mainly memorised. As for the participants who generated a high-creativity design, they tended to memorize topic-related precedents. Participants have reported that they memorized characteristics of fish (design topic), conditions of usage, fish products they have met before, and cartoon fish. Participants who generated a low-creativity design were more likely to memorize the characteristics of fish (design topic). Although both of the groups' participants memorized characteristics of the design topic, the content of memorising was different. Participants who generated a high-creativity design memorized various precedents which they thought

may have the potential to be the sources of their ideas while participants who generated a low-creativity design were more likely to focus on a specific space of fish (design topic), such as the sharks and goldfish.

When memorizing precedents related to products, the participants who generated a low-creativity design have the tendency to memorize the topic-related products, such as the function or shape of the topic-related products. However, as for the participants who generated a high-creativity design, they preferred to memorize various products which they thought may have the potential to be the source of ideas. Although they also memorized the function or shape of the topic-related products, they did not limit themselves to topic-related areas.

4.2 Relations between content of information association and creative design quality

Information association often happens after memorizing processes. This indicated the association processes are based on the results of memorizing. Some participants who generated low-creativity design do not report their association processes in a creative design. This may be because these people have decided which product they will design and the appearance of the product. Therefore, what they need to do was to select a good topic-related shape and combine it with the product that they have decided to design.

In information association processes, participants who generated high-creativity design may associate based on fish-related (topic-related) information, such as shapes similar to fish, where the fish can be used, the meaning of fish, products related to fish (such as boats), places where fish live (such as oceans), and fish-related lectures, presentations, or films. As for the participants who generated low-creativity design, what they associated was mainly with different kinds of fish and fish-related biology (such as birds, flowers, water plants, and shells). Also, there were some association results similar to participants who generated high-creativity design, such as places where fish live, the shape of fish, and fish-related products. During this association, both common association and remote association may happen. However, considering the unclear boundary between remote association and common association, this association forms results were less reliable. For example, some participants (mainly participants who generated high-creativity design) thought the association between fish to the ocean was a common association while some other participants (mainly participants who generated low-creativity design) thought it was a remote association.

The association results of participants who generated high-creativity design were mainly related to products while that of participants who generated low-creativity design were related to topic information. This may explain why some participants can generate high-creativity design. The creative task is limited to product design. If participants associate more product-related information, they may have more ideas on what they can design.

4.3 Relations between content of information combination and creative design quality

Information combination processes are often based on memorizing precedents and information association. Therefore, logically, combination processes happen after memorizing precedents and information association. Participants who generated high-creativity design tended to combine topic-related information from memorizing precedents and information association with products. Although participants have tried to combine information in a remote combination way, this remote combination was hard to be achieved. Participants who generated low-creativity design tended to add the topic-related pattern to a product. This difference in combination may be from the different cognitive working load capabilities. Participants who generated low-creativity design may have a lower working memory capacity. This means participants were curbed to extract useful information on topic-related information and products at the same time, which curbed them to take advantages of information they have associated with and memorized effectively.

4.4 Limitation

This study focused on how memorising precedents, association, or combination of information processes affected creative design quality. However, the other factors that may also affect creative design quality were not included such as the environment, the cultural background, idea expression

ability, and experience in creative design. In the future, the influence of other factors also needs to be identified. In addition, the study adapted CAT as the creative design quality assessment method. Although CAT is a popular assessment method in product creativity, it only includes limited creativity levels and may not distinguish the creative design quality in an effective way. Finally, the study divided the creative design quality subjectively based on the creative scores of creative design. Whether this division method is reliable needs to be further identified. In the future, more division methods will be attempted.

5 CONCLUSION

The study identified the relations between creative design quality and content of memorising precedents, association, or combination of information processes. 71 participants were recruited to finish a creative design task. During the task, participants were asked to use think-aloud method to report their memorising precedents, association, or combination of information processes. After the study, participants were asked to have an interview to deeply explain these processes. 71 creative designs were then assessed by five experts in creative design. The results from this study revealed that participants who generated high-creativity design tend to memorize various topic-related precedents, associate based on topic-related information, and combine topic-related information with products. Participants who generated low-creativity design tend to memorize characteristics of a specific space of design topic, associate based on specific topic-related information, and add the topic-related pattern to a product. The study revealed different content of memorising precedents, association, or combination of information processes and linked it with creative design quality. The results of this study can be used to help designers and researchers to better understand which kind of cognitive performance can lead to higher creative design quality. Also, the study can be used as a cue to help researchers and designers to develop creative design models from cognitive levels and considered how to stimulate creative quality of design.

REFERENCES

Amabile, T. M. (1982). "Social psychology of creativity: A consensual assessment technique", *Journal of personality and social psychology*, Vol. 43, No.5, pp. 997. https://dx.doi.org/10.1037/0022-3514.43.5.997

Amabile, T. M. (2018). *Creativity in context: Update to the social psychology of creativity*, Routledge.

Baer, J. (1991). "Generality of creativity across performance domains", *Creativity Research Journal*, Vol.4, No.1, pp. 23-39. https://doi.org/10.1080/10400419109534371

Baer, J., Kaufman, J. C., & Gentile, C. A. (2004). "Extension of the consensual assessment technique to nonparallel creative products", *Creativity Research Journal*, Vol.16, No.1, pp. 113-117. https://doi.org/10.1207/s15326934crj1601_11

Beda, Z., Smith, S. M., & Orr, J. (2020). "Creativity on demand–Hacking into creative problem solving", *NeuroImage*, Vol.216, pp. 116867. https://doi.org/10.1016/j.neuroimage.2020.116867

Childs, P., Han, J., Chen, L., Jiang, P., Wang, P., Park, D., ... & Vilanova, I. (2022). "The creativity diamond—A framework to aid creativity", *Journal of Intelligence*, Vol.10, No.4, pp.73. https://doi.org/10.3390/jintelligence10040073

Christiaans, H. H. (2002). "Creativity as a design criterion", *Communication Research Journal*, Vol.14, No.1, pp. 41-54. https://doi.org/10.1207/S15326934CRJ1401_4

Chrysikou, E. G., Motyka, K., Nigro, C., Yang, S. I., & Thompson-Schill, S. L. (2016). "Functional fixedness in creative thinking tasks depends on stimulus modality", *Psychology of aesthetics, creativity, and the arts*, Vol.10, No.4, pp. 425. https://dx.doi.org/10.1037/aca0000050.

Cross, N. (2021). *Engineering design methods: strategies for product design*, John Wiley & Sons.

Dubberly, H. (2004). *How do you design. A compendium of models*.

Hu, Y., Du, X., Bryan-Kinns, N., & Guo, Y. (2019). "Identifying divergent design thinking through the observable behavior of service design novices", *International Journal of Technology and Design Education*, Vol.29, No.5, pp. 1179-1191. https://doi.org/10.1007/s10798-018-9479-7

Kaufman, J. C., Baer, J., Cole, J. C., & Sexton, J. D. (2008). "A comparison of expert and nonexpert raters using the consensual assessment technique", *Creativity Research Journal*, Vol.20, No.2, pp. 171-178. https://doi.org/10.1080/10400410802059929

Kim, E., & Kim, K. (2015). "Cognitive styles in design problem solving: Insights from network-based cognitive maps", *Design Studies*, Vol. 40, pp.1-38. https://doi.org/10.1016/j.destud.2015.05.002

Houzangbe, S., Masson, D., Fleury, S., Gómez Jáuregui, D. A., Legardeur, J., Richir, S., & Couture, N. (2022). "Is virtual reality the solution? A comparison between 3D and 2D creative sketching tools in the early

design process", *Frontiers in Virtual Reality*, Vol. 3, pp.3:958223. https://doi.org/10.3389/frvir.2022.958223

Lewis, C. (1982). "Using the" thinking-aloud" method in cognitive interface design", Yorktown Heights, NY: IBM TJ Watson Research Center.

Liu, Q., Wang, K., Li, Y. & Liu, Y. (2020). "Data-driven concept network for inspiring designers' idea generation", *Journal of Computing and Information Science in Engineering*, Vol. 20, No.3. https://doi.org/10.1115/1.4046207

Luo, J., Sarica, S. & Wood, K.L. (2021). "Guiding data-driven design ideation by knowledge distance", *Knowledge-Based Systems*, Vol. 218, pp.106873. https://dx.doi.org/10.1016/j.knosys.2021.106873

Mertens, A. T., McComb, C., & Toh, C. A. (2020, August). "Towards an understanding of semantic memory during idea generation", *In International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Vol. 83921, pp. V003T03A017. American Society of Mechanical Engineers. https://dx.doi.org/10.1115/DETC2020-22577.

Peskin, J., & Ellenbogen, B. (2019). "Cognitive processes while writing poetry: An expert-novice study", *Cognition and Instruction*, Vol.37, No.2, pp.232-251. https://doi.org/10.1080/07370008.2019.1570931

Phillips, M., & Lu, J. (2018). "A quick look at NVivo", *Journal of Electronic Resources Librarianship*, Vol. 30, No. 2, pp.104-106. https://doi.org/10.1080/1941126X.2018.1465535

Sarkar, P., & Chakrabarti, A. (2011). "Assessing design creativity", *Design studies*, Vol.32, No.4, pp. 348-383. https://doi.org/10.1016/j.destud.2011.01.002

Shah, J. J., Millsap, R. E., Woodward, J., & Smith, S. M. (2012). *Applied tests of design skills—part 1: divergent thinking*.

Tulving, E. (1984). "Precis of elements of episodic memory", *Behavioral and Brain Sciences*, Vol. 7, No. 2, pp. 223-38. DOI: 10.1017/S0140525X0004440X.

Wan, W. W., & Chiu, C. Y. (2002). "Effects of novel conceptual combination on creativity", *The Journal of Creative Behavior*, Vol.36, No.4, pp. 227-240. https://doi.org/10.1002/j.2162-6057.2002.tb01066.x

Wilkenfeld, M. J., & Ward, T. B. (2001). "Similarity and emergence in conceptual combination", *Journal of Memory and Language*, Vol.45, No.1, pp. 21-38. https://doi.org/10.1006/jmla.2000.2772

Xue, S., Shen, D., Zhang, E., & Bao, D. (2020, December). "Tradeoff between Episodic and Semantic Precedents in creative design", *In 2020 13th International Symposium on Computational Intelligence and Design (ISCID)*, pp. 230-233, IEEE. DOI: 10.1109/ISCID51228.2020.00058

Yin Y, Wang P and Childs PRN (2022) "Understanding creativity process through electroencephalography measurement on creativity-related cognitive factors", *Front. Neurosci*. Vol.16, pp.951272. doi: 10.3389/fnins.2022.951272

Yin, Y., Han, J., Huang, S., Zuo, H., & Childs, P. (2021). "A study on student: assessing four creativity assessment methods in product design", *Proceedings of the Design Society: International Conference on Engineering Design (ICED21)*, Vol.1, pp. 263-272. https://dx.doi.org/10.1017/pds.2021.2.