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Analogies to Succeed: Application to a Service Design Problem

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Abstract
This study aims to expand current understanding of ideation methods and its transferability from product design domain to service design domain. It applies two Design-by-Analogy (DbA) ideation methods (WordTree and SCAMPER) to a real service design problem in an expert participants setting. Quantity and Novelty metric results are analysed along with design fixation effects. Both DbA methods produced statistically significant larger number of novel ideas when compared to the control. The number of novel ideas with SCAMPER method doubled those generated via WordTree. Fixation effects were counterintuitive since SCAMPER appears to be a method that promotes both fixation and de-fixation effects. These findings suggest DbA ideation methods offer positive capabilities for assisting designers to generate solutions for service design problems.

Keywords: Design-by-Analogy, Design Methods, Creativity, Design fixation

1 Introduction

Over the last three decades, industrial practice shows an increase in service's share of global economic activities. More design solutions focus on the combination of services and products, rather than only pure service or pure product design problems. Designers now need to be able to solve this broader range of design problems. To address this emerging class of problems and effectively support the designer during the early stages of design, particularly when ideas are generated, there is a need to investigate the cognitive mechanisms behind ideation methods, and to evaluate the transferability of ideation methods from product to service domains.

This paper presents a study to explore following research question: Does the application of DbA methods assist service design experts in improving the quantity and novelty of generated ideas or reduce design fixation when solving real service design problems?

1.1 Analogies in cognition

Analogy is the association of a situation from one domain (source) to another (target) due to similarity relations or the mapping of representations [1-3]. Previous studies show a solid relationship between analogical reasoning and the cognitive processes associated with linguistics and semantic memory retrieval [2, 4, 5]. In the context of service design problem solving, analogical reasoning and semantic retrieval may assist designers in associating causal structures to analogous domains or analogies to develop a solution.

1.2 Semantic memory retrieval

Semantic memory refers to the organization of information in the human mind. It is usually represented as a network of concepts (nodes) that are linked through categories [6-8]. From this model, a concept will be accessed more easily if the number of links traversed shortens, or if multiple paths converge to that specific concept. General nodes tend to be connected to a larger number of nodes, thus becoming hubs in the network. Linking new concepts through hubs increases the probability of being retrieved due to distance reduction [6, 9, 8], which is a key mechanism to perform analogical reasoning.

1.3 Design-by-Analogy Methods

Design-by-Analogy operates on the premise that a similar solution to a given design problem may exist either in an analogous domain or, at least in part, in an analogous solution, and that it can be extracted or elaborated on once the connections between source and target are made.

Current DbA methods have a range of sources for analogical inspiration such as exploring analogical categories by means of questions [10, 11], finding inspiration in the natural world [12], using biomimetic and bio-inspired concepts [13-17], developing abstractions of functional models and flows [18-20], creating design problem re-representation and semantic mappings [21, 22], developing search engines and algorithms to identify potential analogies within digital sources, databases, and repositories [23, 24]. However, studies of DbA methods for service design problems are not as prevalent in existent design literature as their product design counterparts, especially involving expert practitioners.

1.4 SCAMPER Method

This method was developed to structure, condense and improve Osborn's brainstorming recommendations [25]. SCAMPER has seven operator categories that may be used to develop solutions to a design problem: (S) Substitute, (C) Combine, (A) Adapt, (M) Modify/Magnify/Minimize, (P) Put to other uses, (E) Eliminate, and (R) Reverse/Rearrange. SCAMPER’s operator categories may be seen as heuristics [26, 27], where for each operator category there is a set of questions that, when attempt to be answered, redirects analogical search to solve a problem. The operator categories and related questions can be seen as directives to systematically search for solutions. As an illustration, if a designer is asked to improve the portability of battery chargers, she may choose (M) Modify. Some triggering questions of the Modify operator are e.g. What can be modified? Convert rotary action to a linear one? How can this approach be altered for the better? These questions may lead to new design ideas such as a shape shifter device that with a pulling force can expand to place the batteries and with a pushing force reduces it size and make it less bulky.

1.5 WordTree Method

The WordTree method was developed within engineering to articulate the concepts of metaphor, analogy, and semantic memory retrieval. WordTree enables design problem re-representation, and detection of potential analogies and analogous domains [21, 28, 29].

The method identifies "key problem descriptors (KPDs)" which can be functional requirements, customer needs, or clarifying descriptions of the design problem. KPDs are then semantically re-represented in a diagram, known as a WordTree, by populating the branches through selected hyperonymy[1] and troponyms[2] extracted from Princeton's WordNet. From this WordTree diagram, potential analogies can be researched and analogous domains explored to discover solutions. The next step consists of developing alternative problem statements, or problem representations. The final step involves another idea generation session, where the results from all previous steps are used to both refine and develop additional concept solutions.

Suppose a designer is asked to improve the storage of clean towels, for example. Some KPDs could be: "maximize storage area," "enable easy towel removal," and "current storage method involves folding and piling towels." The designer may explore the verb "fold" finding that its direct hypernym is "change surface" and that some of its direct troponyms are "curl", "roll" and "buckle". In a similar manner she may find analogous methods to "pile" such as "aggregate" and propose a storage method consisting in rolled towels aggregated as honeycombs to maximize space and allow easy removal.

2 Methods

The study involved 97 service design domain experts from companies in Mexico and Singapore. The study was carried out in two phases and participants worked individually. In phase I, participants used only their intuition and personal experience to generate concepts. A two day period between phases was then provided. In phase II, participants were assigned to a concept generation condition (Figure 1) WordTree (WT), SCAMPER (SCA), or No Technique (NT).WT and SCA groups were trained for 15 minutes in their assigned method. Each condition group worked in separate locations. During the second phase, all groups continued generating concepts for the same design problem posed in phase I using their assigned concept generation condition.

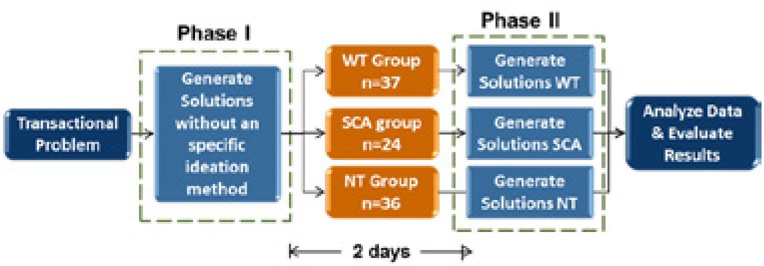

Figure 1. Study design overview

A real service design problem from the financial sector was adopted from a previous study [30]. Participants were asked to generate as many new solutions as possible to the selected

[1] Hyperonymy links to more general concepts.
[2] Troponyms express increasingly specific manners to characterize an event.

design problem: "reduce overdue accounts and unpaid credits". Participants were encouraged to do their best and create as many creative solutions as possible over a 15 minute period.

3 Ideation Metrics

Three ideation metrics were selected to evaluate the results of the study: (1) quantity of ideation, (2) design fixation, (3) novelty.

3.1 Data setup

The experimental data were organized and coded for post-experiment analysis. The ideas recorded by participants were evaluated by two domain-knowledge expert raters who independently sorted the total 1,788 ideas recorded by the participants into bins of distinctive ideas resulting in a total of 148 bins generated by the two raters. A "bin" contains a set of ideas that are related to each other. The term "bin" has been explicitly used in creativity and idea generation studies [31, 32] as well as its synonyms such as: categorical frequency [33], unique response (statistical infrequency) [34], distinct solution [35], or solution method [36]. To determine inter-rater agreement, Cohen's Kappa [37] was calculated, with a result of 0.78 which is considered an "excellent" level [38]. All disagreements were resolved through discussion, resulting in a final total of 134 bins.

3.2 Quantity of ideation

Building on existent definitions and procedures to calculate quantity of concepts within the engineering design domain [31, 39-41], we defined the following variables to account for the quantity of ideas: (1) Quantity of Total ideas (QTotal), (2) Quantity of Non-Repeated ideas (QNR), and (3) Quantity of Repeated ideas.

$$Q_{Total} = \sum all\ ideas\ generated = Q_{NR} + Q_R \tag{1}$$

Quantity of total ideas generated is the summation of all ideas generated (Eq. 1), at different levels, such as in phase (I, II), across experimental groups (WT, SCA, NT), and by each participant. An alternative definition for Q_{Total} is the summation of Quantity of Non-Repeated ideas (Q_{NR}) and Repeated Ideas (Q_R). A repeated idea occurs when a participant states an idea more than once (as a variant or in literal form).

3.3 Design Fixation

Jansson and Smith (1991) define design fixation as "counterproductive effect of prior experience on the generation of creative designs aimed at solving realistic problems" [42]. The inability to develop such unique solutions may be attributed (but not limited) to: the use of a familiar solution ignoring new or better ones, self-imposing constraints [43], or, as in the case of the present study, through the development of basic variants [42, 44, 45]. There is no unified theory or holistic basis to asses design fixation; however, there are common elements in current design fixation metrics related to fluency and repeated solution ideas or features [46, 47]. Therefore, building upon the existent design fixation metric definitions we use the design fixation metric shown in Eq. 2 we proposed in a previous study [30]. This definition aligns with existing literature and also reflects Jansson & Smith's definition because it provides a measure of how counterproductive the effect of prior experience is by relating non-creative designs (repeated ideas) to the total solutions generated (fluency).

$$Fixation = \frac{Total\ \#\ of\ repeated\ ideas}{Total\ \#\ of\ generated\ ideas} = \frac{Q_R}{Q_{Total}} = \frac{R_W + R_B}{Q_{Total}} \tag{2}$$

There are two sources for repeated ideas in the fixation definition presented in Eq. 2:

- Repeated ideas within a phase (R_W): defined as the summation of all repeated ideas in one phase across all participants that have a frequency (F) greater than 1 as shown in Eq. 3.

$$R_{W_i}=\sum_{j=1}^{b}\sum_{k=1}^{n}F_{ijk}-1 \quad \forall\ F_{ijk}>1 \tag{3}$$

  where F_{ijk}=frequency of repeated ideas for the *ith* phase, *jth* bin, and *kth* participant; i=phase number (1, 2); b= number of bins (134); and n= number of participants. A unit is subtracted from F_{ijk} to maintain accountability of the total ideas generated.

- Repeated ideas between phases (R_B): for bin and participant levels, R_B takes into account all ideas that are repeated in phase II after being generated in phase I.

$$R_B=\sum_{j=1}^{b}\sum_{k=1}^{n}F_{2jk} \quad \forall\ F_{1jk}>1 \ \ AND \ \ F_{2jk}>0 \tag{4}$$

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

3.4 Novelty

Building upon Jansson and Smith's [42] and Chan's [35] definitions, we define novelty as the total quantity of non-repeated ideas (Q_{NR}). For calculation purposes, phase I is considered the design space baseline. Novelty is defined as 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.

$$Novelty_{k,l}=\frac{\sum_{j=1}^{b}F_{2jkl} \ \ \forall F_{1jkl}=0 \ \ and \ \ F_{2jkl}>0}{\sum_{j=1}^{b}F_{2jkl}} \tag{5}$$

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

4 Results

To validate the power of the tests performed, we developed a retrospective power and sample size study. For ANOVA and two-sample t-tests, the sample size, as a function of chosen power, was first evaluated by setting the significance level as α=0.05 (as typically chosen for similar cognitive studies), the power as 0.8 (as reasonable value within social science studies), the variance depending on the metric being evaluated, and the minimum difference by using a low and a high value for consideration. For 80% power the study's actual sample sizes are sufficient. To perform sample test comparisons, the normality of data across techniques was tested and verified; therefore, statistical analysis such as ANOVA and t-test can be performed.

4.1 Quantity

Q_{Total} was 1,788 ideas, while Q_{NR} was 1,230 non-repeated ideas as shown in Table 1.

Table 1. Quantity results break down

	NT (n=36)		Δ%	WT (n=37)		Δ%	SCA (n=24)		Δ%	Total (N=97)		Δ%
	Ph I	Ph II		Ph I	Ph II		Ph I	Ph II		Ph I	Ph II	
Q_{Total}	327	330	-0.01	296	193	0.35	318	324	-0.02	941	847	0.10
Q_{NR}	282	158	0.44	247	141	0.43	224	178	0.21	753	477	0.37
Q_{NR} Avg	7.8	4.4	0.44	6.7	3.8	0.43	9.3	7.4	0.20	7.8	4.9	0.37

Only WT shows a reduction in Q_{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 both phases compared to the other two conditions.

Comparing phase I and II for each condition, a statistically significant difference is found in the quantity of non-repeated ideas for the NT and WT conditions (NT: $F=\frac{213.6}{9.77}=21.87$, p-value=0.000; WT: $F=\frac{151.8}{8.8}=17.25$, p-value=0.000). In both cases, the quantity of ideas developed during phase II was smaller. The SCA condition showed no statistically significant difference in the quantity of ideas between the phases ($F=\frac{44.1}{16.6}=2.66$, p-value=0.110).

4.2 Fixation

Counterintuitive results were found for fixation (Table 2). The WT condition appears to effectively manage fixation rate compared to the control scenario (NT). The SCA and control condition (NT) have very similar fixation levels.

Table 2. Fixation results across conditions

	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
$\boldsymbol{Q_R}$	**45**	**172**	**49**	**52**	**94**	**146**
Q_R Average	1.3	4.8	1.3	1.4	3.9	6.1
Fixation %	**13.8%**	**52.1%**	**16.6%**	**26.9%**	**29.6%**	**45.1%**

ANOVA fixation analysis between conditions in phase I shows a statistical significant difference ($F=\frac{0.12}{0.02}=5.26$, p-value=0.007). Tukey's 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, statistical significant differences are shown across conditions (SCA: $F=\frac{0.44}{0.03}=13.41$, p-value=0.001; WT: $F=\frac{0.27}{0.05}=5.81$, p-value=0.019; NT: $F=\frac{2.71}{0.03}=95.34$, p-value=0.000). Phase II results for experimental conditions showed a statistical significant difference ($F=\frac{0.55}{0.05}=10.99$, p-value=0.000) between WT and the other two conditions.

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

4.3 Novelty

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 correspond to a total of 21 non-repeated ideas uniquely generated in phase II (*Novel ideas*). Table 3 presents *Novel idea* distribution across conditions as well as their correspondent novelty values as defined by Eq. 5.

After performing an ANOVA, an overall statistically significant difference between the total number of novel ideas generated is found between the conditions ($F=\frac{1.79}{0.22}=8.06$, p-value=0.001). Tukey's pairwise comparisons showed that the SCA condition is statistically different than the other two conditions.

Table 3. 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%

A similar ANOVA result occurred for calculated novelty values across conditions ($F=\frac{0.027}{0.005}=4.65$, p-value= 0.012). Both DbA conditions, SCA and WT, have higher novelty percentages when compared to the control condition. The SCA condition, however, appears to have the most significant contribution of total novel ideas.

5 Discussion and Conclusions

In these results, DbA methods enable design problem re-representation and improve design space exploration and novel idea production when compared to a non-assisted condition. The modality of representation for both methods, however, is quite different. SCAMPER prompts active questions that guide the designer into developing a response for a proposed situation (category). WordTree, on the other hand, is an open-ended method in that exploration is not directed by specific set of action prompts, but is enabled by designer-driven semantic re-representation of key elements (customer needs, functional requirements, etc.) of a design problem. From the results of the study, we observe that despite the prompt used, re-representation is a similar feature of both methods that enables a divergent mind-set (analogy) when developing solutions for a transactional design problem. This argument is reflected in the statistically improved novelty metrics for both methods when compared to a control.

The large number of repeated ideas developed using SCAMPER could be interpreted as a potential fixation indicator. It is interesting to note the impact of both DbA methods in Novelty results, where the non-assisted condition contributes to 7% of the number of total novel ideas, while the remaining 93% is attributed to the two DbA methods (WordTree=33% and SCAMPER=60%).

The individual average quantity of non-repeated ideas using the WordTree method is almost half that of using SCAMPER (WT/SCA=3.8/7.4=51.4%), and this proportion was also exhibited in the Novelty results (WT/SCA=5/9=55.5%, or 3.5/7.1=49.3%). One possible explanation of the relatively lower level of novelty results of WordTree when compared to SCAMPER is that the method requires more non-intuitive work from the users, while the guided questioning approach of SCAMPER methods reflects our natural process of semantically link concepts in long-term memory.

The fixation effect exhibited by SCAMPER was in the form of idea refinement, while for WordTree and control conditions corresponded to slight variations or rewording of ideas. This finding makes us consider that there may be a "desirable" fixation level that enables refinement and improvement of ideas.

Based on the study, it can be seen that DbA methods have a significantly positive impact in supporting designers to generate ideas for service design problems. Each method complements each other and presents weakness and strengths on different creativity metrics (quantity and novelty) and design fixation. SCA appears to be effective in increasing the quantity and novelty of generated ideas, while WT appears to be effective in mitigating design fixation.

It is not the intention of this study to find the single "best" ideation method, but to explore if analogical reasoning behind DbA can be as an effective approach to support service design problems at it has been to product design. Our intention is to promote a critical reflection about the potential of the suite of techniques, their modalities and the associated cognitive process behind them. We believe that the complexity of real life problems requires the use of flexible approaches (i.e. more than one technique) with a solid foundation in the understanding of the mechanisms and conditions that makes each one more suitable for specific design problems faced by organizations and designers as they engage the ever-changing landscape of markets and grand societal challenges.

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