NordDesign 2006
August 16 – 18, 2006
Reykjavik, Iceland

Exposure Effects in Design Idea Generation: Unconscious Conformity or a Product of Sampling Probability?

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Abstract
The process of idea generation in engineering design is sensitive to many internal and external factors. External representations, such as previous designs, are often issued to designers to strive creativity and productivity through cognitive stimulation. However, past research has shown that examples may cause a negative effect known as design fixation, which limits the diversity of idea production. In this paper, we highlight two opposing explanations for why examples limit the diversity of idea generation, which are that designers unconsciously conform to examples or that examples exhaust the pool of possible solutions before the search has begun. We provide a critical review of theory and empirical research on effects of examples, and present a study that combines several methods of behavioural analysis to illustrate the effect of examples in the idea generation process of sixteen senior students of mechanical engineering. The discussion reflects the findings of the study to the existing body of evidence concerning exposure effects in design idea generation.

Keywords: Idea generation, design fixation, protocol analysis.

1. Introduction
Design research has been concerned with the effects of examples on idea generation performance, since examples are thought to e.g. stimulate the generation of additional ideas. Despite this intention, experimental studies have shown that designers may become fixated on the principles and features represented in the examples, which reduces the flexibility and originality of self-generated designs. Jansson and Smith [16] were the first to demonstrate fixation experimentally in engineering design. The finding was that features, similar to those in the examples, occurred at a higher rate in exposure subjects' designs in comparison to the designs produced in a control group, in which subjects received only a problem statement. Indeed, Jansson and Smith [16] made a convincing case that design fixation occurs and hampers with idea productivity. As a result, researchers often acknowledge fixation, resulting from exposure to examples, as a significant hindrance to design work. Despite these seminal findings, there are conflicting theories on what mechanisms underlie fixation in generative tasks [see e.g. 25, 39]. Up to this date, there has been relatively little progress in explaining

how and why examples affect performance in design idea generation. To unravel this indecision, we review existing theory and empirical studies on fixation-like effects in idea generation. This discussion will converge into highlighting two opposing explanations for why examples limit the diversity of idea generation, which are that subjects unconsciously conform to high-level attributes of examples or that examples exhaust the pool of possible solutions before the search has begun. We will start by reviewing theories of fixation and prior empirical studies. Then, we will present an experiment that was intended to decide between these two explanations.

2. Theory and research

2.1 Fixation in insight problem-solving

Fixation effects were originally studied in the context of insight problem-solving [24]. Insight problems are well-defined problems with single solutions [28]. A characteristic solution pattern in insight problem solving is that initial solution attempts end up in an impasse, and further work on the task (or time off) will result in a sudden revelation (i.e. an "insight") of the solution. The patterns that may cause the impasse are the general forms in which fixation may occur [17]. Three general patterns of fixation are typically considered: functional fixedness [10], mental set or Einstellung [22, 23], and memory blocking or mental-rut [42]. The pattern that causes the impasse for a given situation depends on the type of insight problem. Fixation-effects are often studied by exposing half of experimental subjects to a negative example (or prime), and comparing their performance to a control group that receives no such stimulus. Negative examples include e.g. function-demonstrations, false words, and limited problem representations in respect to the type of insight problem in question. Irrespective of the particular pattern, negative priming has been shown to lengthen time-to-solution, albeit the majority of subjects are eventually able to solve the problem [e.g. 1].

2.2 Design fixation as reproduction

Jansson and Smith [16] were the first to report fixation-like effects in the design process. Their report was the first time that fixation was demonstrated and made public in creative problem solving. After discussing the concepts of functional fixedness and fixation as mental set, Jansson and Smith [16] stated that the intention of their research was to "…investigate the role of similar phenomena [fixation in insight problem solving] in the conceptual engineering design process". They developed a scheme in which half of the subjects were exposed to a pictorial example design prior to idea generation, while the other half of the subjects received only the problem statement. The arrangement was therefore similar as in the studies on insight problem solving. As mentioned earlier, the major finding, replicated for four different design problems, was that features of the examples remained at an abnormal rate in the exposure subjects' designs. In this study, the design fixation effect occurred also for experienced designers, and was prevalent even in cases that the designs included features that were flawed to begin with. Smith et al. [41] extended the findings of Jansson and Smith [16] to more open-ended tasks as well (see also [25]). In a series of three experiments, they asked subjects to generate novel instances of toys and imaginary creatures, while imposing some participants to examples prior to idea generation. The major finding, replicated in all three experiments, was again that examples constrained the features of subsequent ideas. In the closing section, Jansson and Smith [16] focused more on questions than answers, which left the theoretical underpinnings of design fixation open for debate and further experimentation. However, they did state that "Designers can see new configurations based on what they know, not on things they do not know …design fixation…should probably be seen only as that which prevents the consideration of all of the relevant knowledge and experience which should be brought to bear on any given problem". A reasonable interpretation of this statement is that they meant that design fixation relates mostly to having a limited focus on the problem space (i.e. mental set), as opposed to saying that designers do not have 'prior information' that can be exploited as such to solve the problem, which undermines the effect of functional fixedness.

Purcell et al. [37-39] have performed several exposure experiments using design problems from the Jansson and Smith experiments. The general motive of these studies was to determine whether designers become fixated on conceptual or visual features of the examples, and how exposure effects relate to the background of the designer. Perhaps the most interesting finding of these studies is that fixation effects were observed only with example designs that "…include principles which are a part of the expertise of the designer involved" [37]. In these studies, reproduction occurred mostly at the conceptual abstraction level i.e. the subjects were not fixated by the physical properties of the pictorial examples, but by more abstract principles. Furthermore, in one of our exposure studies we showed that reproduction was highest when examples included ideas that were statistically common [36], which further strengthens the link between exposure effects and established knowledge structures. The notion of familiarity with examples (e.g. [37]) was also adapted by Finke [11] who proposed that design fixation was "…a tendency to structure new creations according to familiar forms" (see also [41]). Finke linked the concept of design fixation to the theory of Structured Imagination by Ward [44, 45]. Structured imagination refers to the notion that "…when persons are asked to develop new ideas those ideas are heavily structured based on properties of existing categories and concepts [45]". Similarly, other design studies have reported that subjects, experts in particular, tend to attempt to match the current problem to parallel design problems that they have previously encountered [20]. Familiarity with a problem class also depicts that a subject is familiar with particular solutions within that class. This notion could explain the findings that reproduction of example features occurs mostly with examples that are typical and familiar in respect to a designer's background. Taken together, design fixation, in terms of reproduction of example features for subjects with an engineering background, seems to occur unconsciously at a conceptual level, and only with example designs that contain typical principles of the subject's domain. Therefore, differences between source and target structures emerge only at a detailed attribute level. This type of fixation is later referred to as "unconscious conformity".

The mechanisms that cause fixation in insight problem solving (see section 2.1) are thought to underlie also the fixation effects found in generative tasks. However, it should be noted that functional fixedness as such, is not a likely explanation for the conformity effects observed for design problems. The reason is that objects that are brought-to-mind in a given situation are evidently a sub-set of the objects that could be used to solve parts of the design problem with their ordinary functions. Thus, fixation is likely a question of accessibility rather than a question of limited knowledge of objects that afford specified task-relevant functions. Furthermore, the explanation given by Smith et al. [41] was that initially activated information - retrieved from ones own memory or given as external stimuli e.g. in the form of examples – may inhibit the retrieval of other task-relevant items. This mechanism is similar as to the memory blocking effect as demonstrated by Smith [42], which states that fixation occurs through simple response competition i.e. retrieval of further ideas from memory becomes blocked per se due to the inability of 'forgetting' experimenter-provided examples whose activation is strengthened due to heightened accessibility. However, a simple heightened activation theory cannot explain specific findings from the exposure studies (see [25] for further discussion). Even more, the notion that the activation of externally provided examples would be heightened above a level of e.g. category exemplars, is rather weak, given the fact that examples are usually somewhat arbitrarily chosen, and as a result, may or may not be 'memorizable' for subjects. Thus, if fixation operates according to the patterns observed in insight problem solving, then the remaining explanation for design fixation is that examples affect the mental problem representation of the subjects i.e. examples induce a particular mental-set [23] that may limit the problem space [30] in which solution search takes place. This type of fixation should be relatively easy to avoid, simply by exposing subjects to two or more heterogeneous solutions, which represent different models of the problem.

Chrysikou and Weisberg [6] provided some further explanations to the concept of design fixation. After demonstrating the occurrence of design fixation in a group of undergraduate psychology students, they proposed two explanations of why design fixation persists. The first was that subjects may have followed a case-based other than a model-based (or rule-) approach, which relates to the difference between being influenced by particular features of examples or by the higher order functions that those features represent. The fact that subjects reproduced physical features of the pictorial examples (i.e. followed case-based reasoning) in the Chrysikou and Weisberg [6] study contradicts the findings of Purcell et al. [38], who suggested that designers were only fixated by the more abstract properties of the examples. However, this may have been a result of the simple fact that Chrysikou and Weisberg [6] used subject that were naive to design. The second explanation was that fixation effects might be accounted for by a concept known as cryptomnesia or unconscious plagiarism, defined as "…participants' tendency to reproduce involuntarily previously seen ideas, words, solutions to problems, or examples, with the belief that they are either entirely original or at least original within a given context [3]". This explanation seems especially valid when considering the fact that subjects reproduced example features that were faulty to begin with, a similar finding was observed also in the Jansson and Smith [16] and Purcell et al. [38] experiments.

We have however some concerns about the general notion that design fixation is truly an unconscious effect, which seems to be the main hypothesis held by the experimenters presented above. Studies dealing with creative generation and plagiarism (e.g. [26]) that have shown traces of inadequate source-attribution have used recognition tests in which subjects are retrospectively (i.e. after the idea generation session) asked to determine the original source (e.g. self-generated, given as examples, suggested by others) of ideas that occurred during the session. Hence, these tests have not explicitly focused on the type of 'immediate' plagiarism that is relevant in an exposure context. Even more, in a study by Landau et al. [18], manipulations that increased source monitoring in a generative task, decreased conformity effects with examples. Most importantly, these conformity-reducing experiments included a manipulating the physical presence of the examples. In common terms, if the examples are present during the duration of the idea generation session, then subjects may be able to avoid unconscious conformity. The studies that have led to the conclusion that design fixation results from unconscious conformity, are based on experiments that assess only documented output (not process), and include limited exposure settings i.e. one example shown before idea generation. Therefore, these studies reveal relatively little about the behavioural aspects of idea generation, which however can be captured by observatory research methods such as verbal protocol analysis. An exception was the Chrysikou and Weisberg [6] study, but they only applied protocol analysis to ascertain whether subjects paid attention to and understood the verbal task instructions.

There is a further key-point to make regarding reproductive tendencies and the complexity of design problems. Some design problems are too complex to be approached ‘head-on’. This does not mean that complex design problems cannot be solved, but those problems need to be confronted by first decomposing the problem into manageable parts, and then solving the problem one sub-system (or sub-function) at a time. The exception is that a designer may possess prior complete models that can be e.g. analogically transferred [2, 5] and adapted to solve the current problem [34]. However, in the absence of such complete models, or after they have been exploited, the designer needs to assemble designs from fragmented chunks of knowledge, i.e. follow a sub-target oriented strategy to solve the problem. Furthermore, we remark that designers may only generate partial solutions and re-produce the other sub-systems from prior solutions to make a fully functional design description. The way that this affects results of exposure studies is that when common engineering principles are present in the examples, a subject may simply reproduce them in follow-up designs, because they represent a usable sub-system. In such a case, reproduction is not a product of unconscious conformity, since the designer deliberately re-uses parts of earlier solutions, and indeed, makes progress in his design work, even if that progress involves only an alteration to a sub-system of the design. Of course, this depends on the specific principles included in the examples, but this notion may well explain, at least partially, why designers reproduce some parts of the example designs.

2.3 Design fixation and productivity

An important question that remains is how severe is the design fixation effect on productivity of idea generation. Hence, it should be acknowledged that design fixation, if it exists and is to be found harmful, needs to limit the flexibility of idea generation. Flexibility in design idea generation may best be assessed by summing the number of different principles for primary sub-functions (e.g. [33, 40]). Unfortunately, performance in exposure studies is usually assessed by a simple count of designs, which does not measure this performance aspect. However, it seems likely that the difference in flexibility (non-redundancy eliminated) between exposure and control subjects would have reached statistical significance in these studies. Moreover, the studies presented above have focused on the very first steps of idea generation (total productivity has ranged from about three to four ideas), and therefore, the studies have not evaluated whether the design fixation effect diminishes e.g. as a function of time-on-task or cumulative output. Indeed, as will be discussed next, idea generation seems to possess a temporal characteristic pattern that questions the severity of the design fixation effect.

Ward has extended his theory of Structured Imagination (see page 3) to include the Path of Least Resistance model [44, 45]. This model states that, in creative generation tasks (i.e. idea generation), subjects will first produce category exemplars that are most easy-to-access. This notion has broad scale implications e.g. regarding the commonality of initial responses. If we turn the focus back to engineering, we would assume that designers possess some knowledge structures specific to the objects and actions of designing. There is no penalty for using existing designs in idea generation, in case they are not explicitly forbidden. Indeed, new design problems often share at least surface-level similarities to prior ones, and therefore, designers may be able to generate some ideas from ‘the back of their minds’ with relatively little cognitive effort. Now, the interesting notion is what happens after these initial ideas are explored. In one of our experiments we showed that the categorical novelty of ideas increased as the session proceeded, while the sheer quantity and number of ideas from new categories declined respectively [35]. A similar pattern has been observed for the number [15] and commonality of ideas [7] in non-design idea generation. These findings therefore propose an evident pattern; subjects first access the most common ideas and then move on to search for more distant concepts and knowledge.

As some solutions are easier to generate than others due to high accessibility, and because solution search needs to take more novel paths as the initial models are exploited, a somewhat evident statistical conjunction occurs in regards to exposure effects. That is, if examples include common and easily-accessible ideas that, according to probabilities, would have been generated also without exposure, the exposure group is put to a less-favourable position in comparison to the control group on statistical grounds alone. In other words, exposure subjects will miss the opportunity to add solutions to the idea-pool, because examples 'pre-exhaust' their solution space. We tested this prediction in one of our studies, in which, half of the subjects were given various examples beforehand, while the other half received the examples after twenty minutes into idea generation [35]. The difference in the total number of non-redundant categories surveyed (i.e. diversity of idea production) was significantly lower for the ones receiving the examples beforehand. We called this the sampling probability effect, and proposed that it is a further explanation for why examples limit the diversity of idea production. However, in this study, the subjects did produce ideas from some solution categories represented in the examples, but as we did not use protocol analysis, we were not able to evaluate whether this tendency was a result of e.g. unconscious conformity.

2.4 Cognitive stimulation

All effects related to solution examples are not negative. Recent theories predict that examples may stimulate the production of ideas through associations between external cues and internal knowledge structures. The idea is that examples provide cues that may help a designer to think of ideas that he would not have thought of if he had worked alone (see e.g. [4, 31, 34]). Pictorial examples are rich displays that contain e.g. contextual and semantic features, which may trigger the designer to attain knowledge structures relevant for the current task. However, past findings declare that examples do not promote remote associations at a level that would be statistically quantifiable from the flexibility of total session output [19, 35, 46]. In other words, the stimulation value of examples does not overrule the negative exposure effects i.e. unconscious conformity and/or the sampling probability effect. Nevertheless, it seems that favourable associations resulting from external stimuli are relatively common (see e.g. [13]). Thus, the notion that examples may have a dual-effect on performance (i.e. interference and stimulation) needs to be acknowledged in exposure studies [8, 9, 32, 35].

2.5 Summary and study objective

We have identified two alternative explanations as to why examples limit the diversity of output. The first is that designers unconsciously conform to high-level attributes of examples. The second is that the diversity of idea production decreases through a statistical effect related to the sampling economy of familiar models. In the next section, we present a design experiment that was designed to distinguish between these two effects. The approach taken for quantifying exposure effects was to compare: (1) overall performance; (2) example category frequencies; and (3) the extent to which earlier ideas are consciously built upon (i.e. explicit linkage), between an example exposure and a control group. In addition, we included a qualitative analysis of exposure effects to analyze whether the examples stimulated the production of additional ideas.

The logic of the experiment was to first determine whether examples limited the diversity of original output, and then, to determine the influence of examples on the two other variables:

category frequency and explicit linkage. If only the former proposition (inferior diversity for exposure group) would come true, then this should be considered as evidence for the sampling probability effect. Whereas, if performance was limited along with a higher categorical conformity, then this should be considered as evidence that both factors may affect performance. Explicit linkage was assessed to find support for the premise that subjects may in fact reproduce features from examples, but they do this voluntarily, since earlier designs may incorporate usable sub-systems that can be exploited in additional designs.

3. Study

3.1 Participants

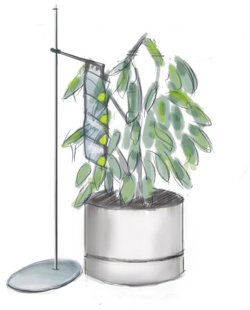
The participants of the study were sixteen predominantly male (one female) undergraduate students of mechanical engineering at the Helsinki University of Technology. Mean age was 27 (SD = 2) years. All participants had completed design related studies at the university level corresponding to a bachelor's degree, having on average completed 137 (SD = 42) study credits from 180 required for master's degree. 75 % (N = 12) of the subjects had more than half a year of design experience in practise. In exchange for their time the participants were given a small non-monetary reward.

3.2 Experiment design and procedure

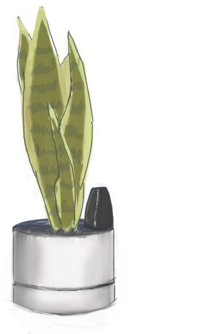
We used a between subjects factorial design. Subjects generated design ideas individually for a single design task, under a time-limit of 20 minutes. Participants were asked to generate and document as many different ideas as possible, and to defer judgement i.e. present each idea that came to mind. Participants were asked to think-aloud [12] during idea generation, their design work was also recorded on video-tape. There were two experimental treatments: one-half of the subjects were given four examples to be used during the task (exposure condition), whereas the other half performed the experiment without prior examples (control condition). The task assignment was the following:

> "Watering of house-plants is an easy task. However, when people leave on holiday or business, this task is often left to other persons. Your assignment is to generate as many different ideas as possible for an automatic watering device for house-plants. The device should provide a plant with about a decilitre of water per week - no more or less. The device should be able to water the plant for a minimum of one month."

The task was presented to the subjects by a two-sided written design brief. One side of the paper contained the written problem statement along with a short background description. The reverse side of the design brief contained either four example designs in the exposure condition or a picture of a house-plant in the control condition. The examples represented solutions that entailed a number of different solution principles i.e. the example set was heterogeneous in nature. Participants in the example condition were not given particular instructions on how to use the examples, but they were instructed not to replicate the examples as such. The four examples are shown in Figure 1; the materials were originally posted in Finnish, they were translated into English for the purpose of this article.

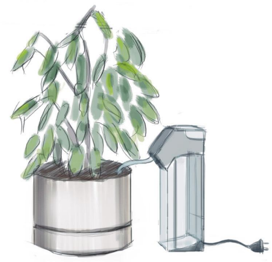


Example 1
Four water-bags hang from a stand. A bag is punctured when desired to release water to the plant.



Example 2
An ice-cube that is inside a thermostat-bag is inserted into the flower-pot. The ice-cube can be defreezed/freezed by changing the temperature of the bag to release water to the plant.

Example 3
A water-container is integrated to the flower-pot. The water slowly vaporises and saturates the mould through breathing-pipes.



Example 4
An electronic pump stands on the side of the plant. Watering is regulated by a timer.

Figure 6. Example designs for an automatic watering device for house-plants.

The examples shown in Figure 1 have some specific features. Examples 1 and 2 both have novel sub-function solutions; Example 1 includes separate cells for containing the water and in Example 2 the water is absorbed into a solid object (i.e. ice). These two examples propose only a partial solution since they do not include a solution for regulating the amount of watering. Example 3 is a passive device that simply vaporizes the water to the use of the plant. The difficulty with this design in practise is that the water might not become vaporised at a sufficient rate. Example 4 includes a typical engineering principle (to pump) for transferring the water from a separate tank to the use of the plant.

3.3 Measurement of overall performance

Three measures [43] were used to assess overall performance:

- The number of ideas (i.e. fluency) was defined as the number of ideas drawn in separate idea frames. The subjects were self-determined on the issue of how to distinguish between two ideas; we did not screen any ideas from the count, even if a subject had depicted only a partial solution in a separate idea-frame.
- The number of categories surveyed (i.e. flexibility/diversity/variety) was defined as the total number of solution categories represented in one’s idea set

- The number of non-redundant categories surveyed was defined as the total number of categories that did not overlap with the solution categories represented in the examples.

To yield a score for the number of categories surveyed, the solutions were classified into pre-defined categories. To accomplish this, we applied a solution classification scheme based on decomposing the overall function into primary sub-functions [33]. This is a suggested approach to assessing design solutions [40]. The following primary sub-functions were identified:

- Water source (SF1): Secure liquid for watering the plant;
- Regulation (SF2): Regulate the amount of watering (1 dl a week for one month);
- Transfer (SF3): Transfer water from the source to the plant;
- Energy source (SF4): Secure energy to operate the device.

These sub-functions are thought to represent independent and meaningful parts of the system. We have used this task and the corresponding decomposition scheme in our earlier studies [21, 34].

3.4 Measurement of categorical frequency
In the opening section of the paper, we discussed that design fixation is usually quantified by assessing the similarity of examples and generated ideas, and comparing whether example features remain at an elevated rate in the exposure groups designs in comparison to the control group. In this case, we assessed and compared categorical frequencies at the conceptual level between the two experimental conditions in respect to the classification scheme presented above. This assessment was done individually for all of the sub-solution categories represented in the examples (see Figure 1).

3.5 Measurement of explicit linkage
To assess the degree to which subjects consciously built upon earlier ideas (ones own or examples), we analysed explicit links within one's idea set In case the subject made an explicit reference to an earlier idea as he begun to generate an additional idea, the follow-up idea was classified as having one of the following three links, depending on the genealogical linkage [36] of principle features of a generated idea (i.e. target) and an attributed earlier idea (i.e. source):

- Part sharing: A follow-up idea is built on a previous idea, but includes one or more new principles to satisfy sub-functions.
- Modification: A follow-up idea is a modification of an earlier idea at the structural level. No new sub-function principles are included.
- Combination: A follow-up idea is a combination of two or more earlier ideas. No new sub-function principles are included.

We also assessed the total percentage of links within ones idea set This measure was attained by dividing the number of ideas with any type of the three explicit genealogical links (part sharing, modification, combination) by the total number of ideas produced. In the control condition (no example exposure) the first idea was removed from the count, since this idea could not naturally have been linked to any idea in the present context.

3.6 Measurement of cognitive stimulation

We examined the degree to which examples stimulate the generation of additional ideas as follows. A case in which a subject explicitly referred to an example just before generating an idea that represented one or more new solution principles (i.e. categories) was considered an indication that some aspects of the example stimulated a further idea.

4. Results

T-tests for pair-wise comparisons were used to assess the statistical significance of differences on the three clusters of performance measures between the example and control groups. Table 1 presents the results of these tests, along with the mean responses and standard deviations on items of overall performance, categorical frequency, and explicit linkage.

Table 1. Means and standard deviations of overall performance, categorical frequency, and explicit linkage per experimental condition, and results from two-tailed T-tests that were performed to assess the statistical significance of differences between the two experimental conditions. Statistically significant differences (95 % confidence level) are given in bold.

MEASURE	ITEM	EXPOSURE		CONTROL		STATISTICS	
		M	SD	M	SD	T	p
Overall Performance	Number of ideas	9.38	4.07	8.75	2.31	-0.33	0.75
	Number of categories	12.88	2.70	13.00	4.54	0.06	0.96
	Number of non-red. categories	6.00	2.00	13.00	4.54	3.74	**0.01**
Categorical Frequency	SF1: Separate tank	0.55	0.18	0.47	0.25	-0.70	0.50
	SF1: Integrated tank	0.12	0.12	0.12	0.09	0.04	0.97
	SF1: Separate cells	0.05	0.08	0.02	0.06	-0.83	0.43
	SF1: Absorbed into object	0.02	0.05	0.03	0.05	0.35	0.73
	SF2: Timer	0.10	0.12	0.16	0.20	0.63	0.55
	SF2: Mould-humidity (autom.)	0.16	0.13	0.24	0.21	1.58	0.16
	SF2: Not defined	0.31	0.18	0.23	0.34	-0.54	0.61
	SF3: Pumped	0.09	0.12	0.14	0.15	0.65	0.54
	SF3: Vaporized (passive)	0.01	0.03	0.03	0.06	0.79	0.46
	SF3: Drained	0.35	0.18	0.24	0.14	-1.42	0.20
	SF3: Not needed	0.13	0.11	0.17	0.15	0.69	0.51
	SF4: Mains-current	0.01	0.02	0.05	0.09	1.19	0.27
	SF4: Passive	0.61	0.17	0.48	0.25	-1.26	0.25
	SF4: Not defined	0.29	0.17	0.37	0.33	0.67	0.53
Explicit Linkage	Part sharing	0.37	0.16	0.31	0.18	-0.62	0.55
	Modification	0.13	0.18	0.20	0.18	0.73	0.49
	Combination	0.14	0.13	0.07	0.14	-1.20	0.27
	Total % of explicit links	0.64	0.14	0.57	0.26	-0.75	0.48

The statistical tests showed that the only significant difference between the two groups (exposure versus control) was on the number of new categories (i.e. non-redundant) surveyed; subjects in the exposure condition surveyed ideas from about 50 % less categories than subjects in the control group. Based on the logic of the study this result suggests that the difference in the diversity of idea production was a result of the sampling probability effect, since the difference between explicit linkage and categorical frequency was non-significant between the two experimental conditions.

Examples may also have stimulation value, so that some features of the examples may provide external cues that evoke additional knowledge sources. Thirteen cases were found in which a subject explicitly referred to a particular example just before producing an additional sub-function solution. Of the total pool of additional solutions generated in the exposure condition (N = 47), about one fourth (27 %) of ideas were therefore at least partially stimulated by the examples.

5. Discussion and conclusions

Design fixation, i.e. a tendency to conform to features or principles of example designs, is often cited as a significant hindrance to idea generation, which limits the diversity and originality of session output. Several studies have shown that when subjects are exposed to solution examples prior to idea generation, features of those examples remain at an elevated rate in following self-generated ideas. A common assumption is that subjects are unconscious of the fact that they are conforming to features of examples (e.g. [6]), which makes design fixation especially harmful, since subjects may perceive that they are making additional contributions even that they are actually conforming to earlier solutions. However, studies that have led to the conclusion that designers unconsciously conform to example features have been performed in rather limited settings using indirect research methods and performance assessment. To contradict the severity of the design fixation effect, we proposed that the diversity of idea production can be limited due to a further, or alternative, factor referred to as the sampling probability effect. This effect relates to the conception that if examples include solutions that have a high probability of emerging during idea generation also without exposure, then exposure subjects are in an inferior position in comparison to control subjects, since they miss the opportunity to add familiar and easily-accessible ideas to their solution-pool.

To distinguish between these two explanations, we compared idea generation behaviour and performance between an example exposure and a control group. The results showed that the only significant difference between the two groups occurred on the number of non-redundant categories surveyed, so that subjects who were exposed to four example solutions surveyed significantly fewer categories than control subjects who received only the problem description. Subjects in both groups built regularly on previous ideas, which was explicitly verbalized during the process, and generated a number of ideas from the categories represented in the examples, but there was no significant difference on these measures between the two experimental groups. Based on the experimental logic and these findings, it seems that the observed performance difference was a result of the sampling probability effect and not a result of unconscious conformity.

The results differed from earlier exposure experiments [6, 16, 38], so that, the exposure subjects' ideas did not include solutions from categories represented in the examples at an elevated frequency. There are several possible explanations for this inconsistency. First, the fact that the subjects were exposed to several alternative designs, instead of a single example (as was the case in earlier design studies) may have caused differences in the results. Second, in this study, the subjects produced significantly more ideas than in earlier studies, which could indicate that fixation effects are most influential in the initial stages of solution search, and diminish as a function of time-on-task. Third, effects of examples may be related to the size of the solution space, so that examples are less influential when alternative designs are relatively easy to generate, as was the case with the design problem used here. Fourth, here, we requested the subjects to generate as many alternative designs as possible and not to reproduce the examples; these specific task instructions may have caused the subjects to deliberately avoid reproducing the examples. And finally, unconscious conforming to examples may be prevalent with more latent attributes of prior designs (see e.g. [27]) than those that were assessed here i.e. basic functional conformity.

Despite the finding that there were no significant differences in behaviour or performance between the two groups in this study, other than differences on the number of new categories surveyed, it is misleading to commit to a statement that examples do not affect the idea generation process. In fact, there were several cases in which the subjects reflected their actions on the examples, whether it was structuring the search space away from the examples or making a decision to combine or re-employ parts from earlier solutions. Most importantly, there were clear cases in which some aspects of the examples stimulated the designers to think of additional ideas, indicating a positive influence of examples. Thus, when considering idea generation in a context that includes combining contributions, such as, real-life design projects, idea generation may even benefit from examples since they stimulate designers and propose a reference which helps to structure further solution search efforts. Despite the series of experiments dealing with exposure effects in design research and social psychology, we believe that further empirical and theoretical contributions are needed before we can make sound judgments on the use of examples. An approach that could further disentangle the influences of examples would be to consider exposure effects in alignment with the temporal patterns in which particular ideas emerge during idea generation.

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