1 ANALYZING CREATIVITY METHODS

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There exists many creativity enhancing methods or techniques. Some of these methods could be more effective than others. Analyzing techniques to select the most suitable one is an important issue during designing. How to identify a good creativity technique?

This paper delivers a methodology for selecting a suitable creativity technique. Detailed analysis of four pre selected design methods (viz. Brainstorming, Ideal Design, Functional Analysis and Innovation Situation Questionnaire) are carried out based on this methodology. The methodology is based on the search efficacy of different methods. The objective is to develop a means for identifying in which phases of design a given creativity method and a participant designer is more effective.

Keywords: Creativity, design, design methods, creativity methods.

1. INTRODUCTION

Design has been expressed as a phenomenon of exploration and search.[1,2] Exploration and search are similar to idea finding since both are divergent processes, where a number of ideas need to be considered before selecting the best ones.[3] These are also important elements of design creativity[4] since creative design is generation and exploration of new search spaces.[5] Search and exploration of design spaces enhance creativity of designers — a necessary ingredient of engineering design.[4] Designers continuously search and explore design spaces to generate or identify solutions.[6]

Design space has been defined as consisting of a set of concepts (which can be problems, solutions or evaluation criteria) that are similar to each other in some respect.[7] Search in general can be expressed as the process of finding new or improved problems, solutions or evaluation criteria within a design space (See Figure 1). Exploration, in general, can be seen as a process by which different design spaces are identified, within which search can be carried out to find new or improved problems, solutions or evaluating criteria by well structuring the design knowledge (See Figure 1).

We conducted a series of observational studies with both novice and experienced designers carrying out various design tasks within a laboratory setting.[7] It was found that designers predominantly searched rather than explored. Designers directly generated a solution (i.e., search took place) instead of first finding a design space and then looking for solutions in it, i.e., exploration did not take place. Designers jumped to a solution in a design space instead of first identifying and analyzing the boundary of the design space and then trying to find solutions in that space. Similar procedures are followed by the designers observed also during problem understanding and solution evaluation.

From these studies, four different kinds of search (viz. unknown, global, local and detail) were found to occur consistently in each of the three phases of design problem solving (viz. problem understanding, solution generation and solution evaluation). Thus, 12 different types of search are identified (Figure 2). These search types are related to one another. Each search at a higher level may contain many searches at lower levels — i.e., occurrence of higher-level searches (i.e., unknown search or 'us', and global

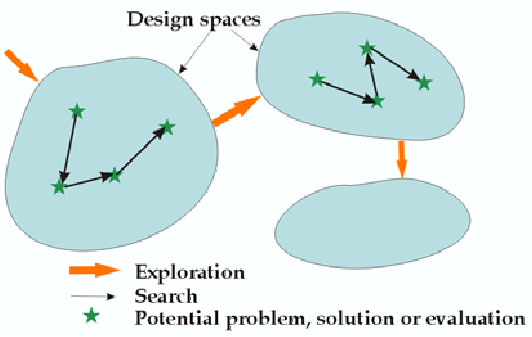

Figure 1. Representation of design space, exploration and search.

search or 'gs') in the hierarchy enhances the occurrence of lower level searches (i.e., local search or 'ls', and detail search or 'ds'). Sarkar and Chakrabarti (2007) explain how these 12 search types can be identified in transcriptions. The greater the number of these searches carried out in a design process, the greater is the number of outcomes generated, and the greater is the subsequent creativity quality of the final outcome from the design process.[7]

Designers have been found to typically search, first unknown or global, then local, and ultimately detailed design spaces, leading to the emerging solutions, problems or evaluation criteria becoming more detailed. 'Global', 'local' and 'detailed' spaces are those that have been previously visited by designers (while solving other similar problems), while 'unknown' spaces have not been. Each search is directed to finding potential problems, generating solutions or identifying evaluation criteria. Design spaces at higher levels in the hierarchy (e.g., 'unknown' or 'global') include design spaces at the lower levels of the hierarchy (e.g., 'local' or 'detailed'). For instance, a 'global problem space' might contain many 'local problem spaces' and 'detailed problem spaces'; leading to expression of several potential problems at various levels of detail (see Figure 2).

2. OBJECTIVES

Creativity methods are variously effective in designing. Some are effective in problem understanding, e.g. 'Bug listing' [8] or 'ISQ',[9] some in solution generation, e.g. 'Ideal design' [9] or 'Brainstorming' [10] while others in solution evaluation, e.g. 'Matrix based evaluation methods'.[11] The objective of this work is to develop a means for identifying the design phases in which a given creativity method and a designer are more effective.

3. RESEARCH METHODOLOGY

The individual effects of four chosen creativity methods on the quality of the outcome in the design processes in which the methods are used are investigated, by assessing the effect of these methods on each phase of design problem solving. Then, the performance of each designer while using each of these methods is analyzed. Next, on average how each method has influenced a designer's performance is estimated. This is done by comparing the effect of each method on design outcome relative to that using the other methods, and by assessing the average effect of each method across all the designers.

Since search is an integral part of design, and generation of more number (quantity) of different kinds of search spaces (variety) increases the creative quality of the eventual outcome of the design.[7] Thus, one could argue that the outcome of a creativity method can be assessed in terms of the number of each type of concept searches (problems, solutions and evaluations) in each phase of design (viz. Problem understanding, solution generation and solution evaluation).

To compare the outcome of various design methods, video protocols of a series of design experiments conducted earlier [12] are used. There were eight design experiments in which six designers participated.

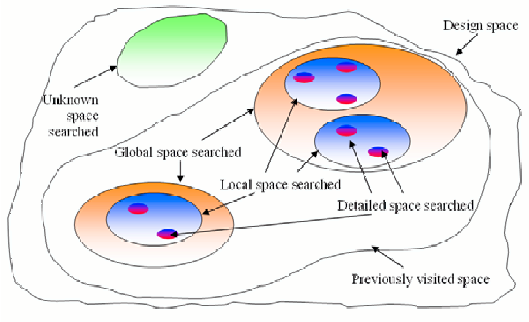

Figure 2. General representation of a 'design space'.

Two groups were formed, each with three members. The experiments were conducted in laboratory setting. Four idea generation methods were used (Brainstorming, Functional analysis, Ideal design and Innovation situation questionnaire, see [6]) and each group solved two different design problems using each method.[12] Designers were asked to discuss audibly while they solved the problems. All design experiments were video taped and transcribed. Details of the experiments are provided in Table 1 in which a designer is represented by the first alphabet of his/her name. Problems used are represented by P1 (Problem 1, related to design of a lock - represented by 'lock' or P1) and P2 (Problem 2, related to removal of leaves from given premises — represented by 'leaf' or P2).

4. IDENTIFYING CREATIVE EFFICACY OF A DESIGN METHOD FROM ITS SEARCH PROFILE

First, each type of search is identified in the protocols of each of these design experiments. Each utterance is classified into the type of search it signifies. Next for each method, both the type and the number of searches generated by each designer in each group are determined. Since there are two design experiments using the same method, the results (different kinds of searches) from both the experiments are averaged to get a representative value of the profile of the searches. This is termed as *average value* (A).

Average value (A) is the average of the total number of searches of each type from the two experiments in which the same method is used. For example (A) of global solution search (gs) for brainstorming (bs) = (24+13)/2= 18.5 (see 10^{th} row 4^{th} column, Table 2).

Next, fraction of the contribution of this method with respect to the other methods for each kind of search is determined. This is taken as R% and is explained in the next section (Section 6). This procedure of analysis is carried out for each of the methods.

4.1. Discussion

First, the number of searches of each type generated by all the designers together in each group in each experiment (i.e., for each specific combination of problem, method and group) are identified (Table 2).

Table 1. Method details.

Exp. no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Method	BS	BS	ID	ID	FA	FA	ISQ	ISQ
Group no.	1	2	1	2	1	2	1	2
Designers	C, P, R	A, G, U	C, P, R	A, G, U	C, P, R	A, G, U	C, P, R	A, G, U
Problem used	P1	P2	P1	P2	P2	P1	P2	P1

Note: BS - Brainstorming, ID - Ideal design, FA - Functional analysis, ISQ - Innovation Situation Questionnaire

For example, the results under bs1 (first column, Table 2) list the total number of searches generated in the design experiment (experiment 1, Table 1) in which brainstorming was used in Problem 1 (related to design of locking system).

Next, experiments in which the same method is used are taken together, and the average ('A' in Table 2) of the number of searches of each type, across the groups is calculated. For a given method, the average number of searches carried out under each search type, taken together, gives the profile of the searches carried out in general in a design process using that method. This is taken to indicate the absolute influence of each design method. For example, the average value of the number of global problem searches carried out in all the brainstorming sessions is 5 (i.e., A=5) as the number of global problem searches carried out in bs1 is 7 and that in bs 2 is 3.

Next, the fraction of the contribution of each method in general to the total general contribution (total number of average searches of all the experiments) is assessed. This is a ratio (expressed in percentage) between the average number of searches of a particular type for a particular method considered and the sum of average numbers of that type of search for all the methods taken together. We attribute this as the 'Relative contribution of a method'. This gives the relative efficacy of a method in comparison to other methods in terms of the number of different kinds of search it is able to help generate. When all the R% of all the searches of a method is considered together, a profile termed here as the 'Relative search profile' is generated. Comparison of relative search profiles of various methods will indicate which method is relatively better in which phase of design problem solving. Equation (1) is developed for calculating this.

*Relative contribution of a particular method for a particular search type (R%) = ((number of searches of that type in experiments using that method) / (total number of searches of that type found in all experiments)) *100. …(1)*

The particular method could be either method bs, id, fa or isq, and a particular search type could be any of the 12 search types. For example, the relative fraction of global problem search for Brainstorming (see row 5-gs and column 5-R% of Table 2) is 20.83% as it computes to (5/(5+6.5+6.5+6))*100=20.83 %.

Comparison of different methods could now be carried out by comparing the number of different kinds of search occurring in each of these experiments. Since generation of a larger number of search of all kinds in a design process have been found to strongly enhance the creative outcome of the design process, the 'best' creative design method should help a designer carry out search of all of the above twelve kinds to the maximum extent possible. However, Table 2 shows that each design method used in this work has influenced search differently, and among these methods there is none that alone is effective in uniformly supporting search of all kinds, i.e., in uniformly carrying out search in all the phases of design. Thus, instead of trying to find the best method, another approach would be to identify methods that are effective in different phases of design problem solving, and use them together.

From Table 2, the following could be observed:

- For problem understanding, ISQ is the most effective (R% = 40.43) followed by Function Analysis (R% = 21.28) and Ideal Design (R% = 20.57) which are all more effective than Brainstorming (R% = 17.73).
- For idea generation, Functional Analysis (R% = 34.43) is the most effective. Brainstorming (R% = 26.23) and ISQ (R% = 23.98) are more effective than Ideal Design (R% = 15.37).
- For solution evaluation, Brainstorming (R% = 37.70) is the most effective, followed by ISQ (R% = 25.14) and Function Analysis (R% = 21.86), with Ideal Design method (R% = 15.30) the least effective.
- Even though functional analysis outperformed in the total number of searches (R% = 29.31), but on average across all phases of design problem solving, ISQ is the best (R% = 29.85).

A further validation to the results shown in Table 2 comes from that fact that the overall results match closely with the overall assessment of creative effects of these methods as estimated by Chakrabarti

Table 2. Comparison of the methods.

	bs1	bs2	A	R %	id1	id2	A	R %	fa1	fa2	A	R %	isq1	isq2	A	R %
Phase: Problem understanding																
up	0	0	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	0	0.00
gp	7	3	5	20.83	10	3	6.5	27.08	7	6	6.5	27.08	5	7	6	25.00
lp	2	2	2	21.05	3	1	2	21.05	6	0	3	31.58	1	4	2.5	26.32
dp	10	1	5.5	14.86	1	11	6	16.22	11	0	5.5	14.86	9	31	20	54.05
Sub T	19	6	12.5	17.73	14	15	14.5	20.57	24	6	15	21.28	15	42	28.5	40.43
Phase: Solution generation																
us	7	6	6.5	86.67	0	1	0.5	6.67	0	1	0.5	6.67	0	0	0	0.00
gs	24	13	18.5	42.53	9	7	8	18.39	13	8	10.5	24.14	10	3	6.5	14.94
ls	15	13	14	30.43	6	5	5.5	11.96	16	21	18.5	40.22	3	13	8	17.39
ds	21	29	25	17.01	32	15	23.5	15.99	60	49	54.5	37.07	41	47	44	29.93
Sub T	67	61	64	26.23	47	28	37.5	15.37	89	79	84	34.43	54	63	58.5	23.98
Phase: Solution evaluation																
ue	0	0	0	0.00	0	0	0	0.00	0	0	0	0.00	0	0	0	0.00
ge	7	3	5	32.26	2	5	3.5	22.58	3	1	2	12.90	5	5	5	32.26
le	7	1	4	32.00	3	1	2	16.00	4	5	4.5	36.00	0	4	2	16.00
de	22	29	25.5	40.16	0	17	8.5	13.39	12	15	13.5	21.26	11	21	16	25.20
Sub T	36	33	34.5	37.70	5	23	14	15.30	19	21	20	21.86	16	30	23	25.14
Total and phase average																
Total			111	27.34			66	16.26			119	29.31			110	27.09
PA				27.22				17.08				25.85				29.85

Note:

- Experiments: bs - outcome of the design experiment in which brain storming method was used, similarly, id- ideal design, fa - functional analysis, isq - innovation situation questionnaire. The numbers 1 or 2 represent the first and the second experiment where this method is used respectively. For example id1 represents first ideal design experiment- experiment no 3 as shown in Table 1, similarly id2 is experiment no. 4.
- Searches: u — unknown search, g — global, l — local, d – detail, p — problem search, s— solution search, e— evaluation search. For example 'ge' means 'global evaluation search'.
- Sub T: Total no in each phase.
- A: average, R%: Relative fraction of the total contribution in percentage.
- PA:Phase average — average R% for the sub total of the three phases.
- The highlighted numbers are the maximum values in each category (row).

[12] using relative time spent in these phases when these methods were used, see relevant excerpts from that work below:

- Brainstorming method: should mainly support solution generation and evaluation with minor support for problem identification, analysis and choice.
- Ideal design method: should mainly support problem identification and analysis and solution generation, with minor support for problem choice and solution evaluation.
- Function analysis method: should mainly support problem identification and analysis, with minor support for problem choice, solution generation and evaluation.
- ISQ method: should mainly support problem identification and analysis.

For example Table 2 shows that brainstorming supports solution generation and evaluation more than it supports problem understanding — which is evident from the corresponding number of searches generated.

It could be argued that, if the use of a design method affects a design process, then the effect can be observed in the kinds of search generated in the design process. It is predicted that use of a method should influence the search finding profile of the designers, and this profile can be compared with the general profile of each method to identify how closely the profile is influenced by the method. In this calculation Average of Relative contribution (A of R%) of a particular method over all designers (R%) is used. It is the average of all the values relative contribution of all the designers for each type of search for each method. Relative values are used to eliminate the effect of individual differences in the ability of the designers involved. Figure 3 shows the plot of the values for the relative contribution of each method.

4.2. Search Generation Profile for Each Participant Designer

For each designer, all the utterances are classified in a table showing the type and number of search of each type that have been generated by that designer for problem understanding, solution generation and solution evaluation. Next, the ratio of the number of searches of each given type performed by the designer while using a given method, to the total number of searches of that type performed by that designer while using all design methods taken together is taken as the *relative search profile* of that designer using that method. Table 3 shows the number of different types of searches generated by designer 'C' individually while solving the problems in groups. Table 3 shows the search profile and relative search profile of designer 'C' for each method. Figure 4 shows a plot of the relative search profile of the designer for each method.

Let us say we are interested to determine the R% for designer C for global solution search (gs) = (8/(8+2+5+3)*100) = 44.44% (see 9th row of Table 3). Also note that each designer has used a method only once.

It seems from Table 3 (see last row — 'Total', which shows the total number of searches performed by the designer while using each method), that the performance of the designer while using functional analysis is better than that while using other methods, as he carried out 57 searches using this method — 41.61% of all searches carried out by the designer across the experiments in which the designer participated. This difference could be due to the individual ability of this designer or due to the presence of the method used. Similarly for all the other designers their search profiles are determined.

5. CONCLUSIONS

Use of methods affects designing. Through design experiments, it has been possible to identify methods that are more effective in different phases of design. Such assessment should help designers select creativity methods based on the type of effects they would require from these methods. The main result obtained in this work is a suite of measures with which the effect of a creativity method on search and exploration can be assessed.

In this work, only four design methods are considered (viz. Brainstorming, Ideal Design, Functional Analysis and Innovation Situation Questionnaire). Each design method used in this work has influenced search differently, and among these methods there is none that alone is effective in uniformly supporting search of all kinds, i.e., in uniformly carrying out search in all the phases of design. For problem understanding, ISQ is the most effective followed by Function Analysis, Ideal Design and Brainstorming. For idea generation, Functional Analysis is the most effective, followed by Brainstorming, ISQ and Ideal Design. For solution evaluation, Brainstorming is the most effective, followed by ISQ, Function Analysis and Ideal Design method. Even though functional analysis is better in terms of total number of searches, yet on average across all phases of design problem solving, ISQ is the better than the other three selected methods. Methods could be identified that are effective in different phases of design problem solving, and use them together.

Thus, use of a design method affects a design process, and the effect can be observed in the kinds of search generated in the design process. It has also been noted that the use of a particular design method during designing, influences the search finding profile of the designers. We argue that using the measures proposed, efficacy of a newly developed design method can also be assessed. One possible

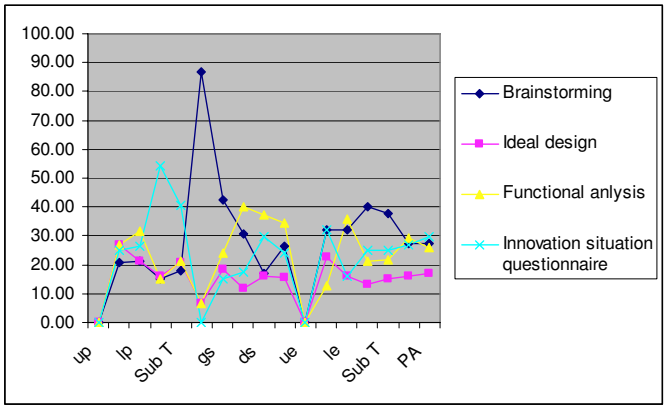

Figure 3. R% plot of Table 2.

Table 3. Types and number of searches generated by designer 'C'.

	bs1 Lock	R%	id1 Lock	R%	fa1 Leaf	R%	isq1 Leaf	R%
up	0	0.00	0	0.00	0	0.00	0	0.00
gp	3	16.67	6	33.33	6	33.33	3	16.67
lp	0	0.00	2	40.00	3	60.00	0	0.00
dp	3	33.33	0	0.00	4	44.44	2	22.22
Sub T	6	18.75	8	25.00	13	40.63	5	15.63
us	2	100.0	0	0.00	0	0.00	0	0.00
gs	8	44.44	2	11.11	5	27.78	3	16.67
ls	3	30.00	0	0.00	6	60.00	1	10.00
ds	6	12.24	6	12.24	24	48.98	13	26.53
Sub T	19	24.05	8	10.13	35	44.30	17	21.52
ue	0	0.00	0	0.00	0	0.00	0	0.00
ge	2	66.67	0	0.00	1	33.33	0	0.00
le	4	66.67	0	0.00	2	33.33	0	0.00
de	6	35.29	0	0.00	6	35.29	5	29.41
Sub T	12	46.15	0	0.00	9	34.62	5	19.23
Total	37	27.01	16	11.68	57	41.61	27	19.71

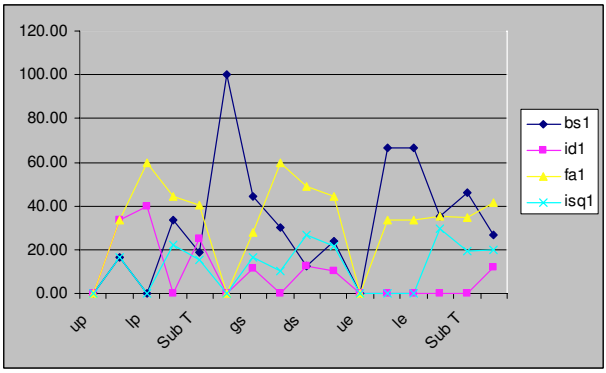

Figure 4. R% profile of designer 'C'

further work is to develop a new idea generation method that will help designers to search different design spaces more uniformly than possible using any current individual method.

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