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TIME CYCLE EFFECTS IN DESIGN IDEATION

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Abstract

Generating alternatives early in the design process is important for finding novel and appropriate solutions for design problems, and for making sure that succeeding design efforts are based on a winning concept. The effects of time elapse on individual solution search efficiency were investigated in a laboratory experiment. The logic of the experiment was that some rough time limit should be found for designers to terminate their individual solution search effort. After individual idea generation, designers could e.g. discuss ideas with one another. This should not be done until the designer has had time to present his concept variants, since others ideas may intervene with the search process. However, we know fairly little about the appropriate time for individuals to disrupt their initial solution search effort. The study demonstrated that solution search completion in terms of quantity and variety of concepts was linearly correlated with the elapse of time. A key conclusion derived from the experimental results was that design fixation might not be a time-correlated attribute at least for a moderate quantity of time, and therefore, individuals should be given enough time to generate ideas on their own, prior to e.g. exchanging ideas with peers.

Keywords: idea generation, conceptual design, laboratory study, design fixation

1. Introduction

Creative problem solving meetings or sessions are usually held at the beginning of a design process. These sessions assist design groups in exploring the problem space and ensuring an overview of possible design directions [1]. The performance of the final product is influenced by the ability of the participants of these meetings to come up with several creative [2] solutions for the design problem. Performing solution search early in the design process reduces the risk of accruing resources on a ‘faulty’ concept, and diminishes the need for design iterations during the design project. Therefore, concept generation is a central activity in design [3,4] that should be properly conducted in the early stages of a design process.

Although various idea generation methods [e.g. 5,6] have been created to assist in the generation of ideas, a more pragmatic approach is needed to scrutinize idea generation, since the approaches documented and suggested by authors lack any basis in serious psychological theory as well as serious attempts to validate them [2]. As highlighted in the work of Shah and colleagues [7,8] this is true for the engineering domain as well. Thus, proper schemes, such as experimental studies, must be undertaken to scientifically study the underlying structures and processes of idea generation. Idea generation methods are composed of numerous parameters that may have an influence on their use and effectiveness. Additionally, the varying characteristics of task environments cause difficulty in choosing appropriate approaches to idea generation.

This paper presents an experimental study in which the effects of time on solution search efficiency were investigated. The hypothesis of the study was that the efficiency of solution search in terms of quantity and variety of concepts is related to the elapse of time. The concern of the research can be further elaborated into the following main research questions: (i) does the time cycle affect individual solution search efficiency; and (ii) does design fixation occur in individual design ideation? The research questions were studied in a laboratory experiment. Designers generated concepts alone for a single task for a defined time period and their advancement was allocated onto a time-line with a sketch-colouring system.

The experiment demonstrates how long individuals can generate ideas without being subjected to cognitive interference. After individual idea generation, designers could e.g. discuss ideas with one another. This should not be done until the designers have had time to present their concept variants, since others ideas may intervene with the search process. The termination of the individual search task should consider stopping strategies of design idea generation.

Design fixation, by early definition, is as a blind adherence to a set of ideas or concepts limiting the output of conceptual design [9,10], it may be regarded as a form of cognitive interference. In other words, design fixation refers to the inability for a designer to see new solutions after he (or she) has been exposed - internally or externally - to solution examples (or models, goal states, concepts, etc.). Therefore, if a person is not able to elaborate new solution principles after a certain period of time, then he is 'fixated' on earlier solutions.

2. Background

The majority of idea generation methods attempt to aid a designer in the generation of a large number of ideas. The number of ideas generated is considered a direct indicator of benefits of certain constructs. The underlying assumption is that quality is elaborated through quantity, or in other words, there exists some statistical 'universal' correlation between the number of ideas and the occurrence of a single high-quality idea. Even though some criticism has been imposed on this view, it still remains as the central premise for idea generation. Therefore, scholars attempt to generate practical procedures to enhance the evocation of a large number of ideas.

A further distinction should be considered for design ideation, that is, the objective is to generate a large number of different ideas. The ideas should differ from one another as much as possible, i.e. the ideas should vary at the highest level of abstraction found appropriate for the context. Design problems are typically classified as ill-defined or ill-structured problems, and for these types of problems there usually exists an infinite, yet limited in practise, number of alternative solutions that satisfy the initial requirements. Design teams should therefore try to produce several competing solutions rather than to directly arrive at a single solution. In other words, breadth instead of depth is favoured. Most economical is to discuss concepts at the basic level [11], analogous to descriptions of design abstraction levels, see e.g. [3,8,12,13].

Scholars suggest that individuals should first produce ideas on their own, and then proceed into group discussion [14]. However, little is known about the appropriate time for individuals to disrupt their initial solution search effort. The logic of this experiment and the more general matter under investigation is that some optimum time should be found, or at least a rough limit, for designers to disrupt their individual solution search effort. The search task should be terminated when interference becomes prevailing and the designer is unable to produce solutions that differ from earlier ones. There are two primary stopping strategies: externally

forced and self-stopping, see e.g. Hong [15] for discussion about stopping strategies in *visual* search tasks. A single optimal stopping time for solution search tasks is difficult to determine due to several contextual factors, but having some implications of such a time limit would be very beneficial for design research and product design in practise.

Nijstad et. al [16] found that, in idea generation, individual subjects may tend to stop generating ideas when they: (1) find it difficult to produce further ideas; (2) no longer enjoy the task; or (3) reach a satisfactory goal-state. These self-stopping strategies of idea generation should be considered also for design ideation. In fact, it has been stated, that the personalized stop rules are unique properties [17,18] of an internal representation of one's design problem space [19]. An assumption is that designers are capable of generating a relatively large pool of ideas, but the main obstacles for retrieving, synthesizing, and externalizing these ideas are cognitive limitations, such as, inappropriate problem space, strategic failure, inability to retrieve knowledge, overloading working memory, and becoming fixated. As hypothesized, these limitations may be accumulated in a short period of time.

Figure 1 presents hypothetical trends of solution search completion, in terms of variety of ideas, in relation to elapse of time. The dashed lines show trends in which the subject becomes fixated on solutions. There are two possible reasons for why designers are not able to produce several alternative solutions for a problem. Firstly, they may have a limited view on the design problem already at the beginning of the session; this is referred to as unreasonable problem framing. Secondly, designers may get 'stuck on' solutions that they have generated, in such cases; fixation may be seen as a function of time elapse.

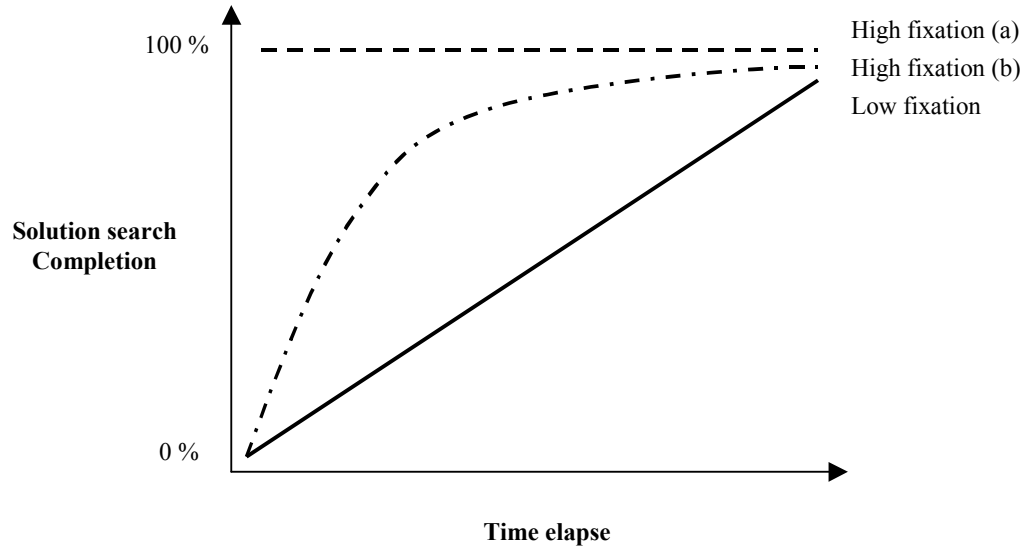


Figure 1. Hypothetical trends of solution search completion in terms of variety of ideas in relation to elapse of time. (a) Type 1: Fixation correlated with (unreasonable) problem framing, (b) Type 2: Fixation correlated with time elapse.

There are several ways to enhance divergent thinking and enforce the generation of additional ideas after subjects have stopped generating ideas, or when their search efficiency is scaled down. For instance, idea sharing in groups [20], i.e. being exposed to others' ideas, may support designers in the generation of further ideas. When solution examples are present prior to idea generation they may have constraining effects on the scope and content of the ideas that are subsequently generated [21]. Therefore, ideas of others may serve as a catalyst for further ideas (stimulating effect), but also possibly narrow down the search effort (interfering effect) [22]. As a result of these implications, we remark that idea sharing (or respective

components) may also limit the idea generation process, and thus, one should plan their use so that they are aligned with beneficial stopping strategies of individual idea generation.

3. Methodology of study

3.1 Experimental task and procedure

In the experiment, participants generated and visualized concepts individually for a single conceptual design task (or assignment or problem) for 45 minutes. The task was to generate design solutions for an automatic device that collects balls from a playing field and delivers them to a goal-area. The participants were not informed of the absolute time limit, instead, it was stated that they have rather adequate time, yet less than an hour, to perform the task. The assignment was presented at a high abstraction level, no specifications or other information was given. The task was presented in writing by projecting it on to a screen in the session-facility; no briefing other than the textual assignment was given. If participants had something to ask about the assignment they were instructed to personally contact the staff by raising their hands. This was done in order to avoid distraction and stimulation of others during the exercise.

Each subject was provided with a standard answering sheet, including instructions on the manner of presenting concepts: simple sketches should be used, together with textual descriptions when found necessary, and the mechanical solution principle as well as main components should be clearly visible. Subjects were asked to fill-out a pre-experimental questionnaire to attain background information.

The data was allocated onto a time-line, composed of nine five-minute intervals, with the help of a two-coloured (red/blue) pencil. Every five minutes participants were asked to switch the colour of their pencils, so doing, each concept was allocated to a certain interval and shifts between intervals could be identified by a change in colour. If no concepts occurred at an interval, subjects were asked to mark the letter x on their answering sheet, in order to avoid misinterpretation. In a case where the subject had used both colours for a single sketch, it was allocated to the preceding interval, being based on the sense that it takes time for designers to visualize an idea as a sketch.

3.2 Subjects

The subjects of the study were mechanical engineering students, i.e. novice designers, at the Helsinki University of Technology. 63 students took part in the experiment. 40 responses were selected for the final take, since the colour coding of 21 participants could not be interpreted and two subjects scored above three standard deviations from average on the response variables of the study. The final take was 64 percent of the initial sample.

The average curriculum phase (final sample) was 120.6 (SD = 24.1) course credits completed from a minimum total of 160 credits required for a master's degree. The average age of respondents was 24.0 (SD = 1.7) years. All had acquired basic knowledge in design methodology and 55 % had more than half a year of practical design experience.

3.3 Response variables

The response variables of the study are based on a set of common divergent-thinking or ideation effectiveness metrics [8]. For basic analysis of the results we used the metrics quantity (fluency) and variety (diversity) of concepts. Quantity is the total number of concepts

and variety is the number of varying concepts at different levels of solution abstraction. A single level of solution abstraction was chosen for the analysis of this study – variation at basic principle level. Quality was not assessed since no quality criteria were specified in the briefing. It is assumed that these metrics are significant and measure capability of effective design ideation when considering the divergent nature and objectives of the design task. The elaboration of the responses of each individual were allocated onto the time line with the following formula:

$$SC_j = \frac{\sum_{i=1}^{m} n_{ji}}{N_j} \times 100\% \quad (1)$$

where N_j is the total number of concepts that differ from each other on basis j and n_{ji} is the number of concepts type j generated during interval i.

The formula computes the percentage of search complete in relation to elapse of time of concepts that differ from each other on the basis of j. Two differentiation basis were chosen for the analysis: j = 1: All concepts are regarded as different; j = 2: A concept that differs from earlier concepts at basic solution principle level is regarded as different.

Figure 2 shows examples of concepts produced by subjects during the experiment. The concepts all use different basic principles to satisfy the main function of - moving balls from a playing field into a goal-area.

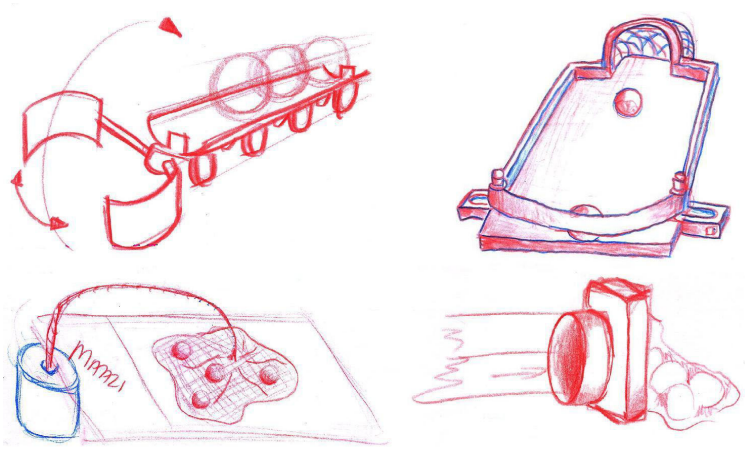


Figure 2. Examples of concepts produced by subjects during the experiment

4. Results and analysis

The average quantity of concepts produced by subjects was 9.65 (SD = 3.61) and the average number of alternative concepts at basic principle level i.e. variety of concepts was 4.95 (SD = 3.61) per subject. Figure 3 shows the completion of the search process per subject at separate cumulative intervals in terms of quantity, and Figure 4 in terms of variety of concepts respectively.

Figure 3. Solution search completion per subject at separate cumulative intervals in terms of quantity of concepts (n = 40)

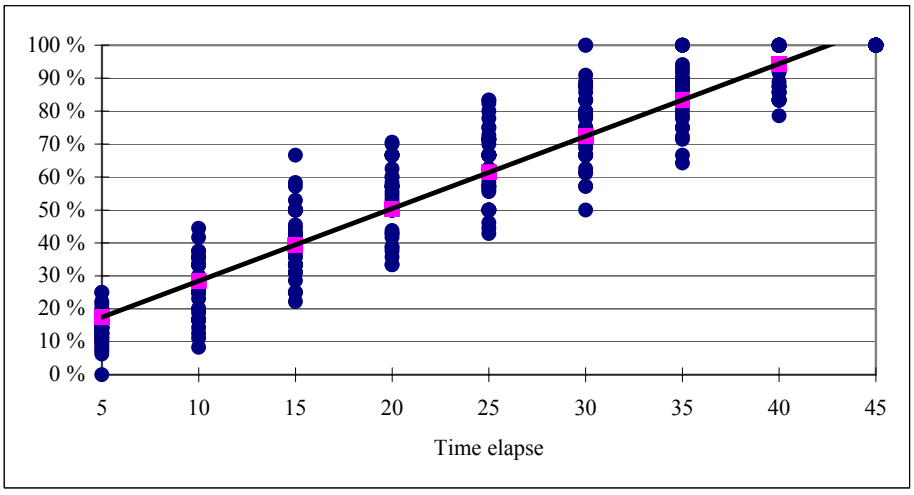
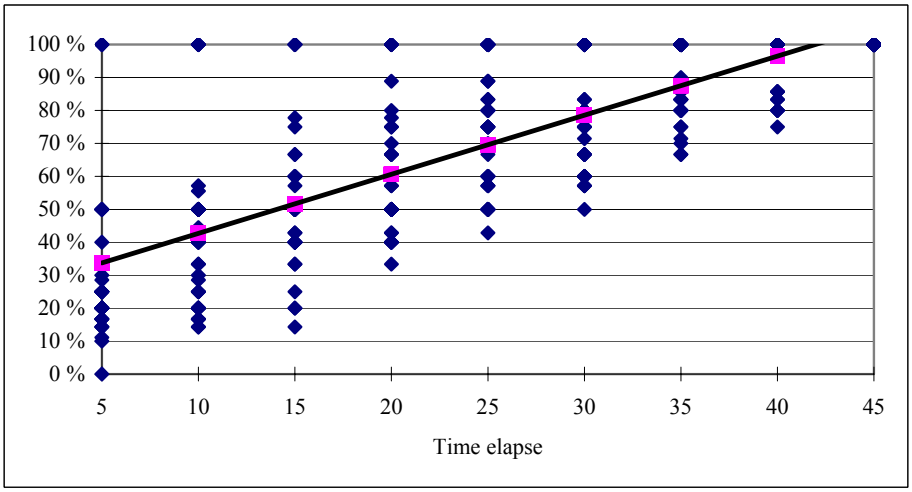


Figure 4. Solution search completion per subject at separate cumulative intervals in terms of variety of concepts (n = 40)



The graphs shown in Figures 3 and 4 were constructed to analyze the relationship of time and elaboration of quantity and variety of concepts. The change in search process completion in terms of quantity of concepts is correlated with time elapse and follows a linear pattern ($y(x) = 0.022x + 0.065$, $R^2 = 0.906$). Also, the elaboration of new principles (i.e. variety) followed a linear pattern relatively well ($y(x) = 0.018x + 0.2477$, $R^2 = 0.640$).

There is considerable variation in search completion for the variety of concepts; therefore the averaging of individual responses may produce a misleading (linear) trend. Some of this variation seems to be caused by Type 1 fixation (See Figure 1); three individual response curves showed a sudden elevation at the start and then remained constant, i.e. these subjects generated only a single principle variant. This is further discussed in the next section.

5. Discussion

A central remark, concerning idea generation in groups, is that designers should first produce ideas on their own, before they e.g. exchange ideas with other group members. A severe effect of early external intervention is that the search process of an individual is limited until the designer has had time to carefully generate and document his concept variants. Therefore, design idea generation should begin with everyone generating ideas alone without any group interaction; and the search process should be terminated when it becomes difficult for individuals to produce ideas that differ from previous ones. An experiment was performed to discover some effects that relate to beneficial stopping times for the designer to terminate the initial solution search process. We proposed that an appropriate time limit would be indicated by the occurrence of design fixation and other interfering phenomena.

The study demonstrated that the majority of the designers were able to generate concepts that varied from preceding concepts at basic solution principle level throughout the session. The trend analysis between time and elaboration of solutions showed that design fixation, or other interfering phenomena, did not have a decisive negative influence on one's solution search process. Solution search completion in terms of elaboration of concepts per se was also linearly correlated with time, and thus, the experiment considered two possible influencing parameters of design fixation - time elapse and number of earlier solutions. A key finding derived from the experimental results was that design fixation is not a time-correlated attribute at least for the designer population and task environment (briefing, design problem etc.) of this particular study. This strengthens the conception that individual work should be favoured at the beginning of idea generation, prior to e.g. exchanging ideas with peers. We conclude that since individual designers are well gifted to perform efficient solution search, then they should be given sufficient time to first produce ideas on their own.

However, some subjects produced only a few alternatives, but this was seen to be due to a limited view on the problem space at the beginning, rather than being a time-related attribute. The occurrence of this particular deficit may be more related to a person and his mental presentation of the problem space; a limited view on the problem space resulted in variation at a lower solution abstraction level than referenced by the problem definition. This may have caused the search process to focus on a single or few principle(s) already at the beginning of the task. The incapability of individuals to find more solutions may have been prevented by mental blocks or unfounded restrictions of the problem space, in opposite to correlation of this deficit with elapse of time, or to the improbable conclusion of some subjects being generally incapable of producing a broader set of concept variants. Based on this conception, we raise the question of problem (or brief) formulation to be one of the central elements to a successful ideation session. It is important to make the task objectives (e.g. variation at high-level) clear for the design team and carefully consider the information contents of the brief, so that designers would not be falsely prejudiced and focused only on a fraction of the actual problem space.

There is also an interesting view on the results that is relevant for design research. It has been speculated that ones own sketches may serve as external stimuli, which is at least mechanically true, but no significant evidence has verified this assumption. This is further put in caution since no fixating effects occurred with time during the experiment. The logic of this indirect evidence is that since one's own earlier sketches did not show traces of interference, they might not entail either catalyzing properties. Since these two effects co-exist, then the effects of one's own sketches are not identical to that of others.

Results gained from laboratory experiments are able to imitate real-life environments only to some extent. It is often argued that findings related to studying novice designers may not be

directly generalized to suit more experienced designers (see e.g. [23] for review) and therefore the results may only concern a segment of the designer population. The nature of the task itself may also cause differences in the results. Still, it would be interesting to learn if such a rough time limit exists, which downsizes the efficiency of a search effort. This question may not be a domain specific matter; instead it may be a matter of subjects 'state of vigilance', and thus, more a psychological question. Therefore, this experiment (or comparable) should be replicated with different types of tasks and subjects in order to find validity for beneficial stopping times in alignment with a proper taxonomy of design problems.

6. Conclusions

The empirical study presented in this paper was aimed at studying the effects of time in design ideation through following the completion of designers' search process in accordance with elapse of time. The results showed that designers were able to produce different concepts throughout the session that lasted for 45 minutes. A key finding was that design fixation is not a time-correlated attribute. The findings strengthen the conception that individual work should be favoured at the beginning of idea generation, prior to e.g. exchanging ideas with peers. We conclude that since individual designers are well gifted to perform efficient solution search, then they should be given sufficient time to first produce ideas on their own.

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