DESIGN FIXATION TO EXAMPLES: A STUDY ON THE TIME DECAY OF FIXATION

Viswanathan, Vimal Kumar
San Jose State University, United States of America

Abstract

When designers fixate during an idea generation session, they replicate the features of any available example or their prior ideas. This paper presents an empirical study to understand the variation in number of novel ideas generated by designers during an idea generation session. Two research questions are investigated (1) Do number of ideas decay over time? and (2) does the fixation to an example design decay over time? A controlled experiment with two conditions using a peanut sheller design problem investigates these two questions. The participants in one condition are given a pictorial example in addition to the design problem statement. The percentage decrement in new ideas is explored as a function of time in both conditions. The results show a decrement in the percentage of new ideas over time. This result is in agreement with some of the prior studies. The quantity of new ideas also shows a very similar trend. However, the ideas derived from example in the Fixation group do not show this decay. In essence, these results show that when an example is available participants remain fixated to the example throughout the session and the fixation effects do not decay over time.

Keywords: Human behaviour in design, Design cognition, Design theory, Design fixation

Contact:
Dr. Vimal Kumar Viswanathan
San Jose State University
Mechanical Engineering
United States of America
vimal.viswanathan@sjsu.edu

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1 INTRODUCTION

In the engineering design community, there is a growing interest in understanding about design fixation. Literature considers design fixation as a cognitive block (Jansson and Smith, 1991). When designers fixate during an idea generation session, they tend to replicate the features of any immediately available example or an already generated idea (e.g., Cardoso and Badke-Schaub, 2011; Jansson and Smith, 1991; Viswanathan and Linsey, 2013a). Since the major aim of most idea generation activities is the generation of novel solutions to design problems, design fixation acts as a hindrance.

Recent empirical research has focused on various factors influencing design fixation during idea generation. Some of these include the modality of examples (Atilola and Linsey, 2005; Cai et al., 2010, Cardoso and Badke-Schaub, 2009a; Viswanathan and Linsey, 2013a), idea generation method employed (Linsey et al., 2012; Viswanathan and Linsey, 2012), expertise of the designer (Chai et al., 2015; Viswanathan and Linsey, 2013b), the commonness of features in the example (Chan et al., 2011; 2015), and the type of representations used for idea generation (Viswanathan and Linsey, 2012). A couple of recent literature review papers also explain the various factors influencing design fixation (Sio et al., 2015; Vasconcelos and Crilly, 2016).

While many existing studies look into the factors influencing the presence or absence of design fixation, not many focus on the progression of fixation during a single idea generation session. One of the most popular methods of inducing design fixation is the introduction of a fixating stimulus such as an example solution. Most of the studies find that the participants, in their designs, knowingly or unknowingly copy some of the features from the example. The studies investigating the time decay of this fixation to example ideas are scarce. One of the prior studies that investigate this issue is by Kohn and Smith (2011). This study shows that there is decay in the total number of ideas generated by participants as a function of time. Another recent study has looked at the variation of the quality of ideas generated by designers as a function of time (Viswanathan and Linsey, 2013c). However, these analyses are used only as supplementary evidence for the primary objectives and are not looked into in detail. The pilot study presented in this paper is an attempt to identify any potential variations in the extent of design fixation as a function of the order of ideas within the same idea generation session.

2 BACKGROUND LITERATURE

2.1 Design Fixation

Many researchers have identified the fixation effects of example solutions on engineering idea generation (e.g., Chrysikou and Weisberg, 2005; Jansson and Smith, 1991; Linsey et al., 2010; Purcell and Gero, 1992; 1996). While designers solve open-ended design problems, design fixation plays a counter-productive role, narrowing the solution space where designers search for their ideas and thus reducing creativity. This also reduces the flexibility of designers in choosing novel features for the solutions they generate (Purcell and Gero, 1996). The prior studies have shown that designers, when fixated to an example solution, replicate many features from said example in their new designs (Chrysikou and Weisberg, 2005; Jansson and Smith, 1991; Linsey et al., 2010; Purcell and Gero, 1992; 1996). Majority of these studies use example solutions in pictorial form, mainly in the form of hand sketches. Some others have shown that richer pictorial stimuli like the photographs of examples can also induce fixation (Cardoso and Badke-Schaub, 2011). Some recent studies by Youmans (2011) and Viswanathan and Linsey (2013b) also investigated the influence of a fixating example in a higher fidelity.

2.2 Mechanisms of Design Fixation

Cognitive Psychology derives an explanation for design fixation from the network models of memory (Matlin, 2005). This theory suggests a network-like structure for long-term memory, where the concepts in the memory form nodes of the network (Anderson, 1983; Collins and Loftus, 1975). When a concept is retrieved from the memory, the corresponding node is activated. The probability of activation of the nodes directly connected to the first node is much higher than those which are totally unrelated. Thus inter-connected concepts are retrieved much easier than the distant ones. When designers generate concepts solving a design problem, the other concepts closely related to the one already retrieved come to their mind instantly. This leads to the generation of ideas that are very similar to each other. When

they encounter an example solution, it acts as a stimulus that triggers the retrieval of a concept similar to the example. Further, the subsequent concepts derived from memory are also very similar to the first one and thus similar to the example solution. This kind of a biased retrieval of concepts from memory (Raaijmakers and Shiffrin, 1981) leads to design fixation.
Another explanation of design fixation pertains to the "working-backwards" strategy adopted by designers while solving open-ended problems as in engineering idea generation. In general, the design problems are considered to be ill-structured and they do not convey full requirements to the designer. As a result, they form the constraints for solving the problem around the example available to them: either given directly or from their prior exposure (Restrepo and Christiaans, 2004). This kind of an approach to solve a problem is termed as a "working-backwards" strategy. This leads designers to develop a pre-mature cognitive commitment towards the initial solutions or the example solution provided to them, leading to design fixation (Cross, 2008).

2.3 Effect of Timing on Engineering Idea Generation

A few studies in literature have dealt with the effect of timing on idea generation. A recent study by Kohn and Smith (2011) shows that when designers perform collaborative brainstorming, they tend to conform to and fixate to the ideas proposed by their peers. Further, they found a steady decrease in the novelty and variety of ideas as the idea generation time progresses. A couple of other studies have looked into the influence of incubation breaks during an idea generation activity on the extent of design fixation (Cardoso and Badke-Schaub, 2009b).
The study described in this paper explores how the presence of a fixating stimulus in the form of a pictorial example effects the generation of novel features as a function of the order of ideas in an idea generation activity. Some of the previous studies have established a natural decrease in the quantity of novel ideas as time progresses during an idea generation (Kohn and Smith, 2011). This study investigates if the fixation to example features also decays over time. More specifically, the following research questions are being investigated:

2.4 Research Questions

During an idea generation activity,
(a) Does the quantity of new ideas decay as a function of the order at which a design solution is generated?
and
(b) Does the time elapsed before the generation of a design solution reduce the design fixation to an available example?

3 METHOD

An empirical study is conducted to investigate the research questions mentioned in the previous section. A group of novice designers are given a realistic design problem to solve along with a fixating stimulus. The solutions generated by these designers are compared against those from a control group, where another group of novice designers generated solutions for the same design problem without the fixating stimulus. The following subsections detail the study design and the method followed.

3.1 Design Problem & Participants

All the participants in this study solved a peanut sheller design problem. The design problem was to generate solutions for a machine that could quickly and efficiently shell peanuts. This machine was for the use in developing economies like Haiti and some West African countries. The participants were told that electrical outlets were scarce in such areas; so said machine was expected to shell peanuts without using electricity. The machine was also expected to shell peanuts with minimum damage to the peanuts. Figure 1 shows the design problem statement provided to the participants.
The peanut sheller design problem was a real-life problem that presented the challenges of a very realistic activity of shelling peanuts. All the participants were mechanical engineering students and were expected to have experienced the routine task of shelling peanuts. This design problem was successfully employed in many prior studies (Linsey et al., 2010; 2011; Viswanathan and Linsey, 2013a; 2013b). However, none of the participants were familiar with the design problem, before generating ideas in this study.

Nineteen senior undergraduate mechanical engineering students volunteered as participants for this study. The experiment had two different conditions - Control and Fixation. The Control condition had 9 participants and the Fixation group consisted of 10. The participants were randomly distributed across the two conditions to avoid any possible bias.

Design Problem - Device to Shell Peanuts

Problem Description:
In places like Haiti and certain West African countries, peanuts are a significant crop. Most peanut farmers shell their peanuts by hand, an inefficient and labor-intensive process. The goal of this project is to design and build a low-cost, easy to manufacture peanut shelling machine that will increase the productivity of the African peanut farmers. The target throughput is approximately 50 kg (110 lbs) per hour.

Customer Needs:

- Must remove the shell with minimal damage to the peanuts.
- Electrical outlets are not available as a power source.
- A large quantity of peanuts must be quickly shelled.
- Low cost.
- Easy to manufacture.

Figure 1. Design problem description provided to the experiment participants

3.2 Experimental Conditions

This experiment had two different experimental conditions - Control and Fixation. Participants in the Control group generated ideas without the help of any external stimuli. The participants in the Fixation condition received an example for solving the design problem. The example was a gas-powered press that was used in many past studies. The sketch provided to participants is shown in Figure 2. This example was originally formulated by Linsey et al., (2010) combining the most popular design ideas from a pilot study. The design used a hopper to import peanuts to the system, a conveyor and inclined plane combination to guide the peanuts to the table and then crushed the peanut shells using a gas-powered press for shelling them. The shelled peanuts were separated using a grate and they were collected in a storage bin below. While it seemed like a feasible solution, this example had several disadvantages like the lack of control to the damage of peanuts, very expensive design and lack of a proper mechanism to separate shells and peanuts. This sketch functioned as a very good fixating example as it consisted of several popular design features for the functions involved in the design problem.

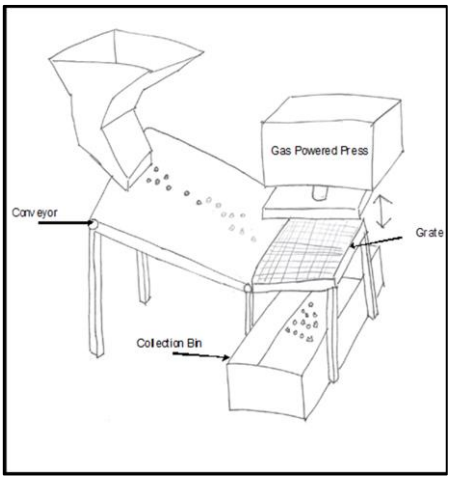

Figure 2. Gas powered press example provided to the Fixation group participants

3.3 Idea Generation Activity

All participants in the experiment were given 45 minutes to generate ideas for the peanut sheller design problem. The experiment was conducted as a part of a regular 50-minute class and all the participants generated ideas at the same time. They were given an instruction sheet describing the design problem (as shown in Figure 1) and blank sheets of paper to draw their ideas. Participants were specifically told

to sketch their ideas and supplement their sketches with brief descriptions. They were also free to annotate their sketches. The participants in the Fixation group also received the example shown in Figure 2 along with their design problem description. The participants were also instructed to indicate the time they finished generating each solution. A clock was displayed on screen for their convenience.

4 METRICS AND ANALYSIS

To investigate the research questions mentioned in the previous section, the solutions generated by the study participants were broken down to individual ideas. For the purpose of this study, a "solution" was defined as the one that solves the entire design problem. The participants were expected to generate complete solutions during the idea generation activity. A solution consisted of several "ideas". An "idea" was defined as a design feature that addresses one of the functional needs within the solution. For example, if the design problem was to create a device to easily carry groceries in a shopping center, one solution could be a wheeled shopping cart. The wheel of the shopping cart was considered to be an idea within the solution as it addressed the functional need of "transport" materials.

For the purpose of analysis, each design solution was broken down to the corresponding ideas. A functional model was created for the design problem and the necessary functions required to solve the problem were identified. Further, each solution generated by the participants was compared to this functional model to break it down to ideas. Once all the solutions were broken down to ideas, the following metrics were calculated.

4.1 Percentage decrement in new ideas

This metric was primarily used to identify if there was a decrease in the number of unique ideas generated by the participants as they moved from their first solution to the last one. It was calculated using Equation (1):

$$\%\ decrement\ of\ new\ ideas\ in\ the\ n^{th}\ solution = \frac{(\#\ \text{new ideas in the } n^{th}\ \text{solution} - \#\ \text{new ideas in the } 1^{st}\ \text{solution})}{\#\ \text{new ideas in the } 1^{st}\ \text{solution}} \quad (1)$$

4.2 Percentage decrement of example ideas used

This metric was used for identifying any intentional or unintentional plagiarism while generating the design solutions. The ideas copied (knowingly or unknowingly) from the example solution were identified and Equation (2) was used for the calculation of this metric.

$$\%\ decrement\ of\ example\ ideas\ used\ in\ the\ n^{th}\text{solution} = \frac{(\#\ \text{example ideas in the } n^{th}\ \text{solution} - \#\ \text{example ideas in the } 1^{st}\ \text{solution})}{\#\ \text{example ideas in the } 1^{st}\ \text{solution}} \quad (2)$$

5 RESULTS

The results show some very interesting trends. It is observed that while most of the participants generate solutions for the design problem throughout the 45 minutes allocated to them, the percentage of new ideas shows a steady decrease. Figure 3 shows this variation as a function of the order of the solution. As evident from the Figure 3, participants generate the maximum number of new ideas in their initial solution. In their further ideas, they tend to come up with less number of new ideas, likely due to design fixation to the ideas in their first solution. Most of the latter solutions contain ideas repeating from the previous one. It was observed that the latter ideas produce new ideas for one or two critical functions for the design and repeat the already generated ideas for other functions. This trend is true for both the experimental conditions.

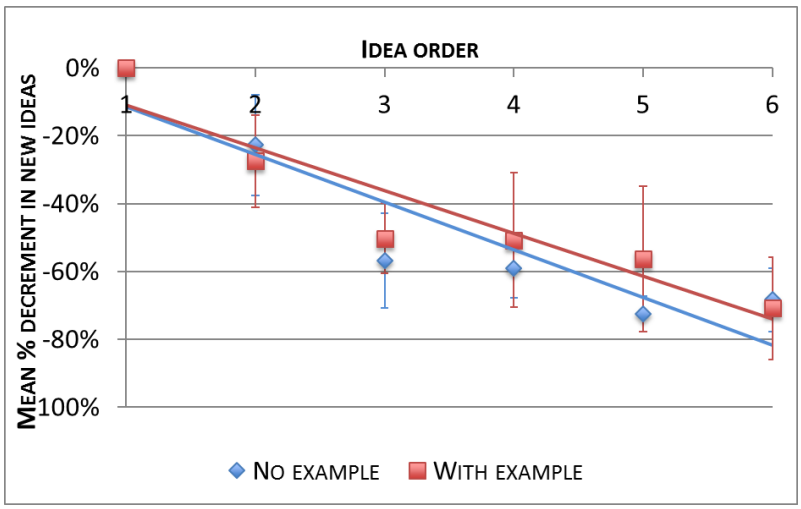

Figure 3. Mean percentage decrement of new ideas during the idea generation session. All error bars show (±) 1 S.E.

A linear regression model of these data shows the existence of a strong correlation between the number of new ideas generated and the order of the idea, regardless of the experimental condition (for Control: slope = -1.15, $t = -5.73$, $p < 0.01$; for Fixation: slope = -1.07, $t = -5.49$, $p < 0.01$). In other words, during the idea generation session, the number of unique ideas that the participants incorporate in the design solution tends to decrease. In most cases, this is due to the reuse of ideas from their own previous designs.

Further analysis is performed to verify if the decay of new ideas with the order is caused by decay in the overall number of ideas generated. Figure 4 shows this variation in the total number of ideas. There is a small reduction in the mean number of total ideas generated. However, a linear regression model shows that this reduction in number of ideas with the idea order is not statistically significant (slope = -0.98, $t = -1.97$, $p = 0.06$). However, the sample size for this pilot study is very small. It might be possible to get a marginally significant result for this analysis with a higher sample size. Even if that is the case, the decay of overall number of ideas is smaller compared to the reduction in the number of new ideas, again indicating design fixation to initially generated ideas.

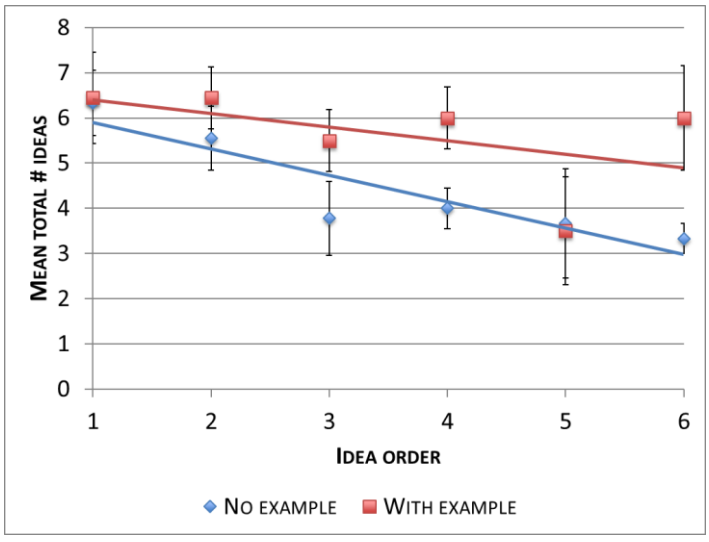

Figure 4. The variation of total number of ideas generated during the idea generation session. All error bars show (±) 1 S.E.

While the data shown in Figure 3 explain the fixation to ideas in the initial design solutions, further analysis is performed on the data to understand the design fixation to the specific ideas present in the example given to the Fixation group. For the purpose of comparison, example ideas are removed from both groups' ideas and the analysis on the decrement of unique ideas is repeated. Figure 5 shows the data after removing the example ideas.

It is observed that even after removing the example ideas, there is a reduction in the number of unique ideas generated by the participants over time. One interesting fact to note here is that the percentage reduction in unique ideas is lower in the case of the Fixation group compared to the Control group. The Control group follows the same pattern of reduction as in Figure 3. In order to analyze these data statistically, a two-factor linear regression model is created. The model shows a strong correlation between the outcome (number of unique ideas) and the two independent variables (experimental condition and the order of the idea) (for experimental condition: slope = -1.06, $t = -2.70$, $p < 0.08$; for the idea order: slope = -0.75, $t = -5.82$, $p < .01$). This indicates that the reduction in the number of unique ideas over time is also influenced by the presence of an example.

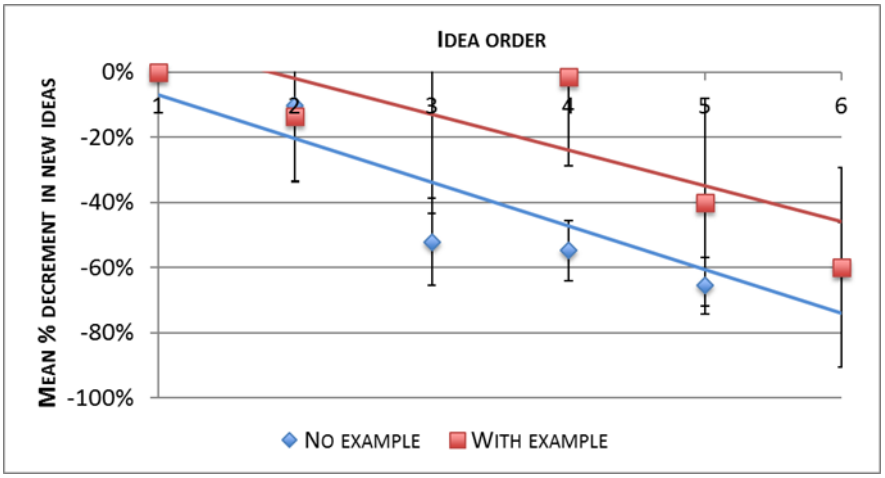

Figure 5. Mean percentage decrement of new ideas excluding the example ideas during the idea generation session. All error bars show (±) 1 S.E.

To understand this further, the variation of the presence of example ideas in the design solutions with the order of the design solution is investigated. Figure 6 shows this variation. As evident from the figure, the occurrence of the example ideas in the Control group's solutions reduces over time and this trend is similar to the one shown in Figure 3. However, in the Fixation group, the percentage of example ideas does not go down significantly. A two-factor regression shows that the interaction effect of the two factors (presence of example and the order of the idea) is not statistically significant. Further follow up analysis shows that within the both the groups, the percentage of example ideas decrease significantly with the idea order (for Control: slope = -0.26, $t = -2.61$, $p = 0.01$; for Fixation: slope = -0.45, $t = -2.85$, $p < 0.01$). Also, the time variation is influenced by the experimental condition (slope = 0.68, $t = 2.33$, $p = 0.02$).

Based on previous studies, when designers fixate, they are expected to generate a lower quantity of novel ideas during the idea generation session. In order to verify that, the total number of novel ideas (excluding the example ideas) is calculated for both the experimental groups. Figure 7 shows the results from this analysis. A statistical analysis shows that there is a significant difference in the unique ideas generated between the two groups (One-way ANOVA: $F = 152.69$; $p < 0.01$). This supports the argument that when an example is present, participants tend to fixate to the ideas in that example, resulting in a lower number of novel ideas in their solutions.

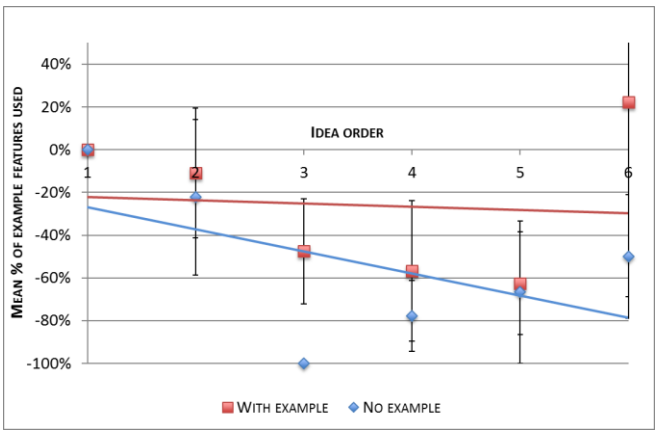

Figure 6. The variation of the mean percentage of example features in participants' solutions with the order of the solution. All error bars show (±) 1 S.E.

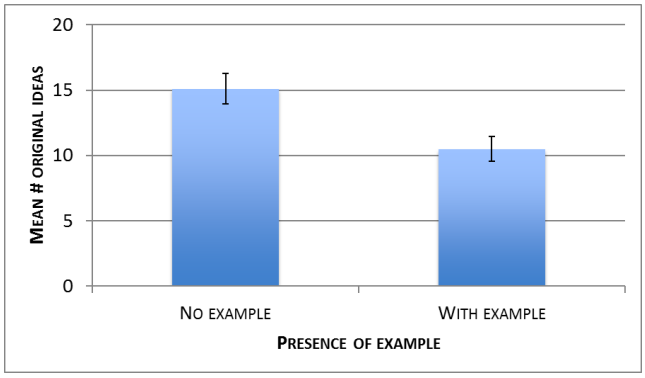

Figure 7. Comparison of mean number of original ideas across the experimental groups. All error bars show (±) 1 S.E.

6 DISCUSSION

The results from this study indicate that during an idea generation period, the quantity of novel ideas within the design solutions decay with the order in which the solution is generated. This is likely due to the fixation to the earlier ideas developed. This is true regardless of the presence of a fixating stimulus. However, this trend is not true for the ideas derived from the example. These example ideas are not considered as novel as they are readily available to the study participants. The fixation to example ideas does not seem to decay over time (as measured with the order of the design solution). This is likely due to the availability of the example throughout the idea generation time and is consistent with the results from a previous study (Cardoso and Badke-Schaub, 2009b). One possible explanation is that the designers might have revisited the example several times during the idea generation activity (this was not tracked). This might have led them to a renewed fixation to the same example features. Further investigation is needed to verify this argument.

While this study investigated the generation of "new" ideas within a design solution, the novelty of these "new" ideas is not taken into account. Some of these new ideas might come from domains that are fairly close to some of the previous ideas. In order to understand the actual extent of design fixation, the novelty of these ideas also should be included as a variable in the analysis. This analysis will be performed as a future work.

7 LIMITATIONS OF THE STUDY

The study described here is conducted as a pilot; hence the sample size is small. In order to make concrete conclusions, a larger sample is required. The intention of this pilot is to refine the data collection and analysis procedures before a larger sample size experiment. All the participants are undergraduate students with very limited experience in the design process. Hence, the results can be considered valid only for novice designers. In this study, the idea generation process is not completely recorded. The participants were specifically instructed to record the time at which they finished a solution. These times

need not necessarily represent the time at which an idea is generated. This is the primary reason for using the order of the solution as the independent variable in this study. Further, some of the participants spent significantly more time on their first or second ideas and spent comparatively shorter time period on others. This might cause a bias in the analysis. This issue will be addressed in the future work.

8 CONCLUSIONS

This paper presents an empirical study to understand the variation in number of novel ideas generated by designers during an idea generation session. Two research questions are investigated (1) Do number of ideas decay with the order in which the solution is generated? and (2) does the fixation to an example design decay with the solution order? A controlled experiment using a peanut sheller design problem investigates these two questions. Participants in the experiment are randomly distributed into two experimental groups: Control and Fixation. In the Fixation condition, the participants are given a pictorial example in addition to the design problem statement. Each solution generated by the participants is divided into ideas addressing functional requirements that are necessary to solve the whole problem. The percentage decrement in new ideas is explored as a function of the order of the solution. The results show a decrement in the percentage of new ideas over time. This result is in agreement with some of the prior studies. The quantity of novel ideas (ideas different from previously generated ones) also shows a very similar trend. However, the ideas derived from example in the Fixation group do not show this decay. In essence, these results show that when the example is available to participants during an idea generation activity, they remain fixated to the example throughout the session and the fixation effects do not decay over time.

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