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Overcoming design fixation: Design by analogy studies and nonintuitive findings

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Abstract

Design fixation is a phenomenon with important significance to many fields of design due to the potential negative impacts it may have in design outcomes, especially during the ideation stage of the design process. The present study aims to provide a framework for understanding, or at least probing, design fixation by presenting a review of existing defixation approaches, as well as metrics that have been employed to understand and account for design fixation. This study also describes the results of two design by analogy (DbA) methods, WordTree and SCAMPER, to overcome design fixation in an experiment that involved 97 knowledge-domain experts. The study outcomes are at least twofold: a common framework of metrics and approaches to overcome design fixation in a wide range of design problems and nonintuitive results for DbA approaches in design fixation and other related creativity metrics. The application of WordTree and SCAMPER shows that both methods yield increased novelty compared to a control, where the SCAMPER results are significantly higher than WordTree. It is also found that WordTree mitigates design fixation whereas SCAMPER appears to be ineffective for this purpose but effective to generate an increased quantity of novel ideas. These results demonstrate that both DbA methods provide defixation capabilities and enhance designers' creativity during idea generation.

Keywords: Creativity; Design by Analogy; Design Cognition; Design Fixation; Design Methods

1. INTRODUCTION

Creativity is defined as the ability to develop concepts or ideas, or produce works (solutions) that are both novel and valuable (useful and appropriated; Sternberg & Lubart, 1999; Sarkar & Chakrabarti, 2007). The creative design process may be inhibited by a focus on existing, standard solutions or variants of existing solutions, that is, by becoming fixated. Fixation can be triggered by diverse causes, such as a designer's unfamiliarity with or limited knowledge of analogous fields of study, cognitive blocks, difficulty in identifying new applications and functions, and familiarity with existing, feasible, and known sets of solutions.

Fixation is a phenomenon that is perceived as unwanted due to its conceptual conflicts with creativity and design. Fixation and its effects in the design process across knowledge domains have been a subject of study from a research and practical viewpoint. Such research has attempted to understand and avoid the negative impact that design fixation may have in the early stage of ideation, for example, limiting design space exploration, and thereby narrowing the range or divergent possibilities of solutions.

A number of methods have been developed to tackle design fixation. One class of such methods is design by analogy (DbA), which has proven to be effective in generating novel and high-quality ideas, as well as in reducing design fixation (Linsey et al., 2007, 2012; Moreno, Hernandez, et al., 2014; Moreno, Yang, Blessing, et al., 2014). A cognitive model for ideation considers ideas to emanate from one of three sources or processes: serendipity, discovery, and analogy (Markman & Wood, 2009). Analogy or analogical transfer appears to support designers in identifying and reaching distant domains that enable the exploration of innovative or disruptive solutions based on experience or external sources of inspiration and knowledge.

Despite being a critical topic and investigated from diverse perspectives, design fixation remains a relatively unexplored and intriguing area of research and exploration, especially in knowledge domains such as engineering. There is still

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much to learn about the capabilities and success factors of de-fixation approaches, as well as, more generally, the extent to which design fixation can limit or benefit the design process.

Based on the discussion above, the present study expands previous work presented in the Design Computer and Cognition Conference (DCC'14; Moreno, Yang, Hernandez, et al., 2014) and addresses the following research questions related to fixation in the context of ideation methods. First, what are the dimensions of de-fixation approaches and to what extent has a cumulative understanding of these approaches been developed? Second, are design fixation metrics comprehensive? Do they capture fixation's concept and extent? Third, considering analogy as a relevant source of ideas and an approach to overcome design fixation, what are the results of applying two different DbA methods (WordTree and SCAMPER) for overcoming design fixation? Are there differences in the creativity and fixation metrics after applying the methods?

2. BACKGROUND AND CONTEXT

2.1. Design fixation

Various definitions of fixation can be found in literature with different characteristics depending on its context or field of knowledge. Examples of fixation include memory fixation, problem-solving fixation (Luchins & Luchins, 1959), cognitive fixation (Smith & Blankenship, 1991), conceptual fixation, knowledge fixation (Youmans & Arciszewski, 2012), operational fixation, functional fixation (Purcell & Gero, 1996), and design fixation (Jansson & Smith, 1991; German & Barrett, 2005).

Design fixation is described as the inability on the part of designers to solve design problems, or the persistent commitment to a limited exploration of alternatives by self-imposing constraints (Youmans, 2007), employing a familiar method ignoring diverse opportunities, or limiting the space of solutions by means of developing variants (Luchins & Luchins, 1959, 1970; Jansson & Smith, 1991). Jansson & Smith (1991) provided one of the first operational definitions of design fixation as "a counterproductive effect of prior experience on the generation of creative designs aimed at solving a realistic problem." These studies indicate that design fixation has a negative connotation, which may explain the research related to fixation and concerted efforts to avoid it when solving design problems.

A number of causes can contribute to design fixation: expertise (Linsey et al., 2010), unfamiliarity with principles of a discipline or domain knowledge (Purcell & Gero, 1996; Cross, 2004), personality types (Toh et al., 2012; Choo et al., 2014), a lack of awareness of technological advances, or conformity due to proficiency in the methods and supporting technologies of an existing solution (Luchins & Luchins, 1959).

During the design process, design fixation can emerge when example solutions are presented (Christensen & Schunn, 2007; Tseng et al., 2008; Jensen, 2010; Linsey et al., 2010; Agogué et al., 2011; Smith & Linsey, 2011), when a considerable quantity of resources are invested in a potential solution (Viswanathan & Linsey, 2011), when there are weak or ill-defined problem connections either internally (within elements of the problem) or externally (between the problem and other problem domains; MacCrimmon & Wagner, 1994), and when there are more vertical (refined version of same idea) than lateral transformations (moving from one idea to another; Goel, 1995).

Design fixation research is critical due to both its impact on design outcomes and the potential, if mitigated, to improve designers' abilities to generate innovative solutions. Studies from diverse design disciplines, engineering, and cognitive science provide findings across a number of fields, as described below.

2.2. Ideation approaches to overcome fixation

Design process success has been linked with ideation stage results (Andersson, 1994; Perttula & Sipilä, 2007). Extensive studies have focused on the formulation of metrics to evaluate ideation process and their outcomes: quality, quantity (fluency), novelty (originality), workability (usefulness), relevance, thoroughness (feasibility), variety, and breadth (MacCrimmon & Wagner, 1994; Shah et al., 2000; McAdams & Wood, 2002; Shah et al., 2003; Srivathsavai et al., 2010; Girotra et al., 2010; Linsey et al., 2011, 2012; Oman et al., 2013; Moreno, Hernandez, et al., 2014). Some studies have considered design fixation directly measurable in a quantitative way, and others as a qualitative finding or measured indirectly through other ideation metrics.

Based on recent ideation studies we developed the framework shown in Figure 1 to characterize the existing approaches that have shown some effectiveness in overcoming design fixation. This framework is composed of quadrants that are defined by means of two dimensions:

- trigger or source provided by a method, which is divided into intrinsic and extrinsic and
- implementation method corresponding to the number of designers involved, either individual or as a team.

Some methods can be found at the intersection of the dimensions presented; for example, functional analysis is an extrinsic method that can be applied individually or as a team.

The next sections describe the modalities and cognitive processes behind each of the intrinsic and extrinsic approaches.

2.2.1. *Intrinsic approaches*

Intrinsic approaches are based on the generation of ideas from intuition or previous experience. Table 1 presents the approaches and related literature for the two quadrants of the intrinsic dimension of Figure 1.

At the individual level, problem rerepresentation or reframing increases retrieval cues for analogical inspiration or expands design space exploration (Andersson, 1994; McKerlie & MacLean, 1994; Linsey et al., 2010; Zahner et al., 2010).

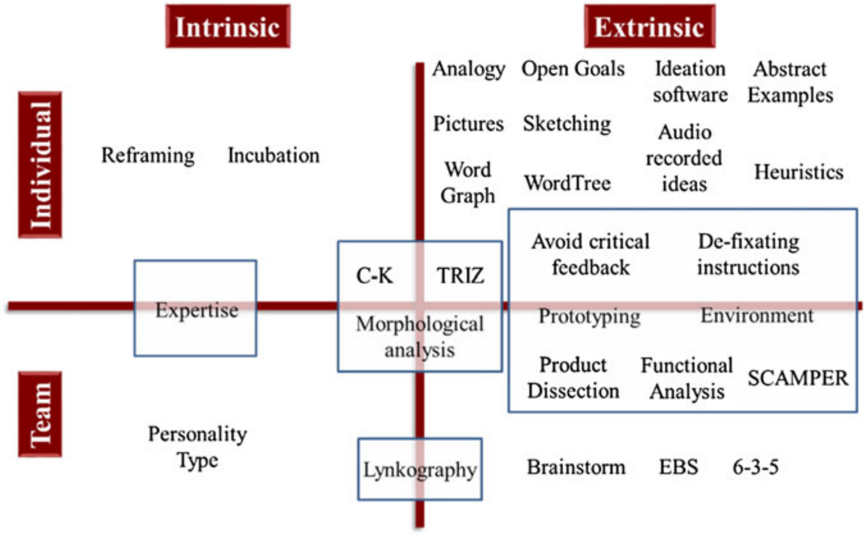

Fig. 1. Approaches to overcome fixation.

Incubation encourages the disconnection from a problem by taking a break or performing a nonrelated task, and by doing that, the individual may access other critical information where insightful ideas may emerge, enabling the development of novel or original solutions (Smith & Blankenship, 1989, 1991; Smith, 1995*b*; Christensen & Schunn, 2005; Kohn & Smith, 2009; Vargas-Hernandez et al., 2010; Smith & Linsey, 2011; Youmans & Arciszewski, 2012).

At the team level, diversify personality type relates to the way people prefer to interact with others. This approach has been found to have a positive impact on design activities. For example, extroverted persons have a preference to participate in dissection activities that have the potential to increase creativity (Linsey et al., 2010; Toh et al., 2012).

2.2.2. *Extrinsic approaches*

Extrinsic approaches make use of heuristics, stimuli/assistance, or prompts external to the designer to promote the development of ideas (see Table 2).

At the individual level, abstract formulation of a problem is proposed to promote divergent thinking processes and generation of original ideas (Zahner et al., 2010).

Approaches that make use of examples to increase the number of original ideas generated are concept–knowledge expansive examples to allow interrelated exploration of the concept and knowledge spaces (Agogué et al., 2011), pictorial examples to allow designers to consider additional design information without over constraining the design (Christiaans & Van Andel, 1993; Purcell & Gero, 1996; Christensen & Schunn, 2007; Tseng et al., 2008; Yang, 2009), and audiorecorded examples to foster retrieval of long-term memory concepts and concepts distantly associated (Dugosh et al., 2000; Dugosh & Paulus, 2005).

Two approaches make use of analogies. The first provides analogies assists in restructuring a problem and triggers new clues to developed solutions (Chrysikou & Weisberg, 2005; Smith & Linsey, 2011). The second provides analogies with open design goals that may (due to the openness) influence cognitive processes in filtering information that will be then incorporated in the concept solutions, thereby increasing originality (Moss, Cagan, et al., 2007; Moss, Kotovsky, et al., 2007).

Design heuristics promote divergent thinking by providing multiple sequential and/or systematic ways to approach a problem and generate novel and original solutions (Yilmaz et al.,

Table 1. *Intrinsic approaches to overcome fixation according to Moreno et al. 2014*

Trigger or Source	Implementation Method	Method, Technique, or Approach	Reference
Intrinsic	Individual level	Problem rerepresentation/reframing	Andersson (1994), Linsey et al. (2010), McKerlie & MacLean (1994), Zahner et al. (2010)
		Enabling incubation	Smith & Blankenship (1989, 1991), Smith (1995*a*, 1995*b*), Christensen & Schunn (2005), Kohn & Smith (2009), Vargas-Hernandez et al. (2010), Smith & Linsey (2011), Youmans & Arciszewski (2012)
	Team level	Diversify personality type	Linsey et al. (2010), Toh et al. (2012)

Table 2. *Extrinsic approaches to overcome fixation according to Moreno et al. 2014*

Trigger or Source	Implementation Method	Method, Technique, or Approach	Reference
Extrinsic	Individual level	Abstract formulation of the problem	Zahner et al. (2010)
		Use of concept–knowledge expansive examples	Agogué et al. (2011)
		Pictorial examples	Christiaans & Van Andel (1993), Purcell & Gero (1996), Christensen & Schunn (2007), Tseng et al. (2008), Yang (2009)
		Audiorecorded examples	Dugosh et al. (2000), Dugosh & Paulus (2005)
		Provide analogies	Chrysikou & Weisberg (2005), Smith & Linsey (2011)
		Provide analogies with open design goals	Moss, Cagan, & Kotovsky (2007); Moss, Kotovsky, & Cagan (2007); Tseng et al. (2008)
		Use of design heuristics	Yilmaz et al. (2010)
		Idea generation enabled with computational tools	MacCrimmon & Wagner (1994), Linsey et al. (2010), Dong & Sarkar (2011)
		Graphical representations	Rodgers et al. (2000), Christensen & Schunn (2007), Yang (2009)
		Case-based reasoning and case-based design	Purcell & Gero (1996), Heylighen & Neuckermans (2003), Yan et al. (2013)
		Use word graphs	Segers et al. (2005)
		Word trees	Dugosh & Paulus (2005), Linsey et al. (2008)
	Team level	Electronic brainstorming	Dugosh et al. (2000), Dugosh & Paulus (2005)
		6-3-5/C-Sketch	Weaver et al. (2009), Vargas-Hernandez et al. (2010), Genco et al. (2012)

2010). Idea generation enabled by computational tools allows a designer or design team to alternate among types of problem representation and provides semantic or visual stimulus that will generate more productive ideas (MacCrimmon & Wagner, 1994; Linsey et al., 2010; Dong & Sarkar, 2011). Graphical representations offer a cognitive structure by means of external representation that highlights design complexity, condenses information, and enables lateral transformations (Rodgers et al., 2000; Christensen & Schunn, 2007; Yang, 2009).

Case-based reasoning (CBR) and case-based design, which is the application of CBR to design, have roots in analogical reasoning by learning from experience (Purcell & Gero, 1996; Heylighen & Neuckermans, 2003; Yan et al., 2013). CBR is used to contrast existing experiences/solutions/cases with new unsolved problems to find similarities and extend existing solutions to those new problems. Word graphs (Segers et al., 2005) and Word trees (Dugosh & Paulus, 2005; Linsey, Markman, et al., 2008; Linsey, Wood, et al., 2008) provide a synergic combination of analogies, semantic and graphical information, computational tools, and graphical representations to generate ideas.

At the Team level, electronic brainstorming enables interaction between members by a computer interface that prompts sets of ideas for overcoming production blocking (Dugosh et al., 2000; Dugosh & Paulus, 2005). 6-3-5/C-Sketch combines "use of examples," "use of design heuristics," and "use of graphical representations" that provide a sequential structure with visual and textual information (Genco et al., 2012; Weaver et al., 2009; Vargas-Hernandez et al., 2010).

2.2.3. Approaches at the dimension's intersections

Figure 1 shows approaches that lay at the intersection of the quadrants determined by the categorization dimensions. Table 3 lists such approaches.

Level of expertise or domain knowledge can be found at the intersection of individual and team levels. Expertise emerges with a designer's immediate knowledge, and can be expanded when working in teams, by using distant and/or different domain knowledge due to interactions with others (Purcell & Gero, 1996; Ball et al., 2004; Cross, 2004; Youmans & Arciszewski, 2012). However, some results indicate that novice designers generate more original concepts (Genco et al., 2012), while others show that experts consider details in their solutions due to a more evident association between problem and previous knowledge (Björklund, 2013). Due to prior exposure to a wide range of problems, situations, and solutions (Purcell & Gero, 1996), experts have the ability to frame and break down a problem into more manageable parts (Ball et al., 2004; Cross, 2004), to work with in-complete or ill-defined problems (Kolodner, 1997), and to identify relevant information, patterns, and principles in complex design problems (Cross, 2004).

There are six approaches at the intersection of individual and team levels: providing de-fixation instructions makes designers aware of features/elements that should be avoided, overcoming repeating ideas and, instead, producing novel ideas (Christensen & Schunn, 2007). Development of physical artifacts deals with design complexity (mental load). These models represent mental concepts as well as identify and manage fixation features (Yang, 2004; Christensen &

Table 3. *Approaches to overcome fixation at the intersection of categorization dimensions according to Moreno et al. 2014*

Trigger or Source	Implementation Method	Method, Technique, or Approach	Reference
Intrinsic	Individual ∩ team	Level of expertise or domain knowledge	Purcell & Gero (1996), Kolodner (1997), Ball et al. (2004), Cross (2004), Björklund (2012), Genco et al. (2012), Youmans & Arciszewski (2012)
Extrinsic	Individual ∩ team	Provide defixation instructions	Christensen & Schunn (2007)
		Develop physical artifacts (prototyping)	Yang (2004), Christensen & Schunn (2007), Youmans (2010), Kershaw et al. (2011), Viswanathan & Linsey (2011)
		SCAMPER	Blosiu (1999), Vargas-Hernandez et al. (2010), Youmans & Arciszewski (2012)
		Provide a creative design environment	Youmans & Arciszewski (2012), Chakrabarti (2013)
		Perform product dissection	Grantham et al. (2010)
		Develop functional modeling	Little et al. (1997), Linsey et al., 2010
Intrinsic ∩ extrinsic	Team level	Translating the design process into a linkography	Kan & Gero (2008)
Intrinsic ∩ extrinsic	Individual ∩ team	TRIZ	Altshuller (1999)
		Conduct a morphological analysis	Otto & Wood (1998)

Schunn, 2007; Youmans, 2010; Viswanathan & Linsey, 2011). Introducing critical feedback during concept generation with prototyping may increase design fixation (Kershaw et al., 2011). SCAMPER is a set of seven brainstorming operator categories that allow problem reframing and increase creativity through the use of analogies and metaphors that expand the design space (Blosiu, 1999; Vargas-Hernandez et al., 2010; Youmans & Arciszewski, 2012). A creative design environment is considered an approach to overcome fixation because designers may be motivated by a nurturing and encouraging environment (Youmans & Arciszewski, 2012; Chakrabarti, 2013). Product dissection allows "examination, study, capture, and modification of existing products." The method improves form and function understanding to develop new and different ideas (Grantham et al., 2010). Functional modeling enables functionality representation, to explore alternative means to link customer needs with product function, thus generating novel solution approaches (Little et al., 1997; Linsey et al., 2010).

Two sets of methods are at the intersection implementation. At the team level, Linkography translates a design process into graphs that represent the designers' cognitive activities (Kan & Gero, 2008). At the intersection of implementation, TRIZ and morphological analysis are found. TRIZ facilitates solutions by matching contradictions in design problems to generalized design parameters and design principles (meta-analogies; Altshuller, 1999). A study comparing graphical representations (sketching), control, and TRIZ showed that TRIZ was best in enhancing novelty (Otto & Wood, 1998; Keller et al., 2009). Morphological analysis enables generation of new solutions by combining different elements recorded in a matrix of functions versus solution principles per function. Concept solutions may be generated combinatorically based on the synthesis of solution principles per function (Otto & Wood, 1998).

The cumulative information presented above provides a better understanding of current approaches as well as implicit opportunities for integration to evaluate possible applications. The presented dimensional classification implies typology of new approaches and possible benefits or outcomes of these approaches.

2.3. Existing design fixation metrics

This section investigates existing metrics that have been developed and applied to assess fixation, considering their comprehensiveness and the way they capture fixation, which covers the broad spectrum of design problems domains from service to products. From the literature reviewed, two distinctive main categories are identified: direct and indirect metrics.

2.3.1. Direct metrics

These metrics inform a designer when fixation occurs and provide a crisp range of understanding for the concept of fixation. Table 4 shows a classification for direct metrics found in the literature. The metric definitions are coincident to the fixation definition in Section 2.1 and enable fixation identification and accountability.

2.3.2. Indirect metrics

Indirect metrics estimate fixation through indicators, but are not explicitly measured (Table 5). These indicators gauge if a designer is fixated, but do not provide additional information to validate the result. Two main classes are identified: personal and experimental. The personal class of indirect metrics are extracted from the designer(s) and their design processes. The experimental class corresponds to predetermined experimental attributes or responses that are contrasted before and after an experiment.

Table 4. *Direct metrics classification according to Moreno et al. 2014*

Class	Metric(s)	Reference
Repeated features	Calculation of fixation percentage; lower values indicate nonfixated designs: $\% \, Fixation: \frac{\# \, of \, similar \, features}{number \, of \, questions \, rated \, by \, the \, coders \, for \, each \, design}$	Toh et al. (2012)
	Comparison of the number and percentage of features included in a solution to a provided example	Purcell & Gero (1996), Linsey et al. (2010)
	Obtaining low values for both variety and novelty metrics: $Novelty = 1 - frequency = 1 - \frac{number \, of \, ideas \, in \, a \, bin}{total \, number \, of \, ideas}$ $Variety = \frac{number \, of \, bins \, a \, participant's \, idea \, occupy}{total \, number \, of \, bins}$	Jansson & Smith (1991); Shah, Kulkarni, & Vargas-Hernandez (2000); Shah, Smith, & Vargas-Hernandez (2003); Viswanathan & Linsey (2011)
	Measurement of functional fixation through dependent measures: (1) frequency of a given functional category at participant level, (2) number of functionally distinct designs, and (3) novelty* that measures solution uniqueness $* \, Novelty = 1 - \frac{\# \, of \, functionally \, similar \, designs \, generated \, by \, other \, subjects}{total \, \# \, of \, designs \, for \, all \, subjects}$	Tseng et al. (2008)
	Originality score (at feature level) and technical feasibility of solutions from a score table; originality evaluated after comparing features in designs with standard elements; higher design feasibility corresponds to higher fixation.	Genco et al. (2012)
	Evaluation of similarity between design brief of the project and the proposed solutions	Kershaw et al. (2011)
Nonredundant ideas	Correlation of the number of nonredundant ideas generated with the total number of unique ideas generated	Dugosh & Paulus (2005)
	Presence of both low quantity and originality in generated solution; originality is defined as statistical infrequency of a particular solution, which is a percentage from 0 to 1	Agogué et al. (2011)

2.4. Service and product design problems

Design problems or opportunities can arise from a variety of situations. Some of these may have an intangible nature, such as obtaining a degree (education service), requesting credit (financial service), or sending a document or object to a recipient (transporting service). Other situations relate to a clear physical product or artifact associated with a solution like using a coffee maker to make coffee (electromechanical appliance). Product design results in tangible artifacts, while service design corresponds to virtual systems of an intangible nature. Shostack (1982) defines services as acts that only exist in time. Vermeulen (2001) notes features that differentiate services from products: intangibility, simultaneity of production and consumption, heterogeneity, and perishability.

Services and products can be found interconnected to varying degrees (e.g., logistics) and may be considered as part of a continuum. This interconnection implies the potential of tools and methods for conceptual design from engineering, architecture, and other domains to be transferred to transactional fields to assist idea generation and overcome design fixation (Moreno, Hernandez, et al., 2014; Moreno, Yang, et al., 2014). It has been opined that the early stage of development for services is no different than for physical products and that it is at the detailed design phase where the methods diverge (Cagan & Vogel, 2013). This viewpoint supports the transferability of design methods between domains at least in the idea generation (ideation) stage.

2.5. DbA selected methods

We explore a DbA approach to overcome fixation due to its relevance, effectiveness, and its potential to have synergic results when integrated with other approaches. There is evidence that design solutions can be developed or adapted from preexisting systems or solutions from other domains (Otto & Wood, 1998; Keller et al., 2009; Fu et al., 2014). For example, astronauts' vortex cooling systems were later adapted as a means to mold and cool glass bottles (Hernández-Luna & Cárdenas-Franco, 1988). Inspiration from analogous domains can be achieved by associations among shared characteristics, attributes, properties, functions, or purposes (Gentner & Markman, 1997; Hey et al., 2007). Once an association between a design problem and a solution in another domain is established, a solution to the design problem can be developed (Bonnardel, 2000; Ball et al., 2004; Linsey et al., 2007; Linsey, Wood, et al., 2008; Markman et al., 2009).

Table 5. *Indirect metrics classification according to Moreno et al. 2014*

Class	Type	Metric(s)	Authors
Personal	Self-assessment	Commitment to an idea via self-assessment; surveys ask about perception of fixation reduction, generation of unexpected ideas, and workflow improvement	Segers et al. (2005)
	Degrees of freedom	Linkography and Shannon's entropy principle: analyze all possible moves on graph and, when moves are interconnected, the ideas are convergent and might be a sign of fixation.	Kan & Gero (2008)
		Goel's type of transformations: vertical and lateral; if more lateral than vertical, fixation can be prevented.	Goel (1995), Rodgers et al. (2000)
Experimental	Response improvement	Calculation of fixation effects for Remote Associates Test, subtracting the number of problems solved correctly between fixating and nonfixating stimuli conditions	Smith & Blankenship (1991), Moss et al. (2007)
	Negative features	Assigning of a discrete value that ranged from 0 to 10 that corresponds to the number of neutral and negative fixation features that were found at given check-in periods	Youmans (2010)
		Fixation identification as a focus in external features (form) and lower variety	Grantham et al. (2010)

Two methods, WordTree and SCAMPER, were selected to investigate a DbA approach to overcome fixation for a service design problem. Though other DbA methods exist, many are meant to be applied to design problems in the physical domain. WordTree and SCAMPER methods were selected considering that their semantic transformations and directives do not assume a design has a physical embodiment that may be more appropriate to service design problems and solutions.

2.5.1. *WordTree*

WordTree (Linsey, Markman, et al., 2008; Linsey, Wood, et al., 2008) is based on semantic transformation of textual representations of design problems by means of Princeton's WordNet or VisualThesaurus, which is a visual display of the WordNet database. WordTree enables rerepresentation of the problem and expansion of solution space due to new semantic associations, finding and exploring potential analogies and analogous domains (Segers & De Vries, 2003; Segers et al., 2005; Linsey, Markman, et al., 2008; Linsey, Wood, et al., 2008; Smith & Linsey, 2011; Verhaegen et al., 2011). Using the WordTree method, a designer constructs a diagram of "key problem descriptors," focusing on key functions and customer needs of the given design problem (Linsey, Markman, et al., 2008). Key problem descriptors are then placed in a tree diagram and semantically rerepresented by hypernyms and troponyms selected from WordNet. The WordTree Diagram facilitates associations; therefore, analogies and/or analogous domains can be identified. All analogies, analogous domains, and new problem statements can then be used to enrich group or individual idea generation.

2.5.2. *SCAMPER*

This method is based in directive transformations that enable a systematic search for solutions (Harris, 1973; Yilmaz et al., 2010). Each of the seven letters from SCAMPER's name correspond to a specific operator category with a set of questions that, when attempt to be answered, redirects analogical search to solve a problem. The operator categories are as follow: substitute (S), combine (C), adapt (A), modify/magnify/minimize (M), put to other uses (P), eliminate (E), and reverse/rearrange (R; Eberle, 1996). When applying the method, the designer may start with any of the operator categories at random, reflecting on the design problem from the category perspective and through the posed questions, which may enable the identification of analogous solutions or domains where a solution may be extracted. The designer can then proceed with exploring more questions of the same operator or move to another operator and repeat the procedure.

3. EXPERIMENTAL METHOD

Ninety-seven transactional process experts were recruited from professional development programs in Mexico and Singapore. Participants came from a variety of disciplines and involved 25 product and 29 service companies. Domain knowledge expertise was based on professional background and work role.

A service design problem was adopted from a previous study from the banking sector (Moreno, Hernandez, et al., 2014; Moreno, Yang, et al., 2014): "Reduce overdue accounts/unpaid credits."

The experiment included control and experimental treatments, and it was conducted in two phases (Table 6). The

Table 6. *Experiment phases and treatments*

Treatment	Phase I	Phase II	Sample Size	Gender (Female/Male)
Control	NT	NT	36	11/25
WordTree	NT	WT	37	12/25
SCAMPER	NT	SCA	24	11/13

control treatment did not specify a method [no technique (NT)] for either phase. Phase I of the Experimental treatments were NT, whereas phase II included two DbA methods: WordTree (WT) and SCAMPER (SCA). Phase I and phase II were held with 2 days in between, with the same design problem in both. Groups were distributed by background, gender, and other demographics.

The experimental phases and treatments enabled the distinction of results. The inclusion of a 2-day separation in between the two experimental phases enables evaluation of incubation effects for the same set of participants. The purpose of having a control (NT) Phase I is to verify that there are no statistical differences between participants. This verification is critical to be able to contrast the results of a control treatment to those of the DbA treatment groups, isolating personal or other factors that may influence the outcomes, that is, comparing prolific participants who may have randomly been assigned to a control (NT) treatment against "average performer" participants assigned to WordTree or SCAMPER treatments.

In all phases, participants were asked to individually create as many solutions for the design problem as possible, recording solutions as text and/or sketches/diagrams. In phase I, all participants were given 15 min to generate solutions using intuition alone (Fig. 2).

For Phase II, participants were divided into three groups, NT, WT, and SCA, and directed to separate rooms. NT participants were asked to continue generating solutions without a specific method for 15 min. WT participants were given a 15-min tutorial of the WordTree DbA method (Linsey, Markman, et al., 2012) and WordTree software (Thinkmap's Visualthesaurus©). Each WT participant was provided with a computer with Thinkmap's Visualthesaurus©. Relevant information and graphical associations between words were displayed by the software. SCA participants were also given a 15-min tutorial of the SCAMPER method. Each SCA participant was provided with a printed template with the operator and corresponding triggering questions. Participants from WT and SCA were then asked to generate solutions to the transactional design problem using the method and software tools for 15 min.

During Phase II, WT participants were asked to select words that rerepresented the design problem, and/or indicated particular solutions or solution domains. The goal was to understand semantic retrieval from the participants' long-term memories that allowed them to switch domains while developing analogous problem statements. Participants were required to list all alternative solutions they developed after extracting useful information from the provided software tool. Similarly, SCA participants were asked to record ideas under the operator category that enabled its generation, to understand how the analogical search and redirection was performed.

At the end of both phases, all listed ideas were collected, coded, sorted by affinity by two domain knowledge expert raters, and analyzed. Participants were also asked to complete a questionnaire after completing each phase to collect their self-perception about the session and their individual performance. The results of these questionnaires are explained in detail in another publication (Moreno et al., 2015).

4. ANALYSIS

One of the research questions for this study relates to analogy as a relevant source of ideas and approach to overcome design fixation. The results of applying two different DbA methods are evaluated and compared, followed by a discussion of references and connections to the comprehensive framework of approaches to overcome fixation (Section 2.2) as well as fixation's existent metrics (Section 2.3).

The collected set of ideas was sorted into bins of similar ideas (affinity). Examples of bins are "negotiation," "reward systems," and "role swap." The sorting process was performed by two independent and domain knowledge raters who separately sorted the total 1,788 ideas recorded by the participants, where a Cohen κ interrater agreement was calculated resulting in a Cohen κ (Von Eye & Mun, 2005) of 0.78, which is considered an "excellent" level (Robson, 2002). All disagreements were resolved through discussion, resulting in a final total of 134 bins.

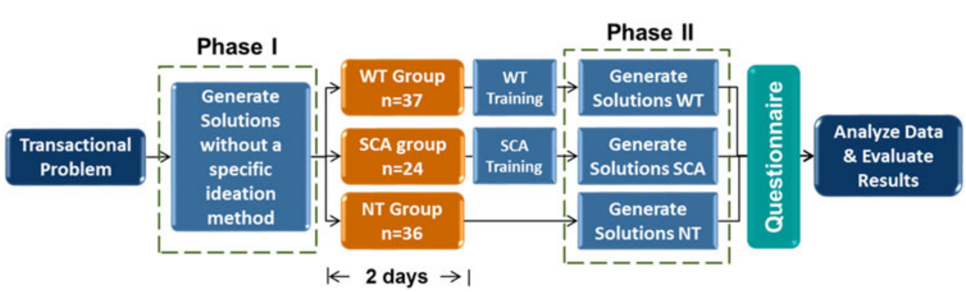

Fig. 2. Experimental execution diagram.

4.1. Quantity of ideas

Three representations are defined: quantity of total ideas generated (Q_{Total}); quantity of repeated ideas (Q_{R}), where a repeated idea occurs when a participant develops a slight variation of a previous idea; and quantity of nonrepeated ideas (Q_{NR}), which corresponds to the remaining number of Q_{Total} once repeated ideas have been removed.

$$Q_{\text{Total}} = \sum \textit{all ideas generated} = Q_{\text{R}} + Q_{\text{NR}} \tag{1}$$

Equation 1 shows that Q_{Total} can be expressed as the summation of all ideas generated at different levels such as by phase (I, II), experimental group (WT, NT), and participant. Alternatively, Q_{Total} can be defined as the addition of its two subcomponents: Q_{NR} and Q_{R}.

Considering that the experiment was designed and executed in two phases, two sources for repeated ideas (Q_{R}) are possible:

- Repeated ideas within a phase (R_{W}): all repeated ideas across all participants for which frequency (F) is greater than 1 [Eq. (2)].

$$R_{\text{W}_i} = \sum_{j=1}^{b}\sum_{k=1}^{n} F_{ijk} - 1 \quad \forall F_{ijk} > 1, \tag{2}$$

  where F_{ijk} is the frequency of repeated ideas for the ith phase, jth bin, and kth participant, respectively; i is the phase number (1, 2); b is the number of bins (134); and n is the number of participants. A unit is subtracted from F_{ijk} to maintain the accountability of the total ideas generated.
- Repeated ideas between phases (R_{B}): all ideas that were generated in Phase I that reappear in Phase II at bin and participant levels [Eq. (3)].

$$R_{\text{B}} = \sum_{j=1}^{b}\sum_{k=1}^{n} F_{2jk} \quad \forall F_{1jk} > 1 \quad \text{AND} \quad F_{2jk} > 0, \tag{3}$$

  where F_{ijk} is the frequency of repeated ideas for the ith phase, jth bin, and kth participant, respectively; i is the phase number (1, 2); b is the number of bins (134); and n is the number of participants

The previous definitions provide identification of the moment where the repeated ideas occur, shedding light on the critical moment where a method can be more effective to overcome the design fixation effect.

4.2. Evaluating fixation

Design fixation was assessed using the procedure outlined by Linsey et al. (2010) and Viswanathan and Linsey (2012) and follows the definitions provided in Section 4.1. The proposed metric elaborates what a repeated idea is for the study and, instead of reporting an absolute value, contrasts or normalizes this value against the total number of ideas developed. This approach provides a sense of the intensity of design fixation. A design fixation definition is implemented as shown in Eq. (4):

$$\textit{Fixation} = \frac{\textit{Total \# of repeated ideas}}{\textit{Total \# of generated ideas}} = \frac{Q_{\text{R}}}{Q_{\text{Total}}} = \frac{R_{\text{W}} + R_{\text{B}}}{Q_{\text{Total}}}. \tag{4}$$

4.3. Novelty

Following the definitions of Jansson and Smith (1991) and Chan (2011*a*), we define novelty as the total quantity of nonrepeated ideas (Q_{NR}). In this experimental design, Phase I is considered the design space baseline. Novelty corresponds to the design space composed of all ideas (not bins) generated by a participant in Phase II that were not generated by any participant in Phase I, over the participant's total Phase II ideas [Eq. (5)].

$$\textit{Novelty}_{k,l} = \frac{\sum_{j=1}^{b} F_{2jkl} \quad \forall F_{1jkl} = 0 \quad \text{AND} \quad F_{2jkl} > 0}{\sum_{j=1}^{b} F_{2jkl}}, \tag{5}$$

where F_{ijkl} is the frequency of ideas for the *ith* phase, *jth* bin, *kth* participant, and *lth* group, respectively; i is the phase number (1, 2); k is the participant number (1, . . . , 97); l is the group (WT, SCA, NT); and b is the number of bins (134).

5. RESULTS

5.1. Statistical data validation

A retrospective power study was performed to validate power of statistical tests and assumptions. For ANOVA and two tailed t tests, power factors were as follows: significance level $\alpha = 0.05$; variability and minimum difference depending on the metric being evaluated; and actual sample sizes of the study (NT = 36, WT = 37, SCA = 24). All power values were greater than 92% for evaluated metrics, corresponding to a suitable power to perform statistical analysis. The normality of the data was tested and verified using Anderson Darling's Normality Test.

5.2. Quantity of ideation

To calculate fixation (Section 4.1), we first determined Q_{Total}, Q_{R} and Q_{NR}. Table 7 presents the quantity of ideas across phases and group levels. Here, Q_{Total} corresponds to 1,788 ideas distributed as 1,230 Q_{NR} ideas and 558 Q_{R} ideas.

Table 7 includes t and p values from paired t tests comparing Q_{Total} of Phase I and II for the three experimental conditions. It was found that NT has no statistically significant difference (which is expected because Phase II is also nonassisted), which in the case of WT there is a statistically significant difference, consistent with previous cognitive studies where intervention scenarios add significant load because of the cognitive processing (Tseng, Moss, Cagan, &

Table 7. *Quantity of generated ideas and nonrepeated ideas*

	NT ($n = 36$)			WT ($n = 37$)			SCA ($n = 24$)			Total ($N = 97$)		
	Ph I	Ph II	*t*, *p*	Ph I	Ph II	*t*, *p*	Ph I	Ph II	*t*, *p*	Ph I	Ph II	Δ%
Q_{Total}	327	330	0.12, 0.908	296	193	−3.54, 0.001	318	324	0.18, 0.856	941	847	0.10
Q_{NR}	282	158	−5.01, 0.000	247	141	−4.37, 0.000	224	178	−1.66, 0.110	753	477	0.37
Q_{NR} Avg	7.8	4.4		6.7	3.8		9.3	7.4		7.8	4.9	0.37

Table 8. *Analysis of variance results for Q_{Total}, Q_R, and Q_{NR}*

Phase	Q_{Total}	Q_{R}	Q_{NR}
I	$t = 7.46$, $p = 0.001$	$t = 8.83$, $p = 0.000$	$t = 3.50$, $p = 0.034$
II	$t = 22.31$, $p = 0.000$	$t = 16.19$, $p = 0.000$	$t = 13.90$, $p = 0.000$

Kotovsky, 2008; Chan et al., 2011*a*, 2011*b*). In the case of SCA, there was no statistically significant difference.

For Q_{NR}, *t* and *p* values from paired *t* tests compare Phase I and II for the three experimental conditions. The results show statistically significant differences in the quantity of ideas for NT and WT. There was no statistically significant difference for SCA in the quantity of nonrepeated ideas between both phases.

An ANOVA showed that the means of the three experimental conditions in both phases and all Q_{Total}, Q_{R}, and Q_{NR} have statistically significant differences (Table 8). Using Tukey pairwise comparisons, we found that in Phase I for both Q_{Total} and Q_{R}, SCA is significantly different (greater) than the other two conditions; and for Q_{NR} SCA is only different than WT (greater). In Phase II for Q_{Total} the three conditions are significantly different from each other; for Q_{NR}, WT is significantly different than the other two (smaller), and SCA is significantly different (greater) than the other two conditions.

Table 7 shows that only WT presents a reduction in $\mathrm{Q}_{\mathrm{Total}}$ from Phase I to Phase II. After removing repeated ideas, all three conditions resulted in a reduction in the number of ideas generated in Phase II from Phase I. SCA produced more Q_{NR} in Phase II compared to the other two conditions.

Table 9 summarizes the quantity of repeated ideas by source as defined in Section 4.2. In the case of repeated ideas between phases (R_{B}), "Impose penalty" is an example of an idea stated in Phase I and then repeated in Phase II by the same person. Likewise, for repeated ideas within phases (R_{W}), "Make credit performance public" was an idea stated by a participant more than once during a single phase.

For the NT group, the quantity of R_{W} is almost the same for both phases, and there is a large quantity of R_{B}; that is, participants repeated ideas they created in Phase I. The WT group reduced the number of repeated ideas within Phase II. The quantity of R_{W} and R_{B} for WT in Phase II is almost the same. SCA had the largest amount of R_{W} in both phases.

Paired *t* tests for Q_{R} contrasting Phase I and II results in the three experimental conditions show that NT exhibits a statistically significant difference ($t = 6.63$, $p = 0.000$) in quantity of ideas of the control group (NT), which is consistent with literature showing that design fixation in the form of repeated ideas can be higher if no method is employed (Dugosh & Paulus, 2005; Toh et al., 2012; Viswanathan & Linsey, 2012). There is no statistically significant difference in the case of WT ($t = 0.26$, $p = 0.799$), which appears to indicate that the use of WT did not change the quantity of repeated ideas between phases, but there likewise was no significant increase in repeated ideas that did dramatically occur for the NT and SCA conditions. Finally, there is also a statistically significant difference ($t = 3.22$, $p = 0.004$) in SCA results, which was not expected.

5.3. Fixation

Table 10 presents the calculated fixation metric as defined in Section 4.1. ANOVA analysis for fixation results for all experimental conditions in Phase I shows a statistical significant difference ($F = 5.26$, $p = 0.007$). Tukey pairwise comparisons show that there is a statistically significant difference between the SCA condition and the other two conditions. Comparing Phase I with Phase II, statistically significant differences are shown across conditions (SCA: $F = 1\,3.41$, $p = 0.001$; WT: $F = 5.81$, $p = 0.019$; NT: $F = 95.34$, $p = 0.000$).

Table 9. *Repeated ideas by group, source, and phase*

	NT ($n = 36$)		WT ($n = 37$)		SCA ($n = 24$)	
	Ph I	Ph II	Ph I	Ph II	Ph I	Ph II
R_{W}	45	40	49	24	94	79
R_{B}	0	132	0	28	0	67
$\boldsymbol{Q_{\mathrm{R}}}$	**45**	**172**	**49**	**52**	**94**	**146**
Q_{R} Avg	1.3	4.8	1.3	1.4	3.9	6.1

Table 10. *Fixation by group and phase*

	NT (n = 36)		WT (n = 37)		SCA (n = 24)	
	Ph I	Ph II	Ph I	Ph II	Ph I	Ph II
Fixation	13.8%	52.1%	16.6%	26.9%	29.6%	45.1%

Phase II results for experimental conditions showed a statistically significant difference (F = 10.99, p = 0.000), and applying Tukey pairwise comparisons, it is found that WT is statistically significantly different than the other two conditions.

These results imply that all conditions resulted in fixation, but what is interesting is that a distinctly lower level was achieved with the WT condition. The participants who used the SCAMPER method exhibited a very similar fixation level as the control condition.

5.4. Novelty

Following the definition given in Section 4.3, a total of 15 bins were uniquely generated in Phase II, with the following distribution: NT = 1, WT = 5, and SCA = 9. These 15 bins contained a total of 21 nonrepeated ideas uniquely generated in Phase II (novel ideas). Table 11 presents the distribution of novel ideas for all experimental conditions as well as their calculated novelty values as defined by Eq. (5).

After performing an ANOVA for novel ideas, a statistically significant difference among all the experimental conditions is found (F = 8.06, p = 0.001). Tukey pairwise comparisons showed that the SCA condition is statistically different (greater) than the other two conditions.

An ANOVA analysis is calculated for novelty values across experimental conditions (F = 4.65, p = 0.012). Both DbA conditions, SCA and WT, have statistically significant higher novelty percentages when compared to NT. The SCA condition, however, appears to have the most significant contribution of total novel ideas.

6. DISCUSSION

To address the research questions related to the existing design defixation approaches, the literature review shows that a holistic and cumulative understanding of design defixation approaches has been investigated across different domains such as cognitive science, architecture, and engineering. These approaches have been developed to avoid the negative impact that design fixation may have in the design process at the idea-generation stage. In particular, much of the literature focuses on external approaches such as the use of heuristics, prompts, or external support to the designer that promote the development of ideas but may also be effective for overcoming design fixation.

Table 11. *Novel ideas and novelty*

NT		WT		SCAMPER	
Novel Ideas	Novelty (%)	Novel Ideas	Novelty (%)	Novel Ideas	Novelty (%)
2	1.0	6	3.5	13	7.1

Although there are few expert studies with sample sizes that can provide sufficient statistical power to support the results found for overcoming design fixation, the findings from literature review shed some light on interesting directions such as analogy-based approaches (TRIZ, SCAMPER, WordTree, Word Graph, providing analogies and in addition having open goals) and visual stimuli (providing inspirational pictures, sketching, and 6-3-5).

The literature review also led to additional questions. Should design defixation approaches be used together, integrated or synthesized? Are there dominant or more attractive approaches? Should a suite of methods be developed, tested, and implemented?

With respect to the research question related to design fixation metrics, a broad range of ways to account for design fixation was identified and classified. These results may indicate that fixation can manifest in multiple forms that range from personal perception to tangible results of the cognitive process (ideas developed). All metrics capture manifestations of design fixation at different levels. The metrics could be applied together or synthesized to provide a better understanding about the way that different factors impact design fixation.

The literature offers several overlapping metrics and indicators for fixation. Direct and indirect dimensions for the design fixation metrics were developed in an attempt to unify metric criteria. A fixation metric is proposed building on previous work to include service design problems. The proposed metric for measuring design fixation captures the intangibles of service problems, and takes into consideration the predominantly semantic nature of service design. The proposed metric can also be applied in the product domain. The results of a study for a service design problem are comparable with the ones obtained in engineering and architecture, allowing possible generalization of conclusions.

Finally, addressing the research questions related to the application of DbA methods to overcome design fixation with a service design problem, it is found that analogies enable generation of increased novel ideas and that DbA methods are transferable across design problem domains (product to service) in the idea-generation stage of the design process.

In our study, there was a reduction in the total quantity of ideas generated by the WordTree participants, which is believed to be a reflection of the cognitive load that the method adds and that is consistent with previous cognitive study findings (Tseng et al., 2008; Chan et al., 2011*a*, 2011*b*). The control (no technique) and SCAMPER groups had similar results for the total quantity of ideas generated, which was not expected, and nonintuitive, and may be an indicator that SCAMPER shares some similarities with nonassisted scenarios. When contrasting these findings with the fixation results, it can be seen that the levels of fixation exhibited by the two experimental groups show no statistical difference, which confirms our hypothesis. It appears, however, that the SCAMPER method also enables fixation in certain cases, which is unexpected. While the SCAMPER method led to increased novelty compared to the control group, which is an indicator of defixation, the use of the SCAMPER method also demonstrated a high number of repeated ideas between phases. It thus appears that as the SCAMPER representation questions were being implemented by designers, they would become fixated in certain regions of the design space, but then new operator questions would result in defixation, allowing designers to navigate to other regions of the space.

The quantity of nonrepeated ideas was reduced in Phase II for the three experimental conditions, but the reduction compared with their respective Phase I was not statistically significant for SCAMPER, which was not expected and may indicate that the method overcomes the cognitive load of learning a new method and provide means to increase the quantity of ideas generated. This result indicates that the SCAMPER method is different from nonassisted scenarios, and it can be seen that it performed better than control when comparing the average number of nonrepeated ideas for the two experimental conditions, which was greater for SCAMPER. The quantity of nonrepeated ideas in phase II shows interesting results because Wordtree had the lowest quantity and SCA the largest; however, contrasting this result to the one obtained for novelty, where both DbA methods yield more novelty than control, demonstrates the effectiveness of DbA methods to support designers during idea generation. One conjectural explanation for the different performance of WordTree compared to SCAMPER could be that WordTree requires more nonintuitive work from the users, and in contrast, the question-guided approach of SCAMPER may better reflect our natural process of semantically linking concepts in long-term memory. This, however, requires further exploration.

The quantity of repeated ideas shows that the WordTree DbA method helped overcome fixation to predeveloped solutions as compared to a control. SCAMPER and control conditions exhibited similar numbers of total repeated ideas, which was not expected, and they both increased in Phase II the baseline of repeated ideas determined in Phase I, which would be an indicator that SCAMPER is not an effective approach to overcome the presence design fixation, at least during certain times as ideas are being offered. However, considering the results obtained for novelty, where SCAMPER yielded the largest quantity of novel ideas, it appears that SCAMPER is a method that provides, unexpectantly, both fixation and defixation means during idea generation.

As stated above, fixation results indicate a similar level of fixation for control and SCAMPER treatments, at least in terms of repeated ideas, while WordTree appears to mitigate fixation much more effectively. However, novelty results show that both SCAMPER and WordTree yielded higher novelty than control, but SCAMPER had the highest number of novel ideas. Previous studies have shown that fixation will typically distract from novelty; therefore, the results presented here are not only counterintuitive but also open new questions about the benefits that fixation may offer for improvement and refinement of ideas.

One possible explanation for this counterintuitive result may be the modality of representation for the selected DbA methods of the study. SCAMPER poses active questions that guide the designer into developing a response, while WordTree is enabled by designer-driven semantic rerepresentation of key elements (customer needs, functional requirements, user activities, clarifying descriptions of the design problem, etc.) of a design problem. The results of the study show that the rerepresentation of the design problem is a shared feature for both methods and enables a divergent mindset (analogy) when developing solutions for a transactional design problem, which is shown in the improved novelty metrics for both methods when compared to a nonassisted condition. In contrast, following a list of active questions of a given SCAMPER category may trigger in the designer the need to rework or complement previously developed ideas, hence promoting fixation. SCAMPER's fixation within a given category or question may be overcome when the designer is required to switch to another category or active question from the method.

Quantity values were used to calculate fixation percentages, revealing that there is a base level of fixation for nonassisted scenarios. Contrasting Phase II with Phase I, all experimental conditions result in fixation; however, comparing the statistical results of the three experimental conditions in Phase II, it is found that the lowest level of fixation is achieved with the WordTree method. These results highlight the efficiency of the WordTree method in mitigating design fixation.

From the study, there is evidence that in a nonassisted scenario (control), a significant portion of the allotted time was devoted to the development of solutions that are not distinctive from each other (quantity of repeated idea was greater than quantity of nonrepeated ideas). It also appears, at least from the number of repeated ideas, that the analogical transfer provided by the WordTree method enables problem rerepresentation, exploration of divergent words, and effective space solution exploration to solve the problem. The fixation level exhibited by SCAMPER was in the form of idea refinement, while the WordTree and control conditions corresponded to minimal variations or rewording of ideas. This unexpected finding leaves open the question of a "desirable" fixation level that enables refinement and improvement of ideas.

The DbA methods used in this paper combine some of the previous approaches that were found and presented in the proposed framework to overcome design fixation, which may explain its performance. From Figure 1, the studied DbA methods incorporate elements from different categories. It includes reframing, by characterizing the problem and problem rerepresentation. The 2-day break between phases served as an incubation period. It considers expertise that allowed working with incomplete information, framing the problem, identifying relevant information, and developing more solutions. It provides and enables analogical exploration. It uses software tools that provide visual representation of the semantic cognitive process, allowing problem and solution representation. It makes use of heuristics or directives that guide and redirect analogical search.

The results obtained from the experiment also align with reported results in the field of psychology. Leynes et al. (2008) found that fixation can be overcome in two ways: first with an incubation period of around 72 h, and second (and closely related to our approach) by presenting alternative semantic information to participants. They found that block and unblock effects occur in different parts of the brain. The results of the present study align with this result because after the semantic stimulation and analogical exploration, the participants were able to overcome design fixation.

7. CONCLUSIONS

In the quest to enhance creativity, avoid design fixation, and better support designers, different factors and methods have been developed with diverse results. The work presented here is critical because it provides for the first time a state-of-the-art review and framework for ideation approaches to overcome design fixation. It also presents the existing ways to account for fixation and proposes a fixation metric that builds on existing literature and that can be implemented across product and service design problems.

The findings from the literature review highlight a promising area to overcome design fixation in the direction of analogy-based approaches. Some DbA approaches were further explored in this article and extended to include service design problems, an area of application that has not been extensively studied. The results presented here are robust and supported in a large sample size that involves service domain experts that are not frequent in literature. The experimental results obtained are encouraging and exciting not only for innovation and idea generation but also to effectively support the spectrum from product to service design. However, there is still much to learn about analogical reasoning behind DbA approaches and the factors that may influence creative performance.

The intention of this study is to promote a critical reflection about the potential of the available suite of techniques, their modalities, and the associated cognitive processes behind them. The complexity of real-life problems requires the use of approaches with solid cognitive foundations and mechanisms that make them suitable for a broad range of design problems and opportunities.

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