A SYSTEMATIC BRAINSTORMING IDEATION METHOD FOR NOVICE DESIGNERS BASED ON SECI THEORY

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ABSTRACT

Design ideation is a critical early step in any design process and especially challenging for novice designers. This paper introduces the "Systematic Brainstorming Ideation (SBI)" method that, as part of a wider design ideation process, improves the range and number of design concepts generated by novice designers. In this paper we give a brief introduction to the design ideation method to set a context for SBI and then introduce SBI in more detail. Evaluation experiments with 101 novice designers, based in UK and South Korea, are reported. Results indicate a 30% improvement in the number of design concepts generated.

Keywords: Conceptual design, Design methods, Early design phases, Case study

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1 INTRODUCTION

Design ideation is a crucial step that occurs early in any design process. Unlike later stages, there are few methods that support design ideation. This is especially problematic for novice (student) designers who lack experience and tend to adopt ad hoc design approaches to stimulate idea generation processes, such as surfing the internet and reviewing books. Novice and experienced designers show different tendencies in actions, reactions and compositions during the ideation process (Dinar, Shah, Cagan *et al*., 2015; Ho, 2001), which are closely related to the success of the ideation outcomes generated (Ball *et al*., 2004). This paper reports the design and development of a systematic method for brainstorming in design ideation with a view to improving the range and number of design concepts generated by novice designers in response to a brief. The method was evaluated through experiments with student designers using bio-inspiration as a case study.
The paper begins, in Section 2, with a review of literature on design ideation with a focus on support for novice designers. This is followed by an outline of the research methodology used to develop and evaluate the Systematic Brainstorming Ideation (SBI) method in Section 3. In Sections 4 and 5, the method is introduced and results of the evaluation experiments that have been carried out are reported. The outcomes are discussed, and conclusions drawn in Sections 6 and 7.

2 BACKGROUND

Design ideation is an important part of any design process because it is where designers use divergent thinking to generate design concepts in response to a design brief (Koronis *et al*., 2018; Valkenburg and Dorst, 1998). This section provides a review of design ideation literature and establishes the requirements for solutions to improve design ideation outcomes for novice designers. Goals and measurement criteria for design ideation processes are considered in Section 2.1 along with key differences between novice and experienced designers. Based on the differences identified between novice and experienced designers, requirements for ideation support tools are proposed in Section 2.2.

2.1 Design ideation and associated measurement criteria

In design development processes, ideation is responsible for developing the initial solution concepts (Farel and Yannou, 2013; Moreno, Blessing *et al*., 2015). The overall goal of design ideation is to generate novel or creative solutions in response to the design brief. The ability to generate ideas is a distinctive characteristic of designers, and the performance of the design ideation stage has a significant impact on the overall success of the design process and its outcomes (Moreno, Yang *et al*., 2015; Orthel and Day, 2016).
An understanding of designers' thought processes during design ideation can support the identification of the difficulties that novice designers face and inform the development of appropriate solutions. Designers start ideation with stimulation, drawing on past experience, by reviewing relevant empirical cases and/or through research in response to the design brief (Koronis *et al*., 2018). Understanding and inspiration acquired during this stage are used to draw analogies and generate new concepts (Nonaka *et al*., 2000). The volume and quality of resources reviewed at this stage impacts the designer's ability to draw fundamental analogies and gain tacit knowledge (Goldschmidt and Smolkov, 2006). Tacit knowledge refers to the underlying core principle(s) obtained from a wide spectrum of cases as an effective ideation solution (Nonaka *et al*., 2000; Self *et al*., 2016) and is closely related to the degree of ideation effectiveness and the designer's abilities. The ideation process model based on a designer's thought process is illustrated in Figure 1 and is used as the basis to establish the method developed in this paper. A number of such processes are available in the literature; this one was chosen because it provides insights into the practicalities of ideation processes and so supports the identification of the requirements for ideation methods along with comparisons between novice designers and experts.

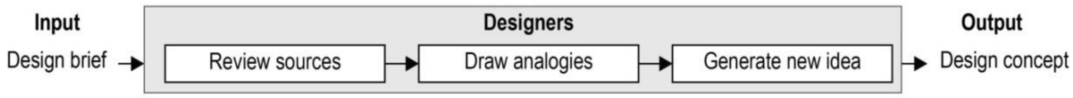

Figure 1. Ideation process model based on designers' thought processes

Empirical research reports that experienced and novice designers tend to adopt different approaches in resource searching strategies, how they respond to difficulties, and in developing a systematic ideation process (Hey *et al*., 2008). These differences affect the degree to which appropriate analogies are drawn from resources and utilised in idea generation. Experienced designers conduct each action with clear objectives that are well linked and structured accordingly (Kavakli and Gero, 2002). They search comprehensively with the aim of identifying tacit or abstract knowledge as valuable solution cues in response to the design brief (Ball *et al*., 2004; Ho, 2001). If difficulties are encountered, they review the required information (Ho, 2001) or switch the ideation strategy from a breadth to depth first identification (Ball *et al*., 1997). On the other hand, novice designers tend to perform concurrent actions with vague objectives (Kavakli and Gero, 2002). They tend to commence with a depth-first search, review all information at the same level, and in particular, overlook the issue(s) that they believe cannot be addressed (Dinar, Shah, Cagan *et al*., 2015; Ho, 2001). This ideation process behaviour limits novice designers' understanding and ideation to surface-level cues from analogies (Ball *et al*., 2004).
Effective measurement criteria refer to the clear and specific objectives to be achieved by the method being developed, and lead to effective development and evaluation processes (Blessing and Chakrabarti, 2009). According to Shah (2003), ideation process effectiveness can be measured by evaluation of ideation outcomes from four perspectives: the total number of generated ideas (quantity), how well ideas correspond to the given design brief (quality), how many solution spaces were explored (variety), and how many unexpected solutions were ideated compared to other cases (novelty). For the selection of measurement criteria for this study, Shah's metrics were reviewed, and the quantity metric used for the preliminary analysis presented in this paper and described in Section 3.

2.2 Requirements for design ideation support tools

The previous section highlighted key differences between the ideation processes of novice and experienced designers. This section reviews literature in order to identify requirements for ideation support tools to improve the effectiveness of the ideation process for novice designers. Experienced designers have their own, often unique, methods and behaviours for effective ideation. By contrast, novice designers tend to lack an established process or the experience to create one. This can be separated into three specific requirements: a systematic ideation process, a designer-friendly method, and stimulation through a greater quantity and variety of resources (for drawing analogies).

- *Systematic ideation process:* As outlined in Section 2.1, narrow information searches, evasion of difficulties, and unfocused objectives are common issues for the novice designer. Research on fixation effects in idea generation has also noted the importance of inhibiting spontaneous design heuristics and following a generative reasoning process (Cassoti *et al*., 2016; Houdé and Borst, 2014). When compared with the process employed by experienced designers, it is evident that the novice designer would benefit from tools that support a structured ideation process and inhibit spontaneous solutions, in order to mitigate limited experience and know-how (Dinar, Shah, Cagan *et al*., 2015; Kavakli and Gero, 2002).
- *Designer-friendly method:* In order for the intended improvements of the method developed to be used and widely practiced, minimising the 'difficulty of use' and 'sense of difference' needs to be addressed at the method design stage. A number of studies have suggested guidelines or methods to resolve the difficulties that novice designers encounter within the ideation process (Goldschmidt and Smolkov, 2006; Orthel and Day, 2016). Despite these efforts it is difficult to find empirical evidence that designers are using the identified methods.
- *Stimulation through a greater quantity and variety of resources:* The resources relevant to a design brief, such as case studies consisting of text and images, assist designers to understand previous design solutions and results. As the quantity of resources increases, the level of stimulation also increases and a greater depth of understanding is achieved (Goucher-Lambert and Cagan, 2017). Furthermore, developments in design theory, in particular design as a generative process (distinctly different from decision-making or creativity), have noted the role of knowledge structures as a condition for generativity (Hatchuel *et al*., 2018). A higher degree of stimulation and knowledge may be achieved from a greater variety and a larger number of resources to better support designers in overcoming fixations, enhancing the creativity, quality and diversity of outcomes (Borgianni *et al*., 2018; Venkataraman *et al*., 2017).

These requirements were used to drive the development of a design ideation process that includes a database of existing designs as sources of stimulation, a perceptual mapping software tool to support the visualisation of designs stored in the database, and a systematic brainstorming method (SBI) to support the generation of design concepts. This paper focuses on the development and evaluation of the systematic brainstorming method to cover two requirements: a systematic ideation process and a designer-friendly method. The wider ideation process will be reported elsewhere.

3 RESEARCH METHODOLOGY

Design Research Methodology (DRM) (Blessing and Chakrabarti, 2009) was used as a framework within this research to develop an ideation method for novice designers. This methodology provides four flexible stages of research: Research Clarification, Descriptive Study I, Prescriptive Study, and Descriptive Study II. This paper reports preliminary findings from a prescriptive study, where initial requirements for an ideation method were identified, and a prototype brainstorming method (SBI) was proposed and evaluated. The prototype method is introduced in Section 4 and preliminary results from an empirical study used to evaluate SBI are reported in Section 5. Details of the experiments used to evaluate SBI are reported in the remainder of this section.

Experimental research with novice (student) designers was undertaken to enable comparative analysis between unstructured ideation on blank paper and structured ideation using the SBI method. The experiment plan was designed in a workshop format with novice designers in the United Kingdom and South Korea (see Table 1 and 2). Participants were first divided into control and experimental groups at random. The SBI method and use of the template were explained to the experimental group, whereas the control group was provided with no structure for the ideation session. Participants were set a brief to design a biologically-inspired chair to be produced using additive manufacturing technologies. In order to initiate the brainstorming process each participant selected one visual theme from a selection of four cue cards provided (cells, water, skeleton, and branches). Participants were able to research further source materials for inspiration using computers or phones and were instructed to clearly record motifs (elements of an image or design) that inspired them. A bio-inspired design theme was chosen for the ideation process to assist in tracking the development of design motifs because they reflect the development process from bio-inspired sources to design outcomes (Wilson *et al*., 2010).

Participants' ideation outcomes were collected at the end of the workshop for comparative analysis between SBI users and the control group. Two evaluation methods were used to measure the novice designers' perceptions of the method (ease of use) and to assess ideation effectiveness (the number of generated ideas). First, at the end of the workshop, participants were asked to complete a questionnaire to provide feedback on their perception of ease of use of the method they followed (either SBI or unstructured). The questionnaire contained the same questions for the Korean and British experiments, although the wording of some questions was adjusted to take into account cultural differences. Secondly, the ideation effectiveness of designers was evaluated by counting the total number of ideas generated, which is the first of Shah's assessment metrics (2003).

Table 1. Experiment plan

Step	Time (minutes)	Action list
1. Introduction	20	- Research and experiment background - Complete ethical review and security maintenance - Explain the brainstorming method
2. Ideation	60	Undertake brainstorming design ideation with two groups 1. Experimental group: SBI 2. Control group: unstructured (blank paper)
3. Evaluation	20	Questionnaire to evaluate the method used and obtain feedback
4. Closing remarks	5	-

Table 2. Experiment design

Variables		Control group	Experimental group
Control Variable	Participants background (age, education, environment)	Same degree course and year of study	
	Experiment design (materials, topic, time plan)	Identical	
Independent Variable	Brainstorming format	Unstructured	SBI
Number of participants	United Kingdom (University of Leeds)	14	16
	South Korea (Korea Polytechnic University)	10	61
	Total	24	77
	Total participants	101	

4 A SYSTEMATIC BRAINSTORMING IDEATION METHOD (SBI)

Brainstorming is a widely used designer-friendly method that is familiar to the majority of novice designers. It has the benefit of being an intuitive and easy way to express and develop thinking based on acquired information and the individual's experience. In this way, as well as increasing the number of concepts, brainstorming can help designers to generate a wider range of design ideas through cognitive stimulation (Dugosh *et al*., 2000; Goldschmidt and Smolkov, 2006; Hernandez *et al*., 2010).
The need for a design ideation method that improves the ideation performance of novice designers was identified in Section 2.2. The brainstorming method introduced in this paper is part of a wider design ideation process that aims to increase design stimuli by encouraging a systematic process for the identification of design concepts and, in turn, analogies that can be used as tacit knowledge for concept generation. This section is divided in two with the first outlining requirements for the brainstorming method and the second introducing the method itself. Later, in Section 5, results of the evaluation of the method are reported.

4.1 Requirements for the SBI method

In existing brainstorming methods, designers write or draw by pen on paper, with sketching recognised as effective tool for design development (Dugosh *et al*., 2000; Kohn and Arditti, 2011). However, at the same time, starting with a blank piece of paper can cause limitations for the novice designer due to differences in their collection and use of information when compared to experienced designers. Additionally, basic brainstorming methods tend to lead to unsystematic processes and do not promote appropriate stimulation from the information and resources that have been gathered.
In order to increase the quantity and variety of ideas generated by novice designers, specific ideation stages are required within the brainstorming method. Since design ideation can be regarded as a knowledge creation process, the SECI model (Nonaka *et al*., 2000) was selected as an appropriate structure to use when developing specific design concepts. SECI and design ideation have a notable common aim: providing a set of stages to better support the knowledge generation process. Brief information on SECI and its application to the SBI method are provided in the following section.

4.2 Proposed SECI-based brainstorming method (SBI)

SECI is a knowledge creation model with four sequential steps (socialisation, externalisation, combination and internalisation), that transform tacit knowledge into explicit knowledge (Nonaka *et al*., 2000) (see Figure 2.a). This conceptual framework is important within design and ideation, providing overall processes for supporting idea generation processes within academic, practice and industrial settings: for example, design of higher education curricula (Chootongchai and Songkram, 2018; Whelan *et al*., 2017), design of learning environments (Mohamad *et al*., 2016), customised design thinking models (Bork *et al*., 2017), and product development (Sakellariou *et al*., 2017). However, it is more frequently used for the development of scenarios and functions rather than design ideation itself. This research developed specific ideation stages for a designer-friendly Systematic Brainstorming Ideation (SBI) method based on SECI that would be suitable for use by novice designers. Table 3 outlines the alignment of the SBI method with the four stages of the SECI theory. These four stages form the basis of the paper template for brainstorming using SBI (shown in Figure 2(c). The structure of the template and usage is illustrated in Figure 2(b). It can be seen from Figure 2 that the method is cyclical in a similar manner to the SECI model. The first stage in a given cycle involves populating the 'motifs' box (in the top-left corner of the SBI template) with the motifs (elements of an image or design) that have been chosen as inspiration. Having done this, the user proceeds through the sections in a clockwise direction. There is, however, a notable difference between SECI and ideation, as the latter needs to be based on the design objectives. Therefore, one section was added to consistently remind designers of the design objective during the ideation process. This section is region 5 in Figure 2(b) and the chair image in the sample template shown in Figure 2(c). The top left-hand box in the SBI template is where the motif(s) is explored and then in the top right-hand box the motif(s) can be applied to particular parts of the design object, e.g. the chair in Figure 2. In the bottom right-hand corner of the template, these applications of the motif are integrated into the whole design as candidate design solutions and finally this is developed into a final design concept in the bottom left-hand corner of the template.

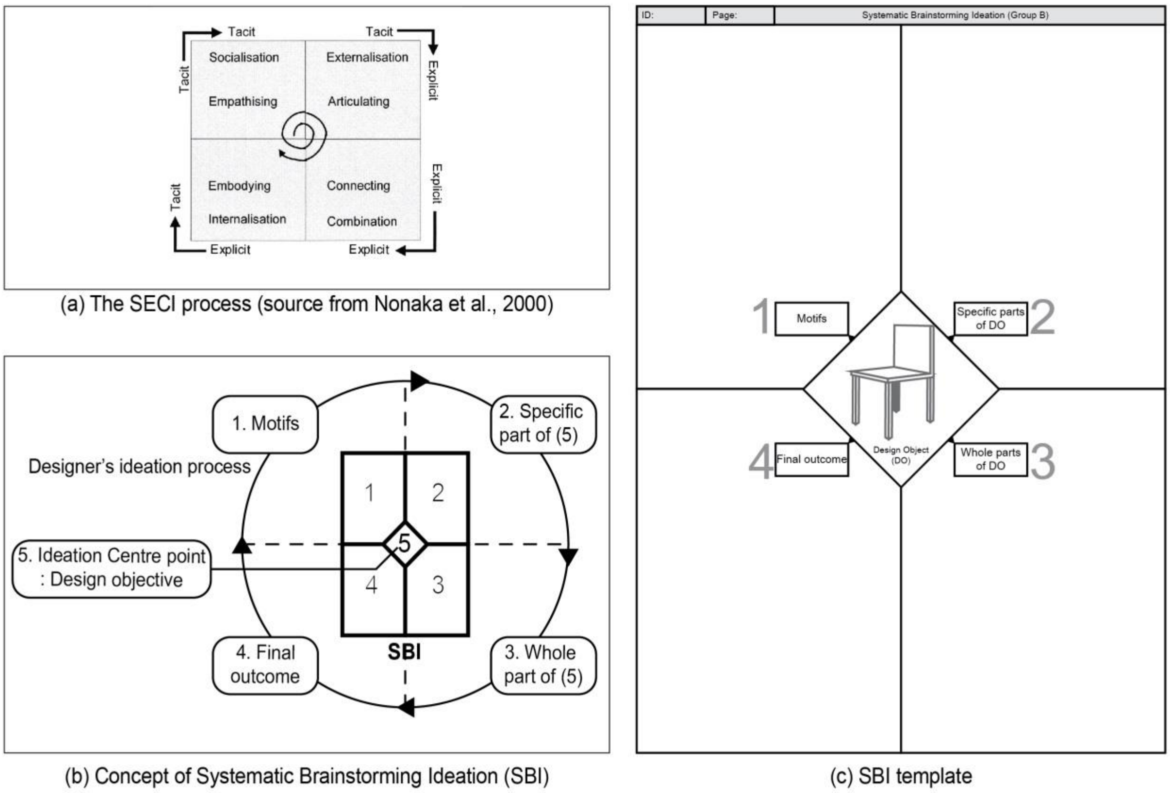

Figure 2. Transforming from SECI to brainstorming ideation stages

Table 3. Relationships between SECI and SBI

SECI theory		SBI method	
1.Socialisation	Explore the tacit knowledge as solution in response to the brief: such as motifs, case study, information or others	1.Motifs	Explore the tacit motifs or clues in response to the brief
2.Externalisation	Define the tacit knowledge to explicit information	2.Specific parts of design object	Apply motifs into specific parts of design object
3.Combination	Apply explicit information to establish solution	3.Whole parts of design object	Apply specific parts' results into the whole design object
4. Internalisation	Optimise the solution	4.Final ideation concept	Ideate the design object based on the previous outcomes

Experimental and control groups used different paper templates as the experimental variable for one-hour ideation sessions. Experimental groups conducted ideation along with the given four stages for 15 minutes each (Table 3 SBI method) with use of SBI (Figure 2c). On the other hand, control groups used blank paper without further guidance.

5 RESULTS

Evaluation experiments involving 101 participants, 30 in the UK and 71 in the South Korea, were carried out. 24 of the participants used an unstructured approach and 77 used the SBI method. A total of 80 SBI templates were completed (examples are shown in Figure 3).

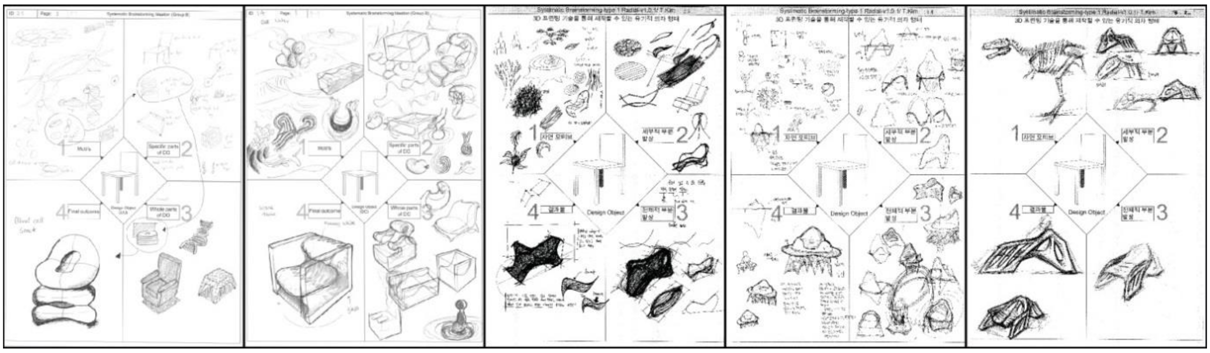

Figure 3. Examples of completed SBI templates

With reference to the quantity metric in Shah (2003), the total number of concepts within each completed template were counted. As can be seen from Figure 4 and Table 4, the SBI users generated 30% more ideas compared to those following an unstructured method (blank paper) in both the UK and South Korea. These results indicate that the four (specific) ideation stages of the SBI method are effective in supporting novice designers' ideation performance with regards to the quantity of ideas generated.

Table 4. The average number of generated ideas

	Control group	Experimental group
Brainstorming format	Unstructured - Blank paper (BP)	SBI
United Kingdom	Total: 19.2	Total: 25
South Korea	Total: 9.2	Total: 12.2

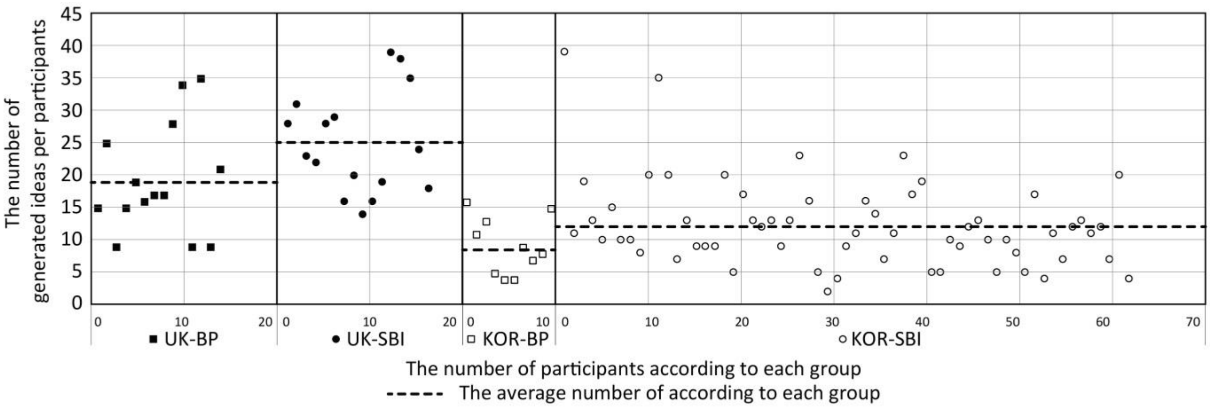

Figure 4. The number of idea elements generated by all participants

In addition to this analysis, feedback on participants' experiences of using SBI was acquired through a questionnaire completed by 96 of the 101 workshop participants after the ideation workshop. The results, shown in Figure 5, indicate that the majority of participants positively evaluated SBI, with consistently better responses compared to the use of blank paper. Responses for SBI and unstructured (blank paper) are summarised as: effectiveness (63.5% vs. 50.0%); ease of use (47.3% vs. 31.8%); likelihood of future use (64.9% vs. 63.7%). The usability findings indicate that the SBI method is designer-friendly, particularly considering that participants were using SBI for the first time during the experiment. It is noteworthy that SBI is reported as being easier to use than blank paper, which is expected to be a familiar method. This highlights the fact that SBI makes the ideation process easy and intuitive for novice designers as it leads them through specific ideation stages. Feedback also noted the effectiveness of SBI with participants ranking the effectiveness twice that of the control group using blank paper.

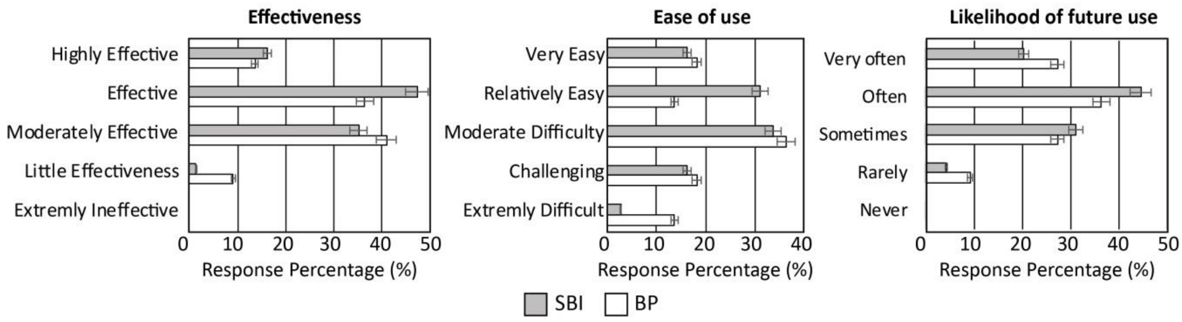

Figure 5. Comparative evaluation between SBI and BP (blank paper). Results show ± five percent standard error

The initial observations made during the experiments also corresponded with the data shown in Figure 5. The control group, using blank paper, generally showed ideation processes that reflected those of novice designers reported in the literature, i.e. concurrent and unsystematic processes (Kavakli and Gero, 2002), avoidance of ideation difficulty (Dinar, Shah, Park *et al*., 2015), with ideas emerging spontaneously without clear connections or a logical development process. Some participants in the control group only created final chair outcomes, exhibiting fixation, and others frequently shifted ideation themes or conducted actions that were not closely related to the ideation (such as colouring). The results from the control group experiments also showed complexly mixed ideas, generated disturbed concentration and caused confusion and so decreased the attainability of a systematic ideation process and correlation among ideas.

On the other hand, the experimental groups using the SBI method achieved a more successful ideation process compared to the control groups. Responses exhibited a logical ideation performance (from tacit motifs to explicit ideas), idea generation based on correlation of previous ideas, and proactive behaviour when faced with difficulties. The ideas were intensively produced and the relationship between the four themes was also enhanced. These preliminary results indicate that the four ideation themes of SBI provide clear and specific objectives to users resulting in a structured ideation process, akin to that of experienced designers (Kavakli and Gero, 2002).

6 DISCUSSION

The results reported in this paper show that (i) the use of SBI can increase the number of design concepts generated and (ii) novice designers reported positive experiences when using it. As noted earlier, the number of concepts generated is just one of four metrics (quantity, quality, variety, and novelty) of design ideation processes identified by Shah (2003). Further work is underway to assess the impact of SBI on the quality, variety, and novelty of generated concepts. Overall, SBI users generated 30% more ideas compared to the blank paper users in both countries. However, UK participants generated double the number of ideas compared to their Korean counterparts in SBI and blank paper groups respectively. The UK and Korean participants' evaluations commonly showed similar results about effectiveness, ease of use, and likelihood of future usage of SBI. Some participants in both countries also described their experience of using SBI as highly satisfactory, allowing them to develop new ideas based on a larger number of analogies according to the given specific ideation stages. Once methods evaluating quality, variety, and novelty have been developed, a more detailed analysis of the results will be carried out. In order to further assess the effectiveness of SBI, methods to analyse collected outcomes need to be developed to support, e.g. assessment of perspectives such as diversity of ideas generated and cultural differences.

7 CONCLUSION

This paper reports an ideation method based on design literature with the aim of improving novice designers' effective ideation according to Design Research Methodology (DRM). The requirements of a systematic/structured ideation process, a designer-friendly method, and greater quantity and variety of resources for analogies were identified from the literature. In order to address these requirements a systematic brainstorming ideation (SBI) method based on SECI was developed.

The SBI method was evaluated through experimental workshops with 101 novice (student) designers in the UK and South Korea. The experimental group used the SBI method while the control group followed an unstructured approach for the ideation session. Two evaluation methods were used: a questionnaire to evaluate the requirement of ease of use/designer-friendly method, and the quantity of ideas generated was measured to assess the effectiveness of the systematic method (SBI). Preliminary analysis results reported in this paper indicate that the SBI method increases novice designers' ideation effectiveness. Compared to the control group, SBI users generated 30% more ideas through use of the systematic and structured method, indicating the method to be significantly more effective than unstructured ideation. The majority of participants positively evaluated SBI. In particular, the ease of use was reported as 47.3% by the novice designers with 64.9% indicating that they are likely to use the method again.

It is noteworthy, and indicates the real value of the method, that the four stages within SBI have been shown to support novice designers in their learning and understanding of ideation processes as they develop into experienced designers. Future work will consider the additional measurement criteria of quality and variety for further assessment of the effectiveness of SBI. Additional experiments will also be conducted with experienced designers for comparative analysis with novice designers.

REFERENCES

Ball, L.J., Ormerod, T.C. and Morley, N.J. (2004), "Spontaneous analogising in engineering design: a comparative analysis of experts and novices", *Design Studies*, Vol. 25 No. 5, pp. 495–508. https://doi.org/10.1016/j.destud.2004.05.004

Ball, L.J., St.B.T. Evans, J., Dennis, I. and Ormerod, T.C. (1997), "Problem-solving Strategies and Expertise in Engineering Design", *Thinking & Reasoning*, Vol. 3 No. 4, pp. 247–270. https://doi.org/10.1080/135467897394284

Blessing, L.T.M. and Chakrabarti, A. (2009), DRM, a Design Research Methodology, Springer, Vol. 39, Springer London, London, available at: https://doi.org/10.1007/978-1-84882-587-1.

Borgianni, Y., Lenarduzzi, V., Rotini, F. and Taibi, D. (2018), "BRINGING STIMULATED IDEATION IN A WEB ENVIRONMENT: STUDENTS' EVALUATIONS OF A BASIC SOFTWARE RELEASE", *Bath*, pp. 411–418.

Bork, D., Karagiannis, D. and Hawryszkiewycz, I. (2017), "Supporting Customized Design Thinking Using a Metamodel-based Approach Metamodel-based Approach for Customized Design Thinking Supporting Customized Design Thinking Using a Metamodel-based Approach", *20th Australasian Conference on Information Systems (ACIS) 2017*, pp. 1–11.

Cassotti, M., Agogué, M., Camarda, A., Houdé, O. and Borst, G. (2016), "Inhibitory Control as a Core Process of Creative Problem Solving and Idea Generation from Childhood to Adulthood", *New Directions for Child and Adolescent Development*, Vol. 2016 No. 151, pp. 61–72. https://doi.org/10.1002/cad.20153

Chootongchai, S. and Songkram, N. (2018), "Design and Development of SECI and Moodle Online Learning Systems to Enhance Thinking and Innovation Skills for Higher Education Learners", *International Journal of Emerging Technologies in Learning (IJET*), Vol. 13 No. 03, p. 154. https://doi.org/10.3991/ijet.v13i03.7991

Dinar, M., Shah, J.J., Cagan, J., Leifer, L., Linsey, J., Smith, S.M. and Hernandez, N.V. (2015a), "Empirical Studies of Designer Thinking: Past, Present, and Future", *Journal of Mechanical Design*, Vol. 137 No. 2, p. 021101. https://doi.org/10.1115/1.4029025

Dinar, M., Shah, J.J., Park, Y. and Langley, P. (2015b), "PATTERNS OF CREATIVE DESIGN: PREDICTING IDEATION FROM PROBLEM FORMULATION", pp. 1–10.

Dugosh, K.L., Paulus, P.B., Roland, E.J. and Yang, H.-C. (2000), "Cognitive stimulation in brainstorming.", *Journal of Personality and Social Psychology*, Vol. 79 No. 5, pp. 722–735. https://doi.org/10.1037/0022-3514.79.5.722

Farel, R. and Yannou, B. (2013), "Bio-Inspired Ideation: Lessons From Teaching Design To Engineering Students", *ICED13: 19th International Conference on Engineering Design*, No. August, pp. 1–9.

Goldschmidt, G. and Smolkov, M. (2006), "Variances in the impact of visual stimuli on design problem solving performance", *Design Studies*, Vol. 27 No. 5, pp. 549–569. https://doi.org/10.1016/j.destud.2006.01.002

Goucher-Lambert, K. and Cagan, J. (2017), “Using crowdsourcing to provide analogies for designer ideation in a cognitive study”, *Proceedings of the International Conference on Engineering Design, ICED*, Vol. 8 No. DS87-8, pp. 529–538.
Hatchuel, A., Le Masson, P., Reich, Y. and Subrahmanian, E. (2018), “Design theory: a foundation of a new paradigm for design science and engineering”, *Research in Engineering Design*, Springer London, Vol. 29 No. 1, pp. 5–21. https://doi.org/10.1007/s00163-017-0275-2
Hernandez, N.V., Shah, J.J. and Smith, S.M. (2010), “Understanding design ideation mechanisms through multilevel aligned empirical studies”, *Design Studies*, Vol. 31 No. 4, pp. 382–410. https://doi.org/10.1016/j.destud.2010.04.001
Hey, J., Linsey, J., Agogino, A.M. and Wood, K.L. (2008), “Analogies and Metaphors in Creative Design”, *International Journal of Engineering Education*, Vol. 24 No. 2, pp. 283–294.
Ho, C.-H. (2001), “Some phenomena of problem decomposition strategy for design thinking: differences between novices and experts”, *Design Studies*, Vol. 22 No. 1, pp. 27–45. https://doi.org/10.1016/S0142-694X(99)00030-7
Houdé, O. and Borst, G. (2014), “Measuring inhibitory control in children and adults: Brain imaging and mental chronometry”, *Frontiers in Psychology*, Vol. 5 No. JUN, pp. 1–7. https://doi.org/10.3389/fpsyg.2014.00616
Kavakli, M. and Gero, J.S. (2002), “The structure of concurrent cognitive actions: a case study on novice and expert designers”, *Design Studies*, Vol. 23 No. 1, pp. 25–40. https://doi.org/10.1016/S0142-694X(01)00021-7
Kohn, N.W. and Arditti, L.E. (2011), “Effects of Quantity and Quality Instructions on Brainstorming”, Vol. 45 No. 1, pp. 38–46. https://doi.org/10.1002/j.2162-6057.2011.tb01083.x
Koronis, G., Silva, A. and Kang, J. (2018), “Impact of Design Briefs on Creativity : a Study on Measuring Student Designers Outcomes”, pp. 2461–2472.
Mohamad, N.A., Anwar, K., Khaidzir, M. and Ibrahim, R. (2016), “A Study on Transforming the Knowledge in Design Learning Environment”, No. August, pp. 29–30.
Moreno, D., Blessing, L., Wood, K., Vögele, C. and Hernández, A. (2015a), “Creativity Predictors: Findings From Design-by-Analogy Ideation Methods’ Learning and Performance”, *27th International Conference on Design Theory and Methodology*, ASME, Boston, USA. https://doi.org/10.1115/DETC2015-47929
Moreno, D.P., Yang, M.C., Hernández, A.A., Linsey, J.S. and Wood, K.L. (2015b), “A Step Beyond to Overcome Design Fixation: A Design-by-Analogy Approach”, *Design Computing and Cognition ‘14*, Springer International Publishing, Cham, pp. 607–624. https://doi.org/10.1007/978-3-319-14956-1_34
Nonaka, I., Toyama, R. and Konno, N. (2000), “SECI, Ba and Leadership: a Unified Model of Dynamic Knowledge Creation”, *Long Range Planning*, Vol. 33 No. 1, pp. 5–34. https://doi.org/10.1016/S0024-6301(99)00115-6
Orthel, B.D. and Day, J.K. (2016), “Processing Beyond Drawing : A Case Study Exploring Ideation for Teaching Design”, *SAGE Open*, Vol. 6 No. 3, pp. 1-16. https://doi.org/10.1177/2158244016663285
Sakellariou, E., Karantinou, K. and Goffin, K. (2017), “‘Telling tales’: Stories, metaphors and tacit knowledge at the fuzzy front-end of NPD”, *Creativity and Innovation Management*, Vol. 26 No. 4, pp. 353–369. https://doi.org/10.1111/caim.12237
Self, J., Evans, M. and Kim, E.J. (2016), “A comparison of digital and conventional sketching: Implications for conceptual design ideation”, *Journal of Design Research*, Vol. 14 No. 2, pp. 171–202. http://dx.doi.org/10.1504/JDR.2016.077028
Shah, J. (2003), “Metrics for measuring ideation effectiveness”, *Design Studies*, Vol. 24 No. 2, pp. 111–134. https://doi.org/10.1016/S0142-694X(02)00034-0
Valkenburg, R. and Dorst, K. (1998), “The reflective practice of design teams”, *Design Studies*, Vol. 19 No. 3, pp. 249–271. https://doi.org/10.1016/S0142-694X(98)00011-8
Venkataraman, S., Binyang, S., Jianxi, L., Karupppasamy, S., Elara, M.R., Blessing, L. and Wood, K. (2017), “Investigating Effects of Stimuli on Ideation Outcomes”, *International Conference on Engineering Design*.
Whelan, L., Maher, C. and Deevy, C. (2017), “Towards a University Design School. Restoring the value of tacit knowledge through assessment”, *The Design Journal*, Routledge, Vol. 20 No. sup1, pp. S1459–S1470.
Wilson, J.O., Rosen, D., Nelson, B.A. and Yen, J. (2010), “The effects of biological examples in idea generation”, *Design Studies*, Elsevier Ltd, Vol. 31 No. 2, pp. 169–186. https://doi.org/10.1080/14606925.2017.1352670

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