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IDEA GENERATION IN CONCEPTUAL DESIGN

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1. Introduction

Creative idea generation is a vital part of the engineering and the new product development process. To illustrate the industrial importance of being creative, recent figures have been released from the UK treasury concluding that the top innovating companies produce 75% of revenue from products or services that did not exist 5 years ago [Cox 2005]. In order to generate creative ideas required for innovation, the preferred technique within industry is still traditional brainstorming, effective for both idea generation and evaluation [Chakrabarti 2003]. However, there is a growing body of research identifying its limitations [Isaksen*, et al.* 2005]. This paper is based on a number of studies which have analysed idea production during brainstorm sessions and has led to the provision of a new method by which to analyse the ideas produced.

Many studies have been made regarding creative idea generation, most based around research from cognitive psychology. Typically these have contributed with large sample sizes and rigorous scientific approach. However, many of these studies use only hypothetical problems, studying ideas from non-professional engineers [Helquist*, et al.* 2007, Massetti 1996, Nijstad*, et al.* 2002, Perttula*, et al.* 2007]. Little work has been conducted which use real engineers, real design tasks, which then objectively analyse the ideas in terms of the actual concepts and solution created from the ideas. The purpose of this study, dealt with in this paper, is to fill such a research gap. This provides essential insights to the larger study, forming the basis of the authors PhD, analysing the effectiveness of stimuli during group brainstorming.

1.1 Research questions

It was possible to construct a number of research questions derived from the theory in section 2 in conjunction with the insights that the authors gained from being imbedded within the a case company's innovation process.

1.1.1 At what time and rate are ideas generated throughout each brainstorm session?

Previous studies have shown a decline in the rate of ideas produced throughout brainstorm sessions [Helquist, et al. 2007]. During the authors time within the case company, it was realised that each brainstorm session often reached an idea saturation point, where members appeared exhausted of ideas. Often this point was recognised by the project manager at around 40 minutes where external stimuli was introduced to reinvigorate the group. The hypothesis would therefore be, that the rate idea generation would steadily reduce hitting a saturation point at roughly 40 minutes.

1.1.2 At what time and rate are appropriate ideas produced throughout each brainstorm session?

Though it is often suggested that early ideas are not the best, with the most creative being produced later, there has been very little academic work to support this. The authors predict that there will be an initial period producing several appropriate ideas as the result of preconceived ideas during the briefing. After this initial period it is hypothesised that the number of appropriate ideas per number of ideas will steadily decrease in frequency for the remainder of the session.

1.1.3 What percentage of chosen concepts contain ideas created during each brainstorm session?

This is an un-researched area and thus is difficult to predict. For the brainstorming session to be a worthwhile part of the innovation process it would be expected to produce ideas within at least 50% of the chosen concepts. Through multiple first hand experiences of the case company's innovation process it can be predicted that this will be achieved.

2. Theory

The following theory will introduce the reader to the background theory behind design and creative processes important for understanding the method and the results. This section will also outline the metrics by which to analyse the success of the ideas produce during the brainstorm sessions.

2.1 The engineering design process

During a previous literature review undertaken by the authors, approximately 50 different design processes were reviewed, of which 23 popular linear processes were tabulated. The headings of each column corresponded to the various design phases of: Identifying a need; Analysis of task; Conceptual design; Embodiment design; Detailed design and Implementation. It was realised that in comparison to the creative processes analysed from cognitive psychology literature, the engineering design authors were in much agreement. It appeared that most contained the four central phases of the design process, or had very similar termed phases.

Despite this agreement within the domain, it is believed by the authors that these representations are idealistic and not adequately descriptive for research purposes [Bucciarelli 1994]. However, they have proven to be very useful for both the teaching of design and the management of design projects, in which stage gates are often imposed onto generic processes. One representation identified by the authors as a representation useful for this research was found in Gero's [2004] FBS framework. This proposes that design can be broken down into 8 design operations moving between the Function (F), Behaviour (B) and Structure (S) of a solution. Figure 1 shows how this relates to the traditional linear view of the design process, where Functions, Behaviours and Structures are primarily set in the Analysis of task, Conceptual design and Embodiment phases, respectively.

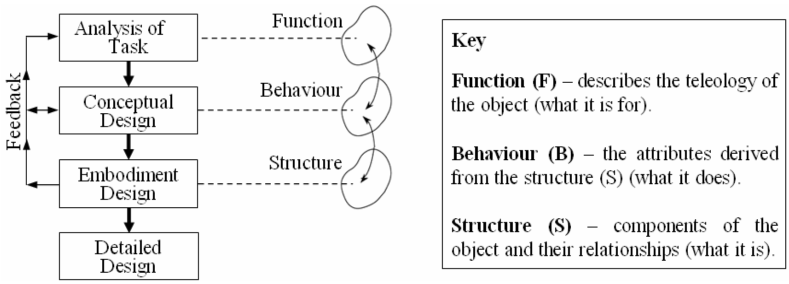

Figure 1. Relationship between the linear design process and FBS [Gero 04]

In Section 2.3. the full FBS framework with its 8 design operators is integrated with the creative process. A more complete argumentation for this integrated process can be found in recent work by the authors [Howard, *et al.* 2008].

2.2 The creative process

During a previous literature review [Howard, et al. 2007] undertaken by the authors, roughly 30 creative processes from psychology were reviewed and tabulated. It was evident that there was less agreement within the cognitive psychology community. Views ranged from that of the earlier inspirationalists assuming a sudden emergence of an idea, through to structuralists who view the creative process as a more logical progression containing similar stages to the design process. Despite these differences in representation it was identified that there was three key phases constant in all processes; these were, the analysis phase, generation phase and the evaluation phase.

Analysis – Cognitive thought regarding the framing of the problem, requirements and constraints.
Generation – Proposition of a function, behaviour or structure involved in solving the problem.
Evaluation – Critique of any proposition proposed in the generation phase.

It is important to note that this process is cyclical where analysis of the problem will form the basis for 'generating' solutions. After 'evaluating' the generated propositions, the knowledge gained is fed back into the 'analysis' of the problem to aid future generation phases.

2.3 The creative design process

From the consensus views of the design process (Section 2.1.) and the creative process (Section 2.2.) found in the previous sections, a hybrid model was formulated (Figure 2). This representation shows the different ways by which it is possible to assess the generation phases of the creative process in terms of engineering design. This will enable researchers to categorise and focus creative idea generation tools to suit the particular stage or activity that the designer is actually undertaking. Most innovation tools such as TRIZ concentrate on design operation 1, helping to produce creative behaviours to fulfil functions. CAD tools aid design operation 2 concerned with embodiment design, however they provide no means by which to propose embodiments for particular behaviours.

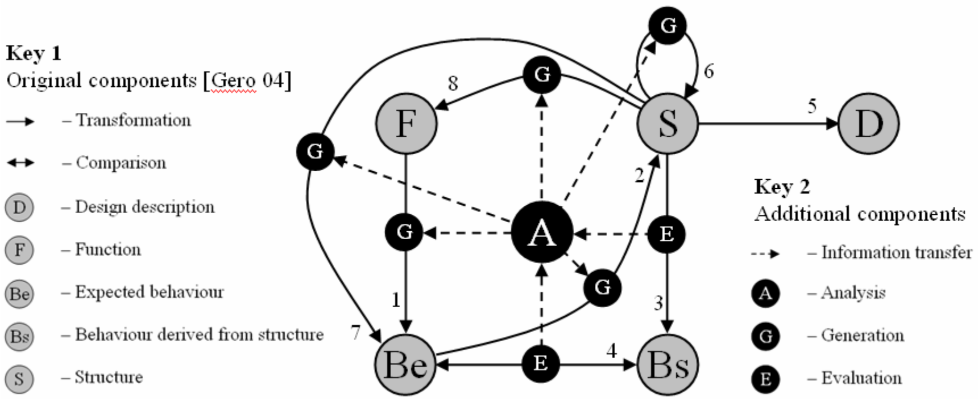

Figure 2. Integrated creative-design process model [Howard, *et al.* 2008]

2.4 Creative performance

The creative performance of a group is often measured using two dependant variables of number of ideas [Nijstad, et al. 2002, Perttula, et al. 2007] and, idea quality. From the vast quantities of literature reviewed, it would appear that creative quality of an idea is generally defined by a propositions 'origniality', 'appropriateness'[Massetti 1996] and un-obviousness [Howard*, et al.* 2006] to a task, however, appropriateness will be the main focus in this paper. To make this more applicable to engineering design, a creative design idea can be defined as an original, appropriate and unobvious idea relating to either the 'function', 'behaviour' or 'structure' of a design solution [Sarkar*, et al.* 2007].

3. Method

Unlike traditional experimental methodologies, this was constructed to take advantage of a unique opportunity within an industrial innovation hub. Though, sample sizes were small and many variables were left uncontrolled, this gave the possibility to participate and capture real design projects with professional engineers. The following section will introduce the reader to the innovation process followed by the case company for each design project (section 3.1.), followed by the methods in which the ideas were captured (section 3.2.) and evaluated (section 3.3.).

3.1 The innovation process

The research method constructed for this study was built around the case company practice. The companies standard innovation process was followed as in all regular new projects. It was the decision of the authors to concentrate the study up to the first stage gate (figure 3.) where it is thought this research will have most effect.

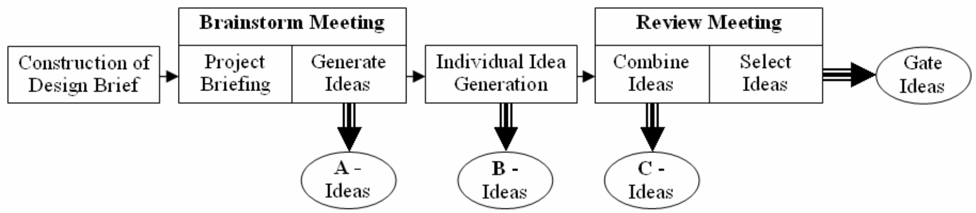

Figure 3. Case company innovation process (up to the first stage gate)

3.1.1 Construction of Brief

Each design project studied, began during the construction of the project brief. During this stage, the mission statement for the project is set along with the various 'musts' and 'desirables' required for the design solution. The project manager is allocated and a team of approximately 8 is assembled for a brainstorming session to generate solution ideas for the brief.

3.1.2 Brainstorm meeting

Within this session, roughly the first 30 minutes would consist of communicating the project brief to the team members whist trying to frame the problem at hand. This is commonly followed by a free thinking brainstorm lasting roughly 70 minutes. In several of the projects, external stimuli was prepared and presented to aid the session after roughly 40 minutes. This section of design was removed and thus does not feature in the analysis in this paper, however, they do feature as part of a larger study currently being undertaken. The ideas that are produced during this section are notated as type A-ideas (figure 3.) and form the basis of this paper.

3.1.3 Individual idea generation

During this phase each team member is given roughly 1 week to produce ideas in the form of 6 concepts. These (noted as type B-ideas) can be constructed from ideas that they particularly like from the brainstorming session or as a result of a totally new idea generated. Each concept is named and drawn on an individual sheet.

3.1.4 Review meeting

During this review meeting team members exhibit each of their individual ideas and are encouraged to group ideas for similarities and to make new and useful combinations, noted as type C-ideas. After all ideas have been shared the most promising concepts are refined. At this stage several of the ideas are rejected due to them being inappropriate. The project manager will then draw up the selected ideas in the form of chosen concepts for the 1st stage gate report. The gate ideas resulting from the review meeting will inevitably be a mixture of A-, B- and C-ideas.

3.2 Case projects

In the following section, this paper presents the results of 5 different innovation projects. All of the projects were conducted within the same domain with similar team members and team sizes. Project 1 can be considered as a technology driven project whereas the other 4 are market driven. All projects followed the standard innovation process and were capture for analysis.

3.3 Idea capture

The author was invited to participate as one of the team members within the brainstorm. As part of the agreement with the case company the session was video and audio captured with synchronised capture of both powerpoint slides and pen and ink illustrations. During this session the author participated as a designer, with no thought of evaluation of the session. It was deemed important to participate to gain better understanding of the retrospective analysis.

When analysing the brainstorm sessions each statement and in many instances the attached illustration was tagged as either 'analysis', 'generation' or evaluation'. The generation statements were then broken down further in terms of whether the statements refer to the function, behaviour or structure of a concept. These sometimes existed together where group members may propose entire concepts. All ideas tagged were annotated chronologically along the brainstorm timeline.

3.4 Idea evaluation and selection

In order to evaluate each idea for its creativity it must be assessed for its un-obviousness, appropriateness and originality. In order to evaluate the un-obviousness of an idea it seem most logical to do this with respect to time (see section 4.1). Ideas produced later in the brainstorming session are considered more unobvious that those produced at the beginning. To measure an idea's appropriateness, it is deemed appropriate if it is selected for use in the gate ideas (see figure 3. and section 4.2). To analyse the originality of an idea, the author went into more depth to assess how each A-idea relates to the various gate concepts (see section 4.3). An example of this concept - idea breakdown using project 4 can be seen in figure 4. In the below example, the circular figure represent A-ideas the have been selected as appropriate and used at the ideas gate. At this gate the ideas a arranged into semi-detailed solutions termed concepts. It can be seen from figure 4 that several ideas refer to the same concept, where only concepts 2,6 and 7 contain A-ideas. It is proposed that the first idea relating to a concept is to be considered original and the rest developmental.

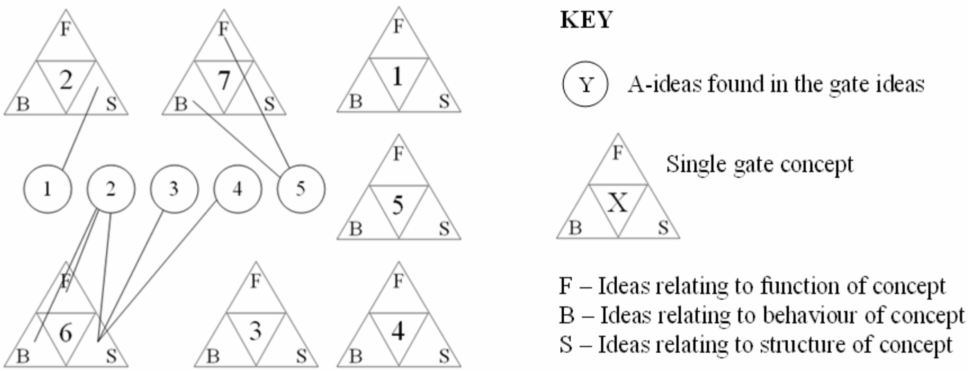

Figure 4. Concept – idea breakdown

4. Results

The following section will provide the reader with the timelines of the brainstorming sessions displaying the specific points at which the ideas are created (section 4.1.). From the analysis of the idea and concept development throughout each project, the most appropriate ideas making it through to the stage gate can be identified along the timeline of each session (section 4.2.). To add depth to the analysis, each session is evaluated on the percentage of different concepts at the stage gate containing ideas from each session.

4.1 Ideas produced

Figure 5. displays the sequence of ideas created for each project during the group brainstorm session. In-keeping with the theory (section 2.4. and 3.3.) these ideas correspond to statements and illustrations tagged to generation. Statements tagged to analysis or evaluation were omitted.

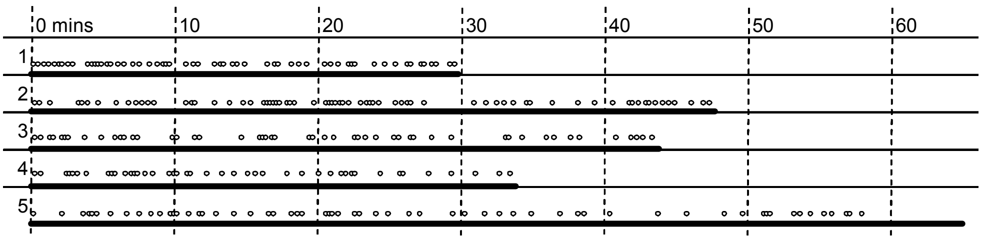

Figure 5. Project brainstorm session idea timeline

The plots display typical characteristics of brainstorming, with several idea clusters [Nijstad, et al. 2002] showing how new ideas spark developmental ideas. For example, providing what correspond to a concepts behaviour and structure to fulfil a new function proposed. It is quite evident from figure 5 that the rate of idea generation is relatively constant throughout the brainstorm sessions, contrary to the hypothesis and previous findings [Helquist, et al. 2007]. The brainstorms also show no sign of exhaustion, with the exception of project 5 occurring roughly 8 minutes before the end of the session.

4.2 Gate ideas produced

Figure 6 shows which of the ideas displayed in figure 5 turned out to be most appropriate, becoming either a functional, behavioural or structural element of a concept at the stage gate.

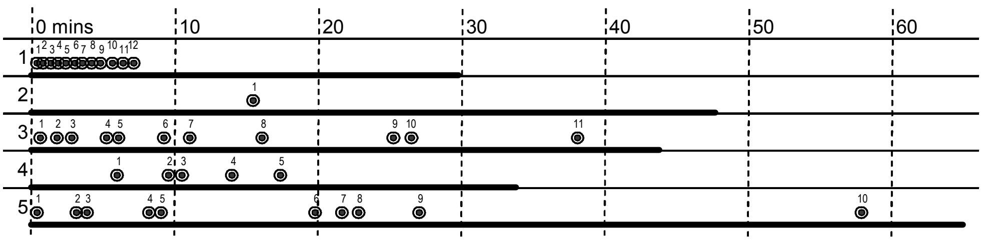

Figure 6. Project brainstorm session idea gate timeline

The above figure 6 sheds new light on the findings displayed in figure 5. As the suggested under the second research question (section 1.1.2), there is a general influx of appropriate ideas during the early stages. However, where the ideas plot (figure 5) suggests idea generation performance stays constant, it can be seen that producing appropriate ideas becomes more and more difficult with time. On average the first 20minutes contains over 80% of session ideas (A-ideas) found within the gate ideas and thus the gate concepts (see figures 3 and 4).

4.3 Gate concept breakdown

Figure 7 shows the percentage of concepts containing the A-ideas from each brainstorming session. For example, project 1 had 13 concepts at the stage gate, but only 10 of the concepts contained ideas generated during the brainstorm.

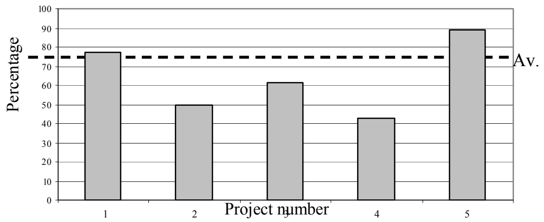

Figure 7. Percentage of concepts containing ideas from each brainstorm session

An average of 64% of stage gate concepts contained ideas generated within the brainstorming session. This means the 64% of the original ideas were produced during this free thinking session, thus suggesting that it is a worthwhile phase of the innovation process. This is regarded by the authors as an important statistic suggesting that only 36% of stage gate concepts are formed throughout the several stages comprising the rest of the innovation process.

5. Conclusion

Though the research questions proposed in the introduction cannot be fully answered by the results of this paper, there is strong evidence to support the hypotheses and previous work [Helquist, et al. 2007]. To address research question 1, the rate of idea production appeared to be constant throughout each session until roughly 60minutes. In many studies, under many forms of analysis, it could therefore be argued that there was constant creative performance throughout the session. It was for this reason question 2 was required regarding the appropriateness of the ideas.

By following an industrial innovation process for real projects, the evaluation of how 'appropriate' an idea is, became un-subjective from the researchers behalf. The robustness of this method gave clear and apparent insight into where appropriate ideas are produced during a brainstorm. The results show that in all cases, over half the appropriate ideas of the session are produced within the first 10 minutes (see figure 6). In-light of this, one suggestion would be that more time could be spent towards the end of brainstorming session on linear development of the ideas already produced.

To address research question 3, Figure 6 and 7 provide a revealing insight into how the ideas produced within the brainstorm session (A-ideas) influence the concepts at the stage gate. Backed up by observations, the results suggest that the majority of the ideas behind each concept at the first stage gate are provided by the 20th minute. This observation would not have been possible by way of a traditional experimental study, where there is no developed solution or concept by which to evaluate such ideas. This study therefore demonstrates a method by which ideas can be evaluated from the actual success and impact on the future concepts proposed, rather than the hypothetical situations, commonly contrived in the literature.

Though in too small sample sizes to fully prove the point, the authors believe that the different design problems have a large effect not only on the ideas produced but the cognitive mechanism by which they are produced. This is highlighted in Figure 6, which illustrates clearly how project 1, the only technology driven project, produced relatively far more appropriate ideas to begin with and far less as time progressed, than the other market driven projects. The authors propose that this is down to which of the 8 design operations in figure 2 becomes most important depending on the nature of the task that has been set. This would suggest different studies may need to be carried out, depending on whether the problem is technology driven, in which case functions will be sought to develop and improve an existing behaviour and structure. In market driven tasks behaviours and structures will be predominantly sought to provide the functions set by the functional requirements [Stone*, et al.* 2005]. Although these results and observations are both interesting and useful in their own right, they also provide a basis by which to test the effectiveness of stimuli provided to brainstorm group, the primary purpose of the overall study and would provide a basis for other engineering design activity related research.

Acknowledgments

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References

Bucciarelli, L. L., "Designing engineers", MIT Press, 1994

Chakrabarti, A., "Towards a measure for assessing creative influences of a creative technique", International Conference on Engineering Design, Folkeson, A., Gralen, K., Norell, M. and Sellgren, U., Proffesional Engineering Publishing, Stockholm, 2003,

Cox, G., "Cox Review of Creativity in Business: building on the UK's strengths", HM Treasury, 2005, http://www.hm-treasury.gov.uk/independent_reviews/cox_review/coxreview_index.cfm

Gero, J. S., "The situated function–behaviour–structure framework", Design studies, Vol.25, No.4, 2004, pp373-391

Helquist, H. J., Santanen, E. L. and Kruse, J., "Participant-driven GSS: Quality of Brainstorming and Allocation of Participant Resources", 40th Annual Hawaii International Conference on System Sciences, IEEE Computer 2007, pp18-27

Howard, T. J., Culley, S. J. and Dekoninck, E., "Information as an input into the creative process", 9th International Design Conference DESIGN 06, Marjanovic, D., Dubrovnik, 2006, pp549-556

Howard, T. J., Culley, S. J. and Dekoninck, E., "Creativity in the Engineering Design Process", 16th International Conference on Engineering Design, ICED 07, Paris, 2007,

Howard, T. J., Culley, S. J. and Dekoninck, E., "Describing the creative design process by the integration of engineering design and cognitive psychology literature", Design Studies, Vol.29, No.2, 2008, pp160-180

Isaksen, S. G. and Gaulin, J. P., "A Reexamination of Brainstorming Research: Implications for Research and Practice", Gifted Child Quarterly, Vol.49, No.4, 2005, pp315-329

Massetti, B., "An Empirical Examination of the Value of Creativity Support Systems on Idea Generation", MIS quarterly, Vol.20, No.1, 1996, pp83-97

Nijstad, B. A., Stroebe, W. and Lodewijkx, H. F. M., "Cognitive stimulation and interference in groups: Exposure effects in an idea generation task", Journal of experimental social psychology, Vol.38, No.16, 2002, pp535-544

Perttula, M. and Sipila, P., "The idea exposure paradigm in design idea generation", Journal of Engineering Design, Vol.18, No.1, 2007, pp93 - 102

Sarkar, P. and Chakrabarti, A., "Developement of a method for assessing design creativity", 16th International Conference on Engineering Design, ICED 07, Paris, 2007,

Stone, R. and Chakrabarti, A., "Special Issue: Engineering applications of representations of function", Artificial intelligence for engineering design, analysis and manufacturing Vol.19, No.3, 2005,

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