Res Eng Design (2014) 25:185–201
DOI 10.1007/s00163-014-0173-9

ORIGINAL PAPER

Ideas generated in conceptual design and their effects on creativity

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Received: 12 November 2012 / Revised: 21 January 2014 / Accepted: 31 March 2014 / Published online: 9 April 2014

Abstract Search of design spaces to generate solutions affects the design outcomes during conceptual design. This research aims to understand the different types of search that occurs during conceptual design and their effect on the design outcomes. Additionally, we study the effect of other factors, such as creativity, problem-solving style, and experience of designers, on the design outcomes. Two sets of design experiments, with experienced and novice designers, are used in this study. We find that designers employ twelve different types of searches during conceptual design for problem understanding, solution generation, and solution evaluation activities. Results also suggest that creativity is influenced positively by the type and amount of searches, duration of designing, and experience of designers.

Keywords Conceptual design · Search · Design space · Creativity · Design activity · Product design

1 Introduction

Conceptual design, in which ideas are generated, is one of the most important tasks in engineering product development cycle (Wang et al. 2002). Various theories have been proposed as to how idea generation takes place; few of these are as follows: convergent–divergent theory (Guilford 1967; Zhang and Sternberg 2005), analogy and inspiration (Eckert and Stacey 2000; Vattam et al. 2010), Wallas model (Wallas 1926; Torrance 1988), Barron's psychic creation model (Barron 1988; Plsek 1996), Osborn's seven-step model (Osborn 1963), and the Creative Problem-Solving (CPS) model (Isaksen and Treffinger 1985; Parnes 1992). Although these theories and models are different from one another, an underlying assumption in most is that designers search for new, appropriate, and improved solutions. Thus, searching for ideas is a major activity of designers during conceptual design. Many researchers hold this view explicitly. For instance, De Silva Garza and Maher (1996) and Gero and Kazakov (1996) argue that design is a phenomenon involving search of new ideas, and Benyon and Imaz (1999) expressed also similar views, discussing ideation as phenomena and proposed usage of experimental cognition in understanding ideation. Roozenburg and Eekels (1995) argue that search of ideas is similar to idea finding, since both are divergent processes, where many ideas need to be considered before selecting the best ones. According to Stal and Turkiyyah (1996), creative design involves generation of new search spaces.

Search is used in finding an *improved* design within a given design space (Gero and Kazakov 1996). It is also

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considered as a process that finds new ideas (points) that are better than previous ones. Thus, s*earch is a process of finding new or improved designs in a design space.*[1]

Gero (1990) established that there are mainly two broad classifications of design—routine designing and non-routine designing. In non-routine designing, all the variables, which specify designs, are already available. The space of possible designs is known, and the space can be predicted, constructed, and evaluated. Search is required only to locate the best design in that space. On the other hand, in non-routine designing, search need to be conducted for both 'best' space of possible designs as well as the 'best' design possible from the space. Thus, search is useful for routine design, and exploration is useful for non-routine design. Gero and Kazakov (1996) used shape grammar to represent knowledge. They formulated both routine and non-routine, or creative design problem using state space and extended state space shape grammar. They then produced two algorithms, which have potential of producing better designs. Gero and Kazakov (2000) argue that in a function–behavior–structure mode, exploratory processes have potential for increasing the space of each of these three individual design spaces (i.e., function, behavior, and structure spaces).

Gelsey et al. (1998) observed that automated search of a space of candidate designs is an attractive way to improve the traditional engineering design process. Langdon and Chakrabarti (1999) discuss some of the positive effects and some limitations of exploration. They argue that effective support for conceptual design should help designers to obtain a thorough overview of the solution space, as well as a detailed understanding of its individual solutions. However, Bryant et al. (2005) state that there are only few computational tools that exist to assist designers in the conceptual phase of design. For example, Bryant et al. (2005) state that there are only few computational tools that exist to assist designers in the conceptual phase of design. They developed concept generator, an automated design tool. They found that the tool is a promising one for supporting designing. Kurtoglu et al. (2005) discuss a methodology to extract design knowledge from an online library of components in the form of grammar rules. They mention that initial implementation of forty-five rules that have been compiled from 15 components extracted of three products. In another interesting work, Nagai and Taura (2006) proposed a design synthesis process and stated that it is key to creative design. They proposed through design study several primitive activities in ideation, such as, concept abstraction and concept blending and discussed how these are related to creativity. Potter et al. (2003) argue that even though design textbooks suggest a number of techniques for supporting design synthesis, synthesis of solutions still predominantly depends on the creativity, skill, and experience of the designers. While it is often argued that factors such as quality of the ideas generated during conceptual design influence creativity of the outcomes of a design process, it is unclear as to what is meant by quality of ideas, and there is little empirical study to establish what influence quality of ideas and experience have on creativity (Potter et al. 2003).

This research thus aims at understanding the process of search and its effect on conceptual design using two sets of design experiments. For this, we categorize the types of searches that occur during problem understanding, solution generation, and solution evaluation and selection, and map them with the creative outcomes of these experiments. Additionally, we also study the effect of other important factors such as experience of participant designers, duration of the design experiments, and creativity and problem-solving style of the designers on the design outcomes, especially creativity of the final solution.

2 Understanding the process of search through design experiments

To understand the process of search, two sets of design experiments (set of design sessions) are conducted. They are as follows:

(i) Design experiments with compulsory use of design methods
(ii) Design experiments without the use of any design methods

2.1 Design experiments with compulsory use of design methods

The first set of experiments, henceforth called 'initial design experiments,' involved eight design sessions, carried out by two groups of designers, three in each group, using four different design methods: Brainstorming, Ideal design, Functional analysis, and Innovation Situation Questionnaire (Chakrabarti 2003). All these designers had

[1] A *'design space'* consists of a set of elements (which can either be problems, solutions, or evaluation criteria) that are similar to each other. Depending on the relationship and the level of abstraction used (see 'Appendix 1'), a design space can overlap with, or subsume other design spaces. 'Design space' is commonly used to mean 'design solution space' (or simply 'solution space') which contains design alternatives (Woodbury et al. 2000). Depending on the content, design spaces are of three types. A 'design problem space' (or simply 'problem space') contains a set of similar problems, as a 'solution space' contains a set of similar solutions; a 'design evaluation space' (or simply an 'evaluation space') contains a set of similar evaluation criteria.

formal training in designing at the postgraduate level; some had experience of designing products in industry.

2.1.1 Experimental setup

The experiments were conducted in a laboratory setting, where the steps of each method were provided in a printed sheet, and blank sheets were provided to the designers to work on and express their outcomes. The designers were asked to discuss audibly while designing, so that their verbal expressions could be captured on videos. Two problems (Table 2) were interchangeably used, and both the groups solved both the problems using all the four methods. Even though there was no time constraint, the average duration of each conceptual design session was about an hour. All sessions are videotaped and subsequently analyzed using video protocol analysis.

Two design problems have been used in these design experiments, as shown in Table 1. Initial Problem 1 (IP1) is related to the *design of a system for locking in which one do not require key or remember numbers or words to use it*. Initial Problem 2 (IP2) *is related to finding out suitable ways of removal of dry leaves from a given place*. Designers are asked not to reuse any solution from previous experiments, if any.

2.1.2 Analysis and results

Each utterance (each statement that the designers made during designing) of each designer in the video protocols of these eight (4 × 2) sessions (on average 300 utterances per experiment) is separated and enlisted. The contents of the transcribed protocols from each session are categorized into one of these three phases: (i) *problem understanding phase*, where the given problem is analyzed, and requirements, related problems, and constraints are identified; (ii) *solution generation phase*, where potential solutions are generated; and (iii) *evaluation and selection phase*, where evaluation criteria are determined, the ideas generated earlier are evaluated, and final design outcome is selected.

In these protocols, for the solutions generated, we identified all the solutions generated during each design session and compared their similarities with the solutions previously generated in the same session. We observed, as shown in Fig. 1 (for IP1), that designers find new solutions:

- either by searching for similar solutions,
- or by generalizing a previously generated solution,
- or by detailing a solution.

The right-hand column of Fig. 1 shows the results from this analysis.

Next, two individual researchers, each with over three years of research experience who had earlier transcribed many video protocols, are asked to cluster all the solutions generated in two of the design sessions, based on the similarity of the ideas. These researchers found that four distinct types of solutions (see 'Appendix 1' for details) were generated by the designers:

- *Type 1:* A designer generates a solution by extending a previous solution by adding details to it. For instance, while solving IP1 (Table 1), a designer expresses that locking could be done remotely using a remote locking device. Next, the designer adds that the remote locking device would have a particular range of frequency. This is an instance when a designer adds details to a solution. We name this pattern as '*detail solution search*.'
- *Type 2:* This occurs when a designer finds a specific solution within a generic solution space. For instance, for IP1, the solution of using one's own 'DNA' that is 'specific to a person' as a means of identifying that person as a 'key' (see Fig. 1) is an example of this pattern. Here, the idea 'DNA' can be taken as a solution that belongs to a space in the generic idea of 'specific to a person.' We name this type of solutions as '*local solution search*,' as the solutions seem to be localized within a generic design space.
- *Type 3:* This occurs when a designer finds a solution that is different from all the solutions found before in the session, and is generic in nature. However, such solutions are known to exist as potential solutions. For instance, a designer generates 'passwords that are common to a person' (see Fig. 1) as a solution to IP1. Here, the designers were generating ideas that belong to

Table 1 Initial design experiments (average duration is 60 min)

Exp. no.	1	2	3	4	5	6	7	8
Method used	BS	BS	ID	ID	FA	FA	ISQ	ISQ
Groups	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2	Group 1	Group 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
Initial problem used	IP1	IP2	IP1	IP2	IP2	IP1	IP2	IP1

BS brainstorming, *ID* ideal design, *FA* functional analysis, *ISQ* innovation situation questionnaire. Identifiers used to distinguish the designers involved: A, C, G, P

Fig. 1 Transcript of a Brainstorming session by three designers while solving IP1

	A	B	C	D
1	Time	Designer	Transcription	Initial analysis
2	3:10	p	I remembered one project done in CEDT, they used the **thumb impression** for his own key as such, the device used the sensation of the picture of this (thumb) and matches and once it stores in the memory, and after that it matches this impression on it and it senses some (and) it sends some signal in the computer in that case, by its and that thing can be done in any level	
3	3:47	s	so we should write **thumb**	
4	3:50	c	**detecting**	
5	3:51	r	also you can see some, **scanners** will be... scan yeah .. **Eye balls**	thumb detection > scanners > eye balls (searching for similar solutions)
6	4:00	p	eye balls .. That will be **specific for a person**	eye balls > specific to a person (generalized solution)
7	4:01	r	yeah, specific for a person, also at the same time we can see in some movies that people removing and chopping the hands of a person and then taking to the scanner and (placing it - shown by hand)	
8	4:10	c	and also the eye balls	
9	4:10	r	also the eye balls if you see minority report, that guy takes eye ball itself	
10	4:15	p	oh,	
11	4:15	s	so, ...hum	
12	4:20	r	I will prefer you keep your hand and without taking the gun it will since the **DNA** of a particular person, so you cannot take any body's DNA ... yeah	specific to a person > DNA (finding similar solutions in a design space)
13	4:32	s	so, we guess we have DNA ...???	
14	4:44	p	Next, we can say every person have **his own some style of own** and **he only knows some secret**, he only knows by some secret like what we use if you forget your password, in that case or some questions that only he knows he can... that type of things	(searching similar solutions)
15	5:00	c	**password**	(searching similar solutions)
16	5:09	p	**password, which can be very common to them**	(generalized solution)
17	5:16	r	here ...??? .... **Numbers and password and they are same and need not to be remembered**	(generalized solution, finding a design space to search)
18	5:23	p	that what I am saying, few thing, numbers...	
19	5:27	c	numbers cannot be personal but these passwords can be personal	
20	5:30	p	It can be a very means... can be very **personal**, I need not to remember that like **when I (first) met my girlfriend**, so it is just a thing like routine, just it is there in my mind, I don't have to remember that	(searching similar solutions)

the generic idea of 'specific to a person' (eye balls and thumb impressions ideas belong to this space), and later, they started generating ideas that belong to 'passwords that are common to them' (personal numbers idea belongs to this space). We name this type of solution as '*global solution search*.'

- *Type 4:* This occurs when the designer finds either a novel idea or a new application of an existing idea. This pattern is similar to global solution search, except that the solutions did not exist before and are not known as potential solutions for similar problems solved earlier. Though found rarely in transcripts, it does not fall into any of the above three categories. For instance, in solving the locking problem (IP1), a designer generates 'we (would) have something which traces the thought coming in our mind, we can (think) unlocking the system so it will unlock. So, if we can trace the thought and if we say unlock, it will unlock.' Thought tracking devices are still in a research stage and have never been used for a locking device. We call this as '*new solution search*.' A 'new solution search' is activated when a designer generates an *idea* (the same is also applicable to finding problem or evaluation criteria), *not* previously known to the designer. These kinds of solutions are potentially novel solutions. However, these have been generated during the idea generation phase of these design experiments and are yet to be evaluated for their suitability as a selected solution. Often, these solutions are new applications of an existing technology in another field. Finding a search space of this kind that is not known at the starting point of the design process should increase the possibility of finding optimum designs (Stal and Turkiyyah 1996) and influence the occurrence of other kinds of search. The low frequency of occurrence of this kind of search could be attributed to the difficulty of identifying these spaces. Stal and Turkiyyah (1996) stated that generation of new search spaces influences the creative outcome of a design process.

We express these findings in the form of a flow diagram, see Fig. 2. As presented in Fig. 2, 'global search' represents search in a space (global) that is less specific than that of the local and detailed spaces.

Figure 2 represents that a designer, while generating solutions, finds different potential solutions in different design spaces, mainly through new or global searches. Once a potential solution is found, the designer starts exploring the same design space both in breadth and in depth, and often finds several other potential solutions though local and detailed searches. In the later part of this paper, as shown in Fig. 4, we see that finding new and global searches helps in finding many local and detailed searches.

As explained above, ideas for solutions generated in conceptual design are a result of searching different design spaces, and each of these ideas can be classified into one of these four types: 'new solution search,' 'global solution

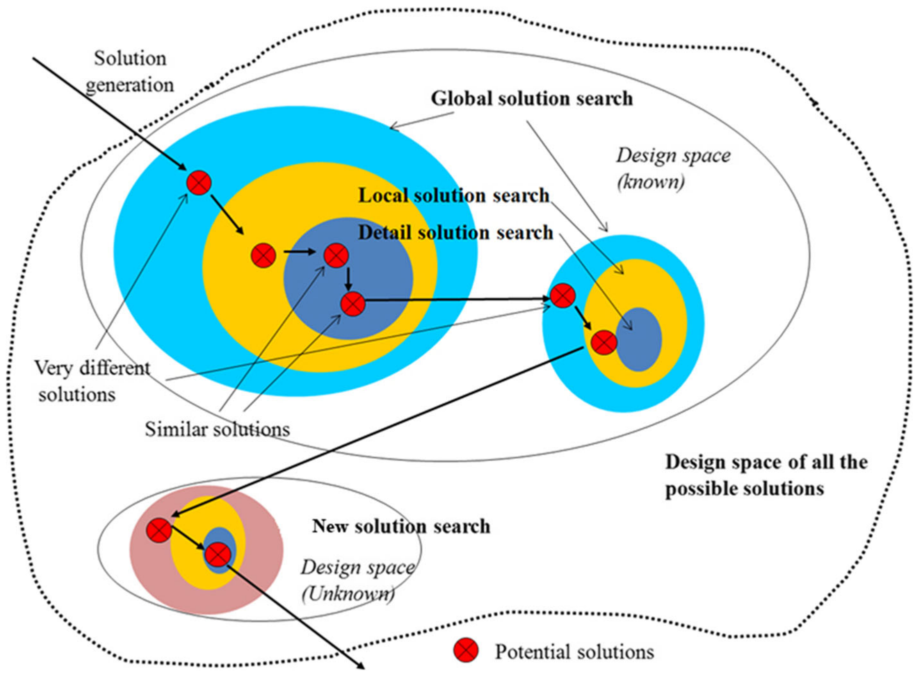


Fig. 2 Representation of a 'design space' and various types of search. The *bold arrows* show typical processes for finding potential solutions by a designer

search,' 'local solution search,' and 'detail solution search.' Further analysis of problems and evaluating criteria identified shows that similar kinds of search also occur in problem understanding and solution evaluation phases (see 'Appendix 1' for details). Consequently, a general pattern of search in conceptual design emerged: designers employ twelve (4 × 3) different types of search (i.e., four types of search in each of the three design phases) in order to search for problems, generate solutions, and identify criteria for evaluation and selection of solutions.

3 Design experiments without the use of any design methods

Since each initial design experiment involved obligatory use of a method, it is possible that these methods had influenced the kinds of search that occurred in these experiments. To ascertain the frequency of different kinds of search taking place in a generic design process, and to propose general conclusions based on them, another set of design experiments was conducted without prescription to use of any design method.

3.1 Experimental setup

In these experiments, eight design experiments were conducted, with four novice designers and four experienced designers, all of them working individually. Two types of problems were provided to the designers to solve—one requires engineering design knowledge and the other requires only general design ability. One problem was given (*P1*) to two novice and two experienced designers and the other (*P2*) to the remaining two novice and two experienced designers. The two problems solved are given below:

- *Problem 1 (P1- requires general design ability):* Design a handheld utensil cleaning system for urban middle-class women.
- *Problem 2 (P2- requires engineering design knowledge):* Design a drilling machine that can drill a hole of variable diameter in a metal block in any direction and is capable of changing its direction even while the drilling is going on inside the block.

All designers had undergone a four-year engineering course (mostly mechanical engineering) at the undergraduate level and a formal two-year course in product design at the postgraduate level. The experienced designers had between two and eight years of design experience in design firms, where they designed tangible products.

Designers participating in these experiments were different from those in the first set of design experiments, in order to reduce the 'subject effect'—the influence of the subjects used on the findings. The problems in these design experiments were interchanged, as shown in Table 2, among the designers to eliminate the 'problem effect,' so that the designers could not reuse solutions from their previous design experiments. The experiments were conducted in a laboratory setting without any intervention. The experimental room was a large mostly vacant room, without any clutter, to avoid designers being getting

Table 2 Searches in the main design experiments

Designer	Abbreviation	Experienced				Novice			
		Dh	Ne	Si	Ch	Bh	Sh	Su	Vi
Experiment no.		1	2	3	4	5	6	7	8
Problem used		P1	P2	P2	P1	P2	P2	P1	P1
Duration (average 77 min.)	t (in minutes)	71	70	42	184	79	68	56	47
Relationships	Occurrence ->								
Agreeing	Agree	0	4	6	20	6	8	2	6
Disagreeing	Disagree	0	0	0	0	0	0	0	0
Clarification	cla	10	41	24	81	63	15	15	9
Method clarification	M cla	7	7	19	2	11	5	1	0
Total clarification	T cla (cla + M cla)	17	48	43	83	74	20	16	9
Selection	sel	2	0	0	0	0	0	0	0
New problem search	np	0	0	0	1	0	1	0	0
Global problem search	gp	7	10	2	4	2	3	5	2
Local problem search	lp	2	7	2	4	0	2	3	0
Detail problem search	dp	11	27	0	9	6	11	1	1
Total problems	T problems	20	44	4	18	8	17	9	3
New solution search	ns	0	1	0	8	2	1	3	0
Global solution search	gs	12	29	4	36	7	12	13	8
Local solution search	ls	4	8	5	14	5	2	6	3
Detail solution search	ds	94	63	34	250	52	51	29	58
Total solutions	T solutions	110	101	43	308	66	66	51	69
New evaluation search	ne	0	0	0	0	0	0	0	0
Global evaluation search	ge	11	12	3	10	5	1	2	1
Local evaluation search	le	3	6	0	1	1	0	0	0
Detail evaluation search	de	14	10	1	5	4	1	1	2
Total evaluating criteria	T evaluations	28	28	4	16	10	2	3	3

inspired with the products in the room. Blank sheets were provided to the designers to work on, or express their solutions. Each designer was asked to express audibly while designing, and think aloud protocol (Jaaskelainen 2010; Sarkar and Chakrabarti 2013) was used. A video camera was used to capture verbal expressions. The duration of these experiments varied between 47 and 184 min (see Table 2).

3.2 Results of the protocol analysis of these design experiments

The transcribed protocol from each design experiment was categorized. Apart from the twelve categories discussed in the previous section (viz. new problem search, global problem search, local problem search, detail problem search, new solution search, global solution search, local solution search, detail solution search, new evaluation search, global evaluation search, local evaluation search, and detail evaluation search), the following categories were used to categorize the remaining portion of the transcripts: 'agree,' 'disagree,' 'clarification,' 'method clarification,' and 'selection' (see 'Appendix 1' for details). The results of categorization are shown in Table 2, and further analyses are presented in the next subsections.

The inter-coder consistency was 88 %, which was assessed by comparing a large portion of coding done by the authors and two different coders, each with three years of transcribing and coding experience. After discussion between them, the entire code, as originally coded by the authors, was accepted by the two coders.

3.3 Analysis

With the results tabulated in Table 2, various analyses are conducted to seek deep relationships, if any, among search, idea generation, time, experience, creativity, and creativity style (using KAI (Kirton 2012)).

3.3.1 Effect of search in new design spaces

In the introductory part of the section, we mentioned that once a designer jumps into a new design space through a new or global search, other searches such as local and

Table 3 Correlations among searches (refer to Table 1 for source data)

Relation	Correlation
Problem understanding	
1. (Total number of) New problem—(Total number of) global problem	−0.19 ($p < 0.1$, no correlation)
2. Global problem–local problem	0.82 ($p < 0.02$, high correlation)
3. Local problem–detail problem	0.76 ($p < 0.02$, high correlation)
4. New problem–(gp + lp + dp)	0.06 ($p < 0.1$, no correlation)
5. Global problem–(lp + dp)	0.86 ($p < 0.01$, very high correlation)
6. (np + gp + lp)–detail problem	0.85 ($p < 0.01$, very high correlation)
Solution generation	
7. New solution–global solution	0.73 ($p < 0.02$, high)
8. Global solution–local solution	0.86 ($p < 0.01$, very high)
9. Local solution–detail solution	0.82 ($p < 0.02$, high)
10. New solution–(gs + ls + ds)	0.84 ($p < 0.01$, very high)
11. Global solution–(ls + ds)	0.78 ($p < 0.02$, high correlation)
12. (ns + gs + ls)–detail solution	0.83 ($p < 0.02$, high correlation)
Solution evaluation	
13. New evaluation–global evaluation	Nil (as no 'new evaluation' is found)
14. Global evaluation–local evaluation	0.84 ($p < 0.01$, very high correlation)
15. Local evaluation–detail evaluation	0.81 ($p < 0.02$, high correlation)
16. New evaluation–(ge + le + de)	Nil (as no 'new evaluation' is found)
17. Global evaluation–(le + de)	0.90 ($p < 0.01$, very high correlation)
18. (ne + ge + le)–detail evaluation	0.89 ($p < 0.01$, very high correlation)

For example, 'new problem–global problem' means Pearson's correlation between the total number of new problem search and total number of global problem search, across all the experiments. For instance, (ns + gs + ls)—detail solution = 0.83 means that the number of instances of detailed solution search generated correlates very highly with the aggregated, total number of new, global, and local solution searches. It is interpreted that number of new problem searches strongly influences the aggregated total number of new, global, and local searches, since the value 0.83 is considered a strong positive correlation in Pearson's correlation scale (Urdan 2010). Level of significance (p) of the above correlation is: $p < 0.1$ for values > 0.62, $p < 0.05$ for values (0.63–0.70), $p < 0.02$ for values (0.71–0.79), and $p < 0.01$ for values > 0.83 (Microbiologybytes 2012) for r(6), two tailed

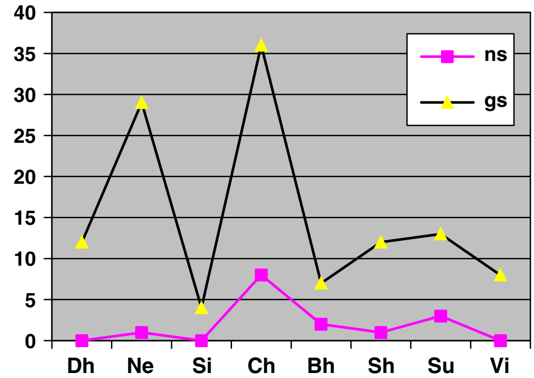


Fig. 3 New solution search (ns) versus global solution search(gs). 'Y' axis shows number of search

detail search follow. Now, we investigate as to whether finding new or global design spaces helps in finding more ideas in that space, or helps in problem solving leading to development of more appropriate ideas. To do this, we ascertain the relative influence of each kind of searches on one another. Standard Pearson's correlation (Gravetter and Wallnau 2008) is used on the data, and the results of the correlation are shown in Table 3.

Solution generation: There are fifteen new solution searches (ns) (see Table 2) that were previously not known to the designers and were found while solving problems. From Table 3, it can be interpreted that new solution search positively influences global solution search (gs). This in turn influences the occurrence of local solution search (ls) and subsequent detailed solution search (dp), see Fig. 3 for an example. Presence of new solution search influences the number of searches in all other types of search. Also, the number of detailed solution searches is influenced by the total number of searches of all other types. Hence, designers who find many design spaces have an increased possibility of finding a large number of solutions.

Problem understanding: As the total number of new problem (np) searches are very few (only two, see Table 2), its relationships with other terms are ignored. From Table 3, it can be concluded that global problem search (gp) influences local problem search (lp), and this in turn influences detailed problem search (dp). Also, global problem search influences both local and detailed problem searches. Again, detailed problem search is influenced by the presence of all other searches at the higher levels of the hierarchy.

Solution evaluation: There was no new evaluation search (ne) in any of these experiments. Table 3 indicates that global evaluation search (ge) positively influences local evaluation search (lp), which in turn influences

Fig. 4 Search hierarchy

Table 4 Relationship among total number of searches of each type (refer Table 2 for source)

Relationship	Correlation
1. (Total number of) problem searches—(total number of) solution searches	0.27 ($p < 0.1$, no correlation)
2. Solution searches—evaluation searches	0.39 ($p < 0.1$, no correlation)
3. Problem searches—evaluation searches	0.78 ($p < 0.02$, high correlation)
4. (clarification + problem searches)—solution searches	0.62 ($p < 0.05$, medium correlation)
5. Clarification (general)—solution	0.71 ($p < 0.02$, high correlation)
6. Method clarification—solution	0.30 ($p < 0.1$, no correlation)

detailed evaluation search (de). Global evaluation search influences both local and detailed evaluation search. It can be concluded that detailed evaluation is influenced by the number of other types of evaluation search carried out in the process.

Thus, we argue that the various types of search spaces (viz. new, global, local, and detail) in all the three phases of design problem solving (viz. problem understanding, solution generation, and evaluation/selection) form a hierarchy and mutually influence each other as shown in Fig. 4.

From Table 3, it is observed that on average:

- For each new problem found, 17 global problems, 10 local problems, and 33 detailed problems were generated, and for each global problem, 0.5 local problems and 2 detailed problems were found.
- A single new solution space found was associated with 8 global solutions, 3 local solutions and 42 detailed solutions. Moreover, each global solution search led to the generation of 0.3 local and 5 detailed solution searches, respectively.
- There was no new evaluation search found. For each global evaluation, on average, 0.2 local and 0.8 detailed evaluation searches, respectively, are found to occur.

From the above observations, we see that presence of generic solutions (i.e., new and global searches) encourages many other similar solutions to be generated. This strengthens our argument that to support conceptual design, designers should explore new design spaces or be exposed to new generic design spaces. Ideas belonging to a different design space should help in the generation of other ideas that are different from that already generated by the designers during solving a problem.

4 Finding related problems and clarifying them to help in solution generation

Smithers et al. (1992) stated that analyzing design problem's characteristics creates and bounds the space within which possible design solutions can be located. Similarly, researchers such as Nidamarthi (1999) have shown that better problem understanding helps better solution generation in terms of requirement satisfaction. Now, let us see whether the results of the experiments reflect this.

To find relationships, if any, among the different kinds of search that took place in the design experiments, the total number of searches within each phase (e.g., problem understanding, solution generation, and solution evaluation) was correlated with that of those in the other phases. The total number of problem search, for instance, is taken as the sum of the number of searches in all four types of problem search. Similar processes are followed for the other outcomes also.

In Table 4, it can be noticed that problem search influences evaluation search (Row 4). Contrary to our expectations, no correlation was found between the numbers of problems identified (total number of searches in all problem search types) by designers and the total number of solutions generated (total number of searches in all solution search types). Nidamarthi (1999) did not differentiate between clarification (general clarification and method clarification) and problem searches; it was found, however, that the amount of solution search is influenced by the presence of clarifications and problem searches (Row 5). Thus, search in solution space is influenced by the search of the problem space. Table 4 also shows that there is a fair correlation between clarification and solution generation, hinting that clarification of a given problem enhances the generation of a number of potential solutions.

Table 5 Effect of duration of the experiment on searches (see Table 2 for data)

Duration–(total number of) solutions	0.97 ($p < 0.01$, very high correlation)
Duration–(problem understanding + clarification)	0.69 ($p < 0.05$, medium correlation)
Duration–solution evaluation	0.30 ($p < 0.1$, no correlation)
Duration–total number of all searches	0.93 ($p < 0.01$, very high correlation)
Duration–new solution searches (us)	0.92 ($p < 0.01$, very high correlation)
Duration–global solution searches (gs)	0.79 ($p < 0.02$, high correlation)
Duration–local solution searches (ls)	0.86 ($p < 0.01$, very high correlation)
Duration–detailed solution searches (ds)	0.96 ($p < 0.01$, very high correlation)

5 Time spent in solving a problem positively affects the design outcome

Does spending more time in conceptual design help generate a larger number of ideas? The effect of the length of the experiment (i.e., the duration of designing) on design outcomes was assessed by finding its correlation with the number of different kinds of searches in the design process (see Table 5).

Table 5 shows that as the duration of the design process increases, the total number of solutions generated, total number of searches generated, total number of problems, and clarifications generated, as well as the total number of global, local, and detailed solutions generated increase. Thus, as designers spend more time on solving a problem by finding out different kinds of search, the number of potential solutions increases. This shows that time is an important deciding factor for creative design: as designers spend more time in thinking and generating ideas, the chances are higher that the outcome will be more creative.

6 Creative ability and experience of designers positively affect the design outcome

It has been already established that creativity of individuals affects the outcome of their activities (Shalley 1991; Woodman et al. 1993; Amabile 1996). Creative outcome also affects company performance (Amabile 1988). In this section, we investigate how this is reflected in the experiments conducted. Creativity of each of designer involved in the main experiments (i.e., the second set of experiments) was assessed using the outcomes of the design sessions in which they were involved.

Sternberg and Lubart (1999) defined creativity as that which 'produce work that is both novel (i.e., original, unexpected) and appropriate (i.e., useful, adaptive concerning task constraints).' Similarly, Weisberg (1993) defined it in terms of 'novel and valuable products, capacity to produce such works, and the activity of generating such products.' In a recent work, Sarkar and Chakrabarti (2011), proposed: 'Creativity in design occurs through a process by which an agent uses its ability to generate ideas, solutions, or products that are novel and valuable (useful).' According to this definition, the core components of creativity are 'novelty' and value (usefulness).'

Sarkar and Chakrabarti (2011) proposed that difference of products in terms of their characteristics can be employed to determine the relative degree of novelty of products. For assessing usefulness or value of ideas, they advocated that products that are good for the society, and are used by or benefit many people for a long period, are more useful than those that are not. Usefulness is expressed in terms of 'importance of usage of a product,' 'its popularity of usage,' and 'the rate or duration of usage,' and used as a criterion for assessing creativity (Sarkar and Chakrabarti 2011).

Chulvi et al. (2012) analyze the influence of several design methods (Brainstorming, Functional Analysis, and SCAMPER method) on the degree of creativity of the design outcome using metric of Moss(1966), the metric of Sarkar and Chakrabarti (2011), as stated before, and the evaluation of innovative potential. They found that Brainstorming provides more creative outcomes than when no method is applied. Another study by Kudrowitz and Wallace (2013) explores a metric for evaluating large quantities of early-stage product sketches and tests the metric through an online service called Mechanical Turk. They found that 'clarity of the sketch positively influenced ratings of idea creativity. Additionally, the quantity of ideas generated by an individual participant had a strong correlation with that participant's overall creativity.' They believe that a metric of three attributes to be used as a first pass in narrowing a large pool of product ideas to the most innovative: novel, useful (or valuable), and feasible (as determined by experts). While in another related study, Oman et al. (2013) presented several methods used to assess the creativity of similar student designs using metrics and judges to determine which product is considered the most creative. They developed a critical survey that provided, along with a comparison of prominent creativity assessment methods for personalities, products and the design process.

In each of these sets of design experiments, the participant designers are selected after one final solution after evaluating all the solutions generated during that session. Two groups, each consisting of two experienced designers,

Table 6 Measure of creativity

	Experienced				Novice			
	Dh	Ne	Si	Ch	Bh	Sh	Su	Vi
Novelty rank	6.25	6.25	4.25	4.25	2.25	4.25	6.25	2.25
Usefulness rank	8	7	2	4	2	4	1	6
Creativity value	50	43.75	8.5	17	4.5	17	6.25	13.5
Creativity rank	8	7	3	5.5	2	5.5	1	4
Average	Experienced			5.87	Novice			3.12

assessed the creative outcomes from each design experiment, using the creativity measurement method proposed by Sarkar and Chakrabarti (2011) as discussed in the last paragraph. The novelty and usefulness of the final designs were assessed, and using these data, creativity was assessed (see Table 6). Table 6 shows that designer 'Dh' has the highest creativity, while designer 'Su' has the lowest.

Table 6 shows that the average creativity of these experienced designers were substantially high compared to that of the novice designers. The average creativity value of the experienced designers is 5.87; the same for the novice designers is 3.12. This hints that experience often has a positive effect on the creative outcome of an individual (other researchers such as, Maher et al. (1995), Amabile (1997), and Kletke et al. (2001) also conveyed similar statements), however, to find out deep relationships, if any, further analysis is conducted as discussed below.

We investigate how creativity of designers affects their design outcomes. For this, we assess the correlation between 'the number of different types of searches found by the designers' and 'the novelty, usefulness, and creativity of the final selected solution,' in each design session. Among many possible correlations among search types and novelty and usefulness, only major correlations are shown in Table 7, which shows that search occurring at the higher levels of the search hierarchy (e.g., new and global search) influences novelty of the outcome. Searches at the lower levels of hierarchy influence usefulness of the outcome. The creativity of the outcome is influenced by the total number of searches occurring in each phase of conceptual design, both individually and combined together.

Table 7 Correlation between novelty, usefulness, and creativity ranks with searches

(Total number of) Global problem searches–novelty	0.89 ($p < 0.01$, very high correlation)
(new, global, and local problem searches)–novelty	0.85 ($p < 0.01$, very high correlation)
Global solution searches–novelty	0.65 ($p < 0.05$, medium correlation)
(New, global, and local solution searches)–novelty	0.67 ($p < 0.05$, medium correlation)
Global evaluation searches–novelty	0.61 ($p < 0.1$, no correlation)
(new, global, and local evaluation searches)–novelty	0.61 ($p < 0.1$, no correlation)
Detailed problem searches–usefulness	0.65 ($p < 0.05$, medium correlation)
Detailed solution searches–usefulness	0.71 ($p < 0.02$, high correlation)
Detailed evaluation searches–usefulness	0.76 ($p < 0.02$, high correlation)
Problem understanding–creativity	0.73 ($p < 0.02$, high correlation)
Solution generation–creativity	0.76 ($p < 0.02$, high correlation)
Solution evaluation–creativity	0.57 ($p < 0.1$, no correlation)
Total searches of all types–creativity	0.76 ($p < 0.02$, high correlation)

7 Effect of creative problem-solving style on design outcomes

Analyses done in the previous sections are based on the outcome of the design experiment. Even the assessment of creativity of individuals as proposed by Sarkar and Chakrabarti and used in this work is also based on assessing individuals based on their creative outcome. In this subsection, we investigate whether designers' intrinsic abilities have any effect on the design outcome. For this, we use Kirton's Adaptive Innovative Inventory (KAI) on all participating designers (Kirton 1977) to assess one of the major intrinsic ability, the creative problem-solving style of the designers (see Table 8).

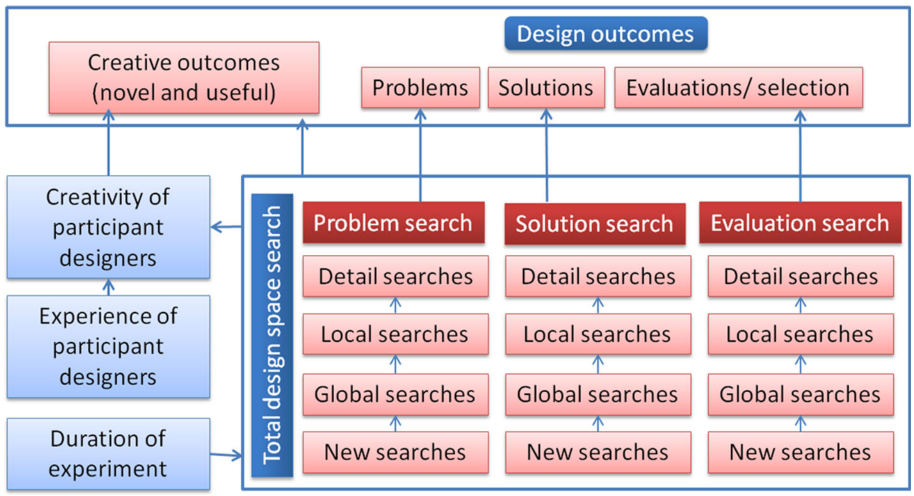
It was found that almost all designers involved are innovative in their problem-solving style (Table 8); thus, we are unable to map different creative problem-solving styles (viz. innovators and adaptors, as proposed by Kirton 1977) with design outcomes. One possible explanation for this observation is that product designers are generally innovative. Similarly, Kirton mapped people with different occupations in the USA, UK, and Europe, and found that engineers have an average KAI score between 95 and 97,

Table 8 Searches in the main design experiments

Designer	Abbreviation	Experienced				Novice			
		Dh	Ne	Si	Ch	Bh	Sh	Su	Vi
Experiment no.		1	2	3	4	5	6	7	8
KAI score		105	108	99	95	105	105	105	118

Score interpretation: score less than 96 ‘adaptive,’ more than 96 ‘innovative.’

Fig. 5 Influence diagram



R&D managers have KAI between 101 and 103, and people involved in fashion have KAI between 104 and 110 (Kirton 1977, 2012).

8 Influence diagram

Influence diagrams are visual representations showing how different factors influence one another, in a decision-making system. The results of the experiments, as described above, indicate that creativity is influenced by several factors such as total number of searches (including the number of solutions, Sect. 3.3), amount of time spent in solution generation (Sect. 3.8), and experience of the designers (Table 6). Based on these findings, we can create an influence diagram for creativity, as Fig. 5, showing how different factors affect the design outcomes and creativity, as observed in this work.

9 Discussion and conclusions

Shalley and Gilson (2004) state that many factors affecting creativity have been identified in literature; however, it is still unclear which of these are major influences. While some factors such as *fluency* and *flexibility* (Torrance 1979) have been proposed after empirical studies, others (such as *being able to predict outcomes* or *bureaucratic procedures*) are based on logical arguments only (Sarkar and Chakrabarti 2008). Given the amount of time and energy required to influence each factor, it is not feasible for a company or individual to work on all the factors. The work reported in this paper highlights some of the important factors (that is, amount and types of search, duration, and experience) that affect the creative outcome of designers.

Within the limitations of the think aloud protocol analysis method (Cross et al. 1996), the number of experiments conducted (16 experiments, 8 initial, and 8 main), the number of designers participated (14 designers, 6 in initial, and 8 in main), the amount of time per experiment (an average 60 and 77 min of length for each initial and main design experiment, respectively), and the limited number of problems used (2 for initial and 2 for main), we were able to investigate influences of only some of the factors on designing and its creativity aspects.

The findings in this research work are summarized as below:

- It has been found that search of design spaces takes place in all phases of conceptual design, where designers search these spaces to identify related problems, generate solutions, and identify associated evaluation criteria.
- During designing, designers enter a new design space through the generation of an idea.

- It was also found that there are four types of search, 'new,' 'global,' 'local,' and 'detail' that take place in each phase of conceptual design. These searches influence each other in all phases of design. These can be interpreted as follows: designers who find many design spaces have an increased possibility of developing a large number of solutions.
- The searches influence both the quality and quantity of the designs created.
- Occurrence of higher-level searches (new and various ideas) in the hierarchy seems to enhance the occurrence of lower level searches (more number of detailed ideas).
- Finding generic problems, solutions, or evaluation criteria (e.g., 'new' and 'global' search) should help in finding specific problems, solutions, or evaluation criteria (e.g., 'local' and 'detail' searches).
- It is also observed that searches occurring at the higher levels of the search hierarchy have a major influence on the novelty of the outcomes. This is further supported by the findings of Srinivasan and Chakrabarti (2010) work, which indicates that novelty of concept space is dependent on its variety.
- Searches at the lower levels of hierarchy (more number of detailed ideas) primarily influence the usefulness of the outcomes.
- The creativity of an outcome is influenced by the total number of searches (many different detailed ideas) occurring in each phase of conceptual design, both individually and taken together. This understanding could be used to make search more efficient at the initial phases of design, if the focus of the design is known—whether on novelty, usefulness, or both (creativity), thus controlling the outcome.

In some way, the results support that presence of certain personal abilities aid creative outcomes, as identified by Torrance (1979) who later developed Torrance Tests of Creative Thinking (TTCT). These abilities are as follows:

(1) Fluency: the ability to produce a large number of ideas (total searches positively influences creativity, see Table 7).
(2) Flexibility: the ability to produce a large variety of ideas (presence of ns and gs—see Table 7).
(3) Elaboration: the ability to develop, embellish, or fill out an idea (presence of ds—see Tables 3 and 7).
(4) Originality: the ability to produce ideas that are unusual, statistically infrequent, not banal, or obvious (presence of us—see Sect. 3.2–3.6).

For instance, following Torrance's work, if fluency is expressed in terms of the total number of ideas or the total number of searches, then fluency influences the creative outcome of an individual. Additionally, if we map novelty and value (or usefulness) also, we find that novelty is influenced by originality (new solution search), fluency (all solution searches), and flexibility (new, global, and local solution search), whereas value (usefulness) is influenced by the designers' fluency (local solution search) and elaboration (detailed solution search).

Yamamoto et al. (2009) attempted to capture the nature of concept generation process by finding an effective thinking pattern for creativity. They considered design spaces that are made of a chain process of concepts that are both explicitly evoked in concept generation process and inexplicitly imagined as a thinking space. First, they refer to the structure of the space, and second, they refer to the latent concepts in that space. They found significant correlation between the structure and creativity. Additionally, Harakawa et al. (2005) found strong relationships between extension of thinking during designing and the level of creativity in the ideas generated; they expressed that extension of thinking space is also a structural feature, and it strongly affects creativity. To some extent, new and global spaces in our work refer to 'structure' in Yamamoto et al. (2009) work, while local and detail searches refer to extension of space in both the above works. As stated by these above two researchers, creativity is enhanced both by the finding of space and its extension; however, in our work, we find a more detailed reason for it. Novelty is influenced predominantly by the new and global space findings, and usefulness is by the local and detailed space findings (from Table 7, new, global, and local problem searches and novelty: 0.85 ($p < 0.01$, very high correlation)). Since creativity is a product of both novelty and usefulness, creativity is affected in both the cases (from Table 7): 0.76 ($p < 0.02$, high correlation).

This study indicates that the creative quality of design outcomes is positively influenced by the total number of searches, amount of time spent in designing, and experience of designers. Thus, to enhance the creative quality of design outcomes, the following could be considered:

- Encourage designers to generate a large number of problems, solutions, and evaluation criteria related to the given set of requirements. Gelsey et al. (1998) suggested that automated search of a space of candidate designs seems an attractive way to improve the traditional engineering design process.
- Encourage designers to spend adequate amount of time in solving the design problem.
- Consider having more numbers of experienced designers. Importance of experience in design has also been echoed by several researchers, such as, Kletke et al. (2001), Amabile (1997), and Maher et al. (1995).

Acknowledgments We acknowledge the help received from the participant designers.

Appendix 1: Terms related to design space search used in the analysis of design experiments

The characteristics of different kinds of search are shown below. The following design problem is used to illustrate these: Design a drilling machine that can drill a hole of variable diameter in a metal block in any direction and capable of changing its direction even while the drilling is going on inside the block (problem 2, Sect. 3).

Solution generation

Product or idea characteristics can be expressed in many ways, such as technical specifications, feature listing, and others, which are specific to the type of product. A widely used model for expressing product or idea characteristics is by means of its function, behavior, and structure (FBS) (Qian and Gero 1996; Umeda et al. 1996; Goel 1997). The SAPPhIRE model of causality—a detailed model of causality developed by Chakrabarti et al. (2005)—was used for clustering the solution-related searches. Its elementary constructs are as follows: *Action*: An abstract description or high-level interpretation of a change of state, a changed state, or creation of an input. *State*: The attributes and values of attributes that define the properties of a given system at a given instant of time during its operation. *Physical phenomenon*: A set of potential changes associated with a given physical effect for a given organ and inputs. *Physical effect*: The laws of nature governing change. *Organ*: The structural context necessary for a physical effect to be activated. *Input*: The energy, information, or material requirements for a physical effect to be activated and interpretation of energy/material parameters of a change of state in the context of an organ. *Parts*: A set of physical components and interfaces constituting the system and its environment of interaction.

New solution search (ns)

Designers commonly use solutions from their past knowledge while solving a current problem. In some cases, however, a designer might generate solutions that are not from any knowledge base available or known to them. The number of such cases is very few (see Table 2). New—what is not familiar or known (CUP 2013)—is used to describe these new solutions that were previously new to the designer. A new search is characterized by one or more of these:

- Occurs when a designer finds a new solution, while searching a previously new solution space. To identify these cases, a designer could also be asked whether or not the generated solution were previously known to the design as a solution for any other problem
- Ideas generated are not presearched, i.e., the designer did not have any previous idea about any possible solution of any problem which lies in that space
- Search is characterized by identification of a new function or action. That is, when compared with function of other products, the function of recently generated solution is not found in any other product
- The term ‘new’ is used to mean that the design space is ‘new’ or ‘new’ to the designer(s). Thus, the solution is a new solution to the designer.

Example: ‘Use 3D lasers (fitted outside a block) from multiple directions to burn soft material inside a closed hard block.’ That such a technology could be used for this purpose was ‘new’ to the designer. Laser technology exists, however, that multiple lasers could be focused in one point inside a hard block to remove material without damaging the external block did not exist at that time and the designer did not know of such a system. The aim here is not to see whether it is viable (that would be done during evaluation) but to see whether it could be a potential solution.

Global solution search (gs)

Global solution searches are carried out when a designer generates a solution that is new for the current problem; however, they are known to the designer while solving a previous problem in the past or are available in the literature. Designers often modify a past solution before considering that as a solution for the current problem. A global search is characterized by one or more of these:

- Occurs when a solution is generated through the search of a global solution space. The designer might have modified the solution after retrieving it from that space. The solution belongs to a new global solution space, i.e., it does not belong to any previously visited global solution space during the same experiment, but is from previously available knowledge or experience. Thus, it creates a new idea through global search (from global search spaces)
- Search is recognized by a new solution belonging to a new domain or a change in perspective
- New solution created is different from other previous solutions in terms of ‘state change,’ ‘input’ ‘physical effect,’ ‘physical phenomenon,’ ‘organ,’ and ‘parts.’

Example: ‘Use microrobots to cut inside the block.’ The designers expressed this idea by drawing a small robot connected with wires, inside a block. Robots have been used in manufacturing industry in many countries; however, it was a global search for the designer since such an idea was used for the first time in solving this particular problem. The solution as such is not novel but the solution is different from previous ideas in terms of 'state change,' 'input,' and others.

Local solution search (ls)

- Local search takes place when a designer searches within global and new search spaces. Local search is characterized by one or more of the following:
- New idea is generated through search of a local search space.
- Since a local search space is within a global search space, the idea generated is similar to other ideas generated earlier in the design in terms of its 'input' and 'action,' however, different in its 'physical effect,' 'physical phenomenon' 'organ,' and 'parts' used.

Example: 'Use of remote-controlled microrobot drilling system.' Here, the designer uses a new physical effect for this solution. The initial solution was using microrobots for drilling inside a metal block with wires attached to it. Now, the designer wishes to use wireless technology instead of physical wire to move this robot inside the block (possibly the designer is envisaging that the wires might get tangled easily).

Detail solution search (ds)

Detail search takes place when a designer searches within local search spaces making the idea more detail in terms of the physical description of the components and how they are suppose to work, thus making the description of a solution richer. Detail search is characterized by one or more of the following:

- A new idea is created (or modified from a local idea) through searching in detail a detail search space.
- Solutions generated are similar to those in a local search in terms of the 'state change/action' and 'physical phenomena' and 'physical effects,' but are more detailed, and it looks as if one has zoomed into the space to have better clarity on a small set of ideas. Difference is only in terms of 'organs' and 'parts.'
- This search is identified when there is a partial change in the structure, addition of another structure, or modification of the same structure to fulfill other subfunctions.

Example: '…use microrobots that is fitted with a crawler, have three stepper motors for three axis movement.' Here, the designer detailed a solution that has already been generated earlier. Previously, the designer has only expressed the intension of using microrobots fitted with wire for removing material from a block (global solution search). Next, the designer replaced the wire with wireless connection (Local solution search). Now, the designer is detailing the components to be used in the microrobot (by sketching and by verbally expressing).

Problem understanding and problem clarification

New problem search (np)

'New problem search' occurs when a new problem or requirement is found that was not found in relation to any other previous problems or occurs when a designer finds a new problem while searching a new problem space. An example is: 'It can be called a cavity maker.' Here, the designer has found a generic problem by generalizing the problem to him. Another instance: 'I have to make an object with no material in certain part.' In this case, it seems that the designer has inverted the given problem. Instead of removing material from a block, the designer is thinking of creating a block which does not have material in certain places thus achieving the desired shape.

Global problem search (gp)

'Global problem search' occurs when a new problem is found through searching of a global search space. It is characterized by a 'chronologically' new problem found by the designer. That is, the problem is searched for the first time while solving this problem. The problem may be not 'purely' new, i.e., the problem can be given in the requirement list, the designer may have already encountered this problem in the past, or problems of such type are already solved by other designers in the past; however, it has been used for the first time during this particular design process. An example is: 'The drilling process is not about drilling circular holes; it is (about) removing material in straight direction; not even straight it is about removing in any direction.' 'We need to drill hole in 3D.' Here, the designers are finding new problems that they have not found sill that time of the design experiment.

Local problem search (lp)

'Local problem search' occurs when a problem is searched within a global search space or some other specific requirements found. Example: 'It should be able to change the drill also.' In the transcript, this statement appears after the statement. 'We need to drill hole in 3D.' The designer is trying to search associated problems with the 'global problem search' as part of requirements during the design process.

Detail problem search (dp)

'Detail problem search' occurs when subproblems are found within a local or global problem space, or any expansion or modification of a previous requirement (problem) is found. An example is: 'The drill can rotate like this (shown using hand movement in the video) and should be able to position itself.' This statement appears in the transcript after the statement 'It should be able to change the drill also.' In this case. designer is detailing how exactly the designer wants to move the drill.

Solution evaluation

New evaluation search (ne)

New evaluation search is characterized by identification of a new evaluation criterion, of which the designer was not previously aware.

Global evaluation search (ge)

Global evaluation search occurs when some general evaluation is done, or general evaluation criteria are introduced. The criteria may already have been provided in the problem or developed during problem understanding. Examples: 'I am thinking practical difficulties that we would be facing such as machining.' Here, designer has used a new evaluating criteria 'possibility of machining' or 'manufacturing feasibility.' This evaluating criterion is known to the designer; however, during this particular design process, the designer has mentioned this evaluating criterion for the first time; thus, this evaluating criterion is global evaluation search.

Local evaluation search (le)

Local evaluation search occurs when an evaluation is carried out within a global evaluation search space. An example is: 'Now, I will try to remove some designs which are difficult to make with the available technology.' This statement appears in the transcript after the statement 'I am thinking … such as machining' (global evaluation search). Here, the designer has found some evaluation searches related to that of 'machining.' Here, the designer adds other available technologies of making a product to 'machining' as an evaluating criterion to judge which design is feasible to be made (produced).

Detail evaluation search (de)

Detail evaluation search takes place when subevaluations are found with a local or global evaluation space, or only a single idea is evaluated in detail, for example, 'The electric motor is more efficient.' Here, the designer is finding an evaluating criterion for evaluating drives used in the design of a microrobot. These microrobots are being evaluated for its feasibility of machining with available technologies. Thus, this evaluating criterion 'efficiency of drives' is within another evaluation search space here 'machining feasibility.'

Other categories

Apart from the above different types of searches, several additional categories are used to code and analyze the protocols to foster a greater understanding of the design process. These are as follows:

Agree

These types of utterances occur when a designer agrees with another designer(s). Examples: 'Yes,' 'I understand,' 'ok fine.' We believe that when one agrees with, or understands the idea generated by the others, one will explore the possibility of generating other ideas based on that, or build upon that idea, or try to search similar design spaces.

Disagree

During designing, a designer might disagree with other designers. These statements are classified as 'disagree.' Contrary to agreeing, if one is not willing to accept an idea, it is unlikely that one would explore or modify the idea further to generate similar solutions. Examples: 'I do not agree,' 'may be,' or 'but I think that the previous idea was better.'

Clarification

Clarification consists of statements that designers use to understand each other or to know their next action. This is general clarification. General clarification includes statements pertaining to ideas generated by other designers, clarifying, or questioning the idea in order to understand it better. Examples: 'You should have drawn this in 3D,' 'what do you mean by this (statement)?'

Method clarification

These consist of clarifying the process that should be followed during the design experiment, including any clarification regarding the aim of the experiment or the use of tools such as a paper, or a pen during the experiment. Examples: 'Should I read the entire problem first?' 'You need to be bit louder,' 'can I evaluate during solution generation or should I finish it and then evaluate?'

Selection

When someone selects an idea after evaluation, the statement can be taken as a selection. Examples: 'I consider this idea,' 'this solution is fine' (pointing to a sketch), 'for the time being I will consider this one.'

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