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The use of Creative Stimuli at early stages of Industrial Product Innovation

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Abstract

Creative ideas are essential to original concept generation and ultimately innovation. But where and when do these vital creative ideas occur during product innovation and more importantly how can they be influenced? The following paper describes an industrially-based study of several innovation projects following the actual processes of professional designers. Some ideas from the early brainstorm can be traced all the way through to concepts that are selected at the company's stage gate. Those early ideas are marked as 'appropriate' which provides an objective evaluation of the influence of any prescribed creative stimuli being used during the brainstorm sessions in relation to the output of the innovation process. The results showed that the frequency of idea production remained roughly constant during the first 30 minutes but steadily reduced after this period. However, the number of 'appropriate' ideas decreased rapidly, where 75% of the appropriate ideas in the first 30minutes had been expressed after just 15minutes. By introducing various forms of stimuli to the groups, the frequency of idea generation was maintained and in many cases increased. The stimuli were also shown to help generate more appropriate ideas which were included within concepts proposed at the stage-gate.

Introduction

Creative idea generation is a vital part of both the engineering design and new product development process (Howard et al. 2008). 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). As a result, a strategy for innovation and new technology has been adopted for "turning good ideas into new products" (Sainsbury 2007). In order to produce the most promising creative ideas required for innovation, the preferred technique within industry is still traditional brainstorming (Faure 2004) despite the growing body of research identifying its limitations (Isaksen and Gaulin 2005).

Brainstorming is group creativity technique pioneered by Alex Osborn (1953). It has several simple rules that suggest: no idea is a bad idea, no idea should be judged or criticised during sessions, ideas should be built upon and expanded, and members should aim for quantity of ideas over quality. In industry, these brainstorming rules are applied in dynamic brainstorming sessions, where the aim is to generate a large number of ideas, often in the earliest stages of design. In practice, this involves getting teams together and recording all ideas, solutions and creative responses to the design brief or problem set.

This paper is based on a number of industry-based experiments which analyse idea production during brainstorm sessions within the case company. More specifically, the research will identify how the brainstorm groups' creative performance was affected when provided with creative stimuli.

Assessing creative performance

Many studies have been conducted regarding creative idea generation, most based around research from cognitive psychology. Typically, these have contributed with large sample sizes and a rigorous scientific approach. However, many of these studies use only hypothetical problems, studying ideas from non-professional engineers or designers (Massetti 1996; Benami and Jin 2002; Nijstad et al. 2002; Kristensson and Norlander 2003; Helquist et al. 2007; Perttula and Sipila 2007; Mak and Shu 2008) with few exceptions (Kim et al. 2005; Napier and Nilsson 2006) and thus show "little similarity [to] design concept generation in the real world" (Shah and Vargas-Hernandez 2003). Little empirical work has been conducted using professional designers working on actual design tasks within industry. Furthermore, few studies take advantage of the industrial evaluation of ideas and concepts during real design projects, instead using more hypothetical forms of idea-evaluation.

In many of these studies, creative performance of a group is determined by the evaluation of the outputs (ideas, concepts or designs) in terms of two dependant variables: number of ideas (Nijstad et al. 2002; Perttula and Sipila 2007), and, quality of ideas (Wierenga 1998). From the literature reviewed, it would appear that creative quality of an idea is generally defined by a proposition's 'originality' and 'appropriateness' to a task (Massetti 1996) and in some instances a third specialising criteria such as 'unexpectedness' (Gero 1996) or 'unobviosness' (Howard et al. 2006; Howard 2008) which can be linked to the time that the idea was produced. However, these criteria are often difficult to measure in reality.

To aid the measurement of the above criteria it is useful to place the ideas being evaluated within a design research framework, such as the function (F) – behaviour (B) – structure (S) framework proposed by Gero (2004). Here, function describes what the design is for, behaviour describes how the design works and structure describes what the design is (in terms of its form or embodiment). Understanding whether an idea relates to the F, B or S can be used to create more detailed measurement of an idea's novelty and appropriateness to the task, as shown in previous theoretical work (Howard et al. 2008b).

It is worth noting that in this work, 'an idea' is defined as a generative proposition of function, behaviour or structure, whilst 'a concept' is defined as a semi-detailed or partially unknown solution (Hatchuel and Weil 2009) comprising of functional, behavioural and structural ideas.

Related studies

In a previous study on stimulating creativity, Benami and Jin (2002) exhibit results showing that creative stimuli displayed as functions, behaviours, structures and complete concepts produced on average 3, 6, 5, and 2 ideas respectively, during design sessions. From this it was deduced that more ambiguous stimuli tended to be less fixating, enabling designers to produce more- and more diverse- ideas as a result. However, their study did not provide evidence to suggest that the use of stimuli is more effective than generating ideas without stimuli. Their study also used a hypothetical design task posed in such a way that the ideas generated will tend to be more related to 'behaviour'. Further effects of stimuli and contextual cueing (hinting at an area for a solution) were described by Liikkanen and Perttula (2007), showing that there is likely to be a notably greater number of ideas generated in the same (homogenous) category as the idea/stimulus being experienced. In previous research it has also been argued (Altshuller 1999) and shown (Howard et al. 2010) that a case-based approach for retrieving stimuli can be of benefit.

Nijstad et al. (2002) performed a similar experiment to assess whether ideas proposed by other group members are stimulating or suppressing to an individual's creativity, though they only conducted the experiment using electronic representations of the group's ideas. During the study, the design task was posed in such a way that the ideas generated were likely to be 'functional' ideas. The study concluded that the productivity in terms of number of ideas generated is increased in any of the four experimental conditions in which individuals were subjected to previous ideas (stimuli) in comparison to the control group.

These studies show that brainstorming results are affected by introducing stimuli and also that there are some links between the nature/type of stimuli and the nature of the resulting ideas. None of the previous work has assessed the usefulness of the outputs. The research presented here, analyses the effect of the stimuli on the usefulness of the ideas output, by tracing those ideas through to a real industrial stage-gate.

Research questions

The following section will detail two key topics regarding, idea generation and the influence of creative stimuli. For each topic, three research questions (RQ's) are posed and the hypotheses discussed.

Ideas produced during the free thinking brainstorm

During the free thinking phase of the brainstorm, ideas are generated by group members with no prescribed stimuli. This paper will analyse the ideas produced during this phase in terms of the following three research questions:

RQ1: At what time and rate are ideas generated during each brainstorm session?

Previous studies have shown declines in the number of ideas produced per unit time (Helquist et al. 2007). During the researcher's time within the case company, it was noticed that the natural time to introduce stimuli to reinvigorate the group was after roughly 30-40 minutes, which seemed to be the same regardless of the design task or group members. The hypothesis would therefore be that the rate idea generation would steadily reduce hitting a saturation point at roughly 30 minutes.

RQ2: At what time and rate are appropriate ideas produced throughout each brainstorm session?

Appropriate ideas are ideas judged to be useful or suitable to the task at hand. Though it is often suggested that the best ideas take time to produce (BS7000 2008), there has been very little academic work to support this. The authors hypothesise that there is an initial period, when several appropriate ideas are produced as the result of preconceived ideas during the briefing. After this initial period, it is hypothesised that the rate of appropriate idea production will steadily decrease. The metric for appropriateness in this study is described under 'Idea evaluation'.

RQ3: How many of the stage-gate concepts contain ideas generated during early brainstorm sessions?

A stage-gate is a rigid point in a design process where after evaluation, a proportion of concepts are selected for further development whilst often the majority are rejected. This question looks at how many of the ideas generated in the brainstorming session make it through into stage-gate concepts – i.e. concepts that are taken to the stage-gate meeting at the company. This is a relatively un-researched area and thus is difficult to predict. However, it is thought that most of the concepts presented at the stage-gate meeting will have started with ideas from the brainstorm session. This assumes that the designers will extensively explore the design space during the brainstorm, thus generating most of the appropriate ideas.

The definition of “stage-gate concept” is explained further in the description of the company’s process under ‘The innovation process’.

Ideas produced by brainstorming using prepared stimuli

Following the free thinking phase of the brainstorm, ideas are generated by group members influenced by prepared and prescribed stimuli. This paper will analyse the ideas produced during this phase in terms of the following three research questions.

RQ4: How does the introduction of stimuli affect the rate of idea generation?

Based on previous findings (Nijstad et al. 2002), it is expected that the quantity of ideas produced will be raised due to the introduction of the stimuli. However, it is quite feasible that the stimuli may divert or distract the designers, thus lowering the rate of ideas being generated.

RQ5: How does the introduction of stimuli affect the appropriateness of the ideas?

Though this has not been covered by previous studies it can be predicted that the stimuli will increase the number of appropriate ideas produced, due to the increased quantity of ideas being produced. However, the stimuli may encourage more extreme divergent thinking, making ideas more novel and outrageous but less appropriate.

RQ6: How many ideas influenced by the stimuli initiated new stage-gate concepts?

This refers to the number of stage-gate concepts that were started by an idea that was conceived under the influence of the prescribed stimuli. It is thought that the stimuli should produce enough ideas and creative responses to eventually result in totally new stage-gate concepts.

Method

The methods used were constructed to take advantage of a unique opportunity within an industrial innovation hub of a multinational packaging firm who design and manufacture food, beverage, aerosol and speciality metal packaging. Though sample sizes were small and inevitably some variables (such as the task and design group) were left uncontrolled, the study gave the possibility to capture real design activities with professional engineers and designers.

The innovation process

The research method constructed for this study was built around the case company's practices. The company's standard innovation process was followed, as for all regular new projects. Their process has a proven track record, allowing room for creativity whilst providing a structure useful for managing innovation projects. The authors decided to concentrate the study up to the first stage-gate (figure 1) where it is thought this research on stimulation will have most effect.

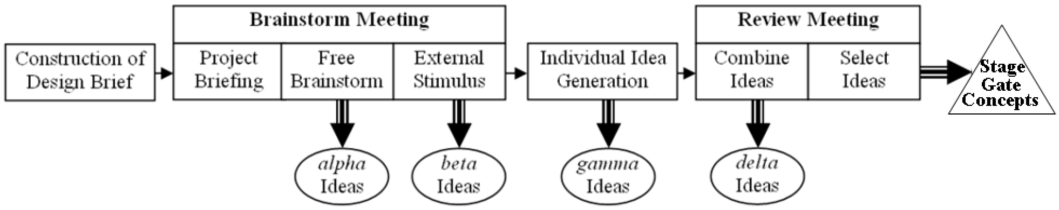


Figure 1. Model of the Ideas earliest stages of the industrial collaborator's Innovation Process.

Each design project studied began with the construction of the project brief. During this stage, the mission statement for the project is set, along with the various 'musts' and 'desirables' (types of design requirements) for the design solution.

During the brainstorm meeting, roughly the first 30 minutes would consist of communicating the project brief to the team members. This is commonly followed by a free thinking brainstorm lasting between 30 and 70 minutes during which alpha-ideas will be generated. After this period the group is often exposed to creative stimuli for roughly 40 minutes generating what the authors have termed beta-ideas.

Following the brainstorm each team member is given roughly 1 week to produce 6 ideas (these ideas are to be in concept form, complete with function, behaviour and structure). These gamma-ideas can be constructed from ideas from the brainstorm or as a result of a totally new idea. It is worth noting that in this company, the ideas output from the brainstorm session are not filtered /selected but are used as a "library" for the individual idea generation.

During the review meeting, team members exhibit each of their individual gamma-ideas and are encouraged to group ideas for similarities and to make new and useful combinations (delta-ideas) until all ideas have been shared. 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 concepts for the first stage-gate report. These stage-gate concepts are used to mark the appropriateness of the alpha- and beta- ideas produced in the brainstorm session. The stage-gate concepts resulting from the review meeting will therefore inevitably be a mixture of alpha-, beta-, gamma- and delta-ideas.

Case projects

All of the projects studied were within the packaging industry, predominantly focusing on metal packaging for food, drinks and other small products. In total, the researcher attended over 15 brainstorm and review sessions and captured roughly 40 hours of footage. However, only 5 projects were chosen for extensive analysis due to the completeness of the data sets.

The 5 projects were also chosen as they were deemed more comparable than other projects. It was thought essential that brainstorms for each project be tested at the same stage of the design process, the ideas stage. It was also deemed extremely important to ensure that the project managers of each project were experienced designers, as it was observed that projects managed by trainee or student designers could not be relied upon to follow standard procedure. Projects 1-4 of the chosen projects used creative stimuli; project 5 was provided with no creative stimuli and was used as a control group.

Types of stimuli

Brainstorm groups in projects 1-4 were subjected to stimuli during the brainstorm session. Each individual stimulus was presented in the form of a presentation slide, which contained pictorial information with some supporting text. Each slide was constructed to display roughly similar amounts of information, containing diagrams and supporting text of artefacts, solution principles or design concepts. An example stimulus of a design concept is shown in figure 2 which describes a novel concept for a liquid closure layout. The slide was taken from a previous project in the company's information repository. The slide shows in detail how a pouring device fits with bottle and cap. It was thought important that each of the stimulus slides described elements relating to function, behaviour and structure. This was felt an important quality of the stimuli which is discussed later in the 'Nature of creative stimuli' section.

A range of different stimuli were used, retrieved from different sources, both from external sources (the Internet), used in projects 1 and 2; and from within the case company's information repository (intranet), used in projects 3 and 4. To retrieve the stimuli a mixture of approaches were used. Stimuli was either randomly retrieved (used in projects 1 and 3), or guided by using the TRIZ contradiction matrix/inventive principles (Altshuller 1999) used in project 2, or a newly developed Sweeper tool (Howard et al. 2010) used in project 4. Sweeper proposes stimuli retrieved from previous projects by using a simple case-based design synthesis approach (Xu et al. 2006) to match requirements of the previous projects with the current project.

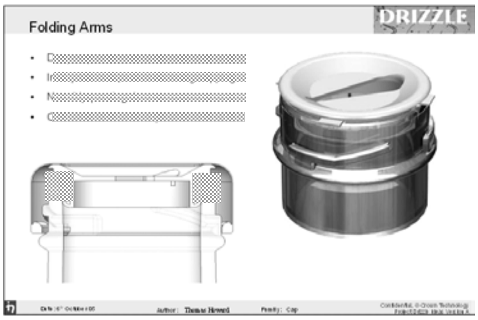


Figure 2. Example of a stimulus slide

Project number 5 was used as a control group in which no stimuli were presented to the brainstorm group. In order to disrupt the brainstorm session as little as possible, it was left to the group to decide when they would like to introduce the first stimulus. Each stimulus was left on the screen until the group had exhausted its use and were ready to move onto the next. The stimuli were used to the extent that suited the brainstorm group. However, in all instances they were continuously used until the end of the brainstorm session.

Idea capture

The researcher participated as one of the team members within the brainstorms. As part of the agreement with the case company, the sessions were video-audio captured and synchronised with the PowerPoint slides used and the 'pen and ink' illustrations created. During this session the researcher participated as a designer in a formal role, with no thought of evaluation of the session. The coding scheme and evaluation was developed afterwards using a grounded theory approach. Participation enabled the researcher to gain better understanding of the process and also made the retrospective analysis of the session content easier.

There were however inevitable limitations to this study. Group sessions, such as the ones being analysed, are useful in the sense that participants externalise their ideas. However, it was not transparent as to when an idea was first conceived and whether all ideas were externalised. Also, the camera could only capture one angle and may have caused participants to behave unnaturally, though this affect was thought insignificant. The audio quality was good so the accuracy of transcripts caused no obvious problems.

Capturing the context of the recorded data can also be a problem with protocol studies. However, using Quindi® meeting analysis software (www.quindi.com), the video, audio, slides, illustrations and transcriptions were able to be viewed at the same time along a common timeline, preserving more context for the evaluation and coding of the data.

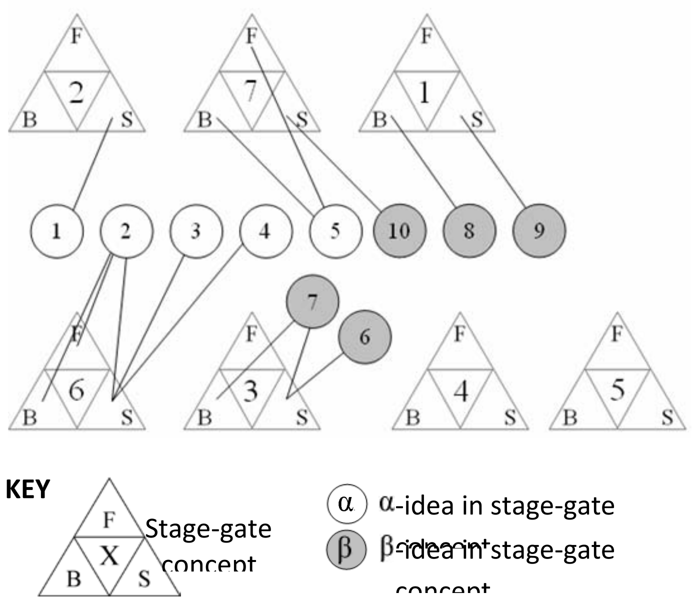
When analysing the brainstorm sessions, each statement, and in many instances, the attached illustration was tagged as a stage of the creative process, namely, 'analysis', 'generation' or evaluation' (Howard et al. 2008). Once the ideas (or generation statements/illustrations) were tagged along the timeline,(shown in figure 5) each idea was re-visited and coded as a function, behaviour or structure of a concept (described in figure 4). Each of the ideas and timelines were then evaluated to establish the idea generation rates.

Idea evaluation

The following section describes the objective measures this study uses for idea quality. This paper looks predominantly at appropriateness as a measure of quality (the other metrics, originality and unobviousness are discussed in (Howard et al. 2008)) by evaluating each of the ideas (generative propositions of function, behaviour or structure) against the concepts (semi-detailed solutions, comprising of functional, behavioural and structural ideas) proposed at the stage-gate meeting.

An idea is considered appropriate if there is evidence of its use in a stage-gate concept. For ideas to make it through to the stage-gate concepts they will have been through a rigorous idea selection procedure during the review meeting (shown on right side of figure 1). Coding the brainstorming ideas based on their success at that later stage means the researcher is not guessing at the appropriateness of each idea, but can state that, an idea is appropriate if selected and used to create a stage-gate concept, or not appropriate if not used. The originality of an idea can be assessed by how it relates to the concepts put forward at the gate meeting.

In figure 3 the circular figures represent ideas that have been selected as appropriate and used at the stage-gate, an example is given in figure 4. The triangular figures represent the concepts proposed at the gate meeting, for example design concept 7 comprises of idea 5 (from the free thinking brainstorm) and idea 10 (inspired by a stimulus). Several ideas may be linked to the same concept, the first idea assigned to a particular concept is deemed as original, the subsequent ideas relating to the concept are considered developmental.



F – Ideas relating to function of stage-gate
B – Ideas relating to behaviour of stage-gate concept
S – Ideas relating to structure of stage-gate

Figure 3. Linking brainstorm ideas to stage-gate concepts

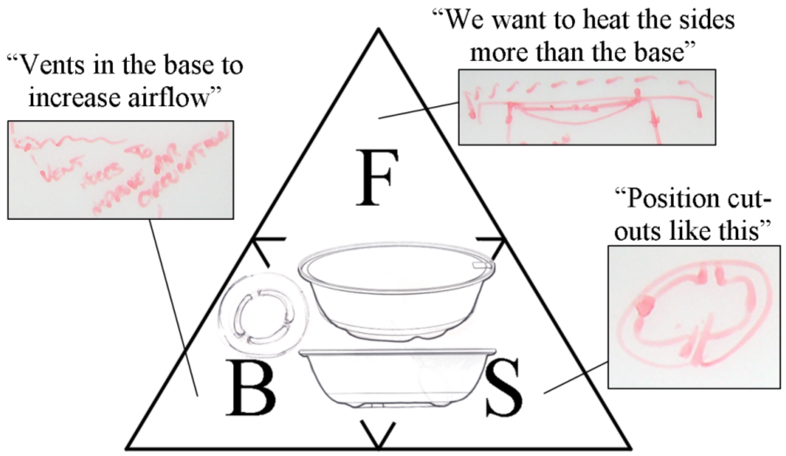


Figure 4. Example of brainstorming ideas relation to concept described by FBS

This method of detailed idea-evaluation helps accurately trace ideas from the brainstorming session all the way through to the stage-gate concepts.

Coding Validation

To validate this scheme for notating ideas an inter-observer reliability check was conducted. Three researchers were asked to mark up 10 minutes of video and audio footage each. Each was given the classification scheme and asked to place a note where an idea had occurred along with a description of the idea.

On comparison of the results, the scheme was well validated, where the fellow researchers missed only 14% of the ideas, identifying the rest correctly. It is likely that this 14% can be put down to audio qualities and not hearing each member of the group clearly. If segment size is set at 10second intervals this gives a Cohen's Kappa of 0.87 showing very strong agreement.

Validation of the mark-up regarding how each appropriate idea relates to each concept (shown in figure 3) was conducted by an independent researcher for 1 of the case projects. The researcher was given the definitions for function, behaviour and structure and was then asked to mark the connections between the appropriate alpha- and beta-ideas and the functions, behaviours and structures of the concepts (as shown in figure 3). The fellow researcher was also given an example of this mark-up from another project to work with. After comparison, 92% of the researcher's notation was correctly identified giving a Cohen's Kappa value of 0.89.

Statistical Analysis

The statistical analyses were performed using statistical software SPSS 16.0 (SPSS Inc, USA). The timeline for each group was split into two minute intervals. First, an analysis of variance was conducted for the first 30minutes of each brain storm using an ANOVA test, revealing that there were no significant differences (significance level p=0.05) between the groups. The groups were then compared over their entire period using ANOVA which showed there were significant differences in both the number of ideas and appropriate ideas. For the number of ideas produced, Levene's test showed all groups were characterised by equal variance. An LSD (least significant difference) was then used, showing that project group 1 was significantly different from groups 2,4,5, and group 3 was significantly different from group 5 in terms of the number of idea being produced. For the number of appropriate ideas produced, Levene's test showed that the groups were characterised by non-equal variance. A Games-Howell test was then used showing there to be only a significant difference between groups 2 and 3 in terms of the appropriate ideas being produced.

Results

The following section will provide the reader with the timelines of the brainstorming sessions. Firstly, the alpha-ideas produced during the free thinking brainstorm phase are analysed. This is followed by the analysis of beta-ideas produced under the influence of the stimuli shown to the brainstorm members. During this section the research questions and hypotheses laid out earlier in the paper are dealt with along with the analyses.

Ideas produced under free thinking brainstorming

This section displays results regarding the rate of alpha-idea generation, the appropriateness of alpha-ideas and an assessment of what proportion of stage-gate concepts contained alpha-idea(s).

Rate of idea generation

Figure 5 addresses RQ1 displaying the sequence of ideas created for each project during the group brainstorm session. Each small circle represents an idea. The bold figures give the total number of ideas produced and italic figures provide the rates of idea production (ideas/minute).

The plots display typical characteristics of brainstorming, with several idea clusters (Nijstad et al. 2002) showing how new ideas spark developmental ideas. From figure 5 it can be seen that the rate of idea production remained relatively constant throughout the first 30 minutes of each session where a normal distribution was observed and there was shown to be no significant difference between the groups. After 30minutes this rate began to drop, where in group 5 (the control group) using a Mann-Whitney test, the average ideas per minute changed from 1.2 ideas per minute to 0.7 (statistically significant to p=0.05) supporting previous findings (Helquist et al. 2007).

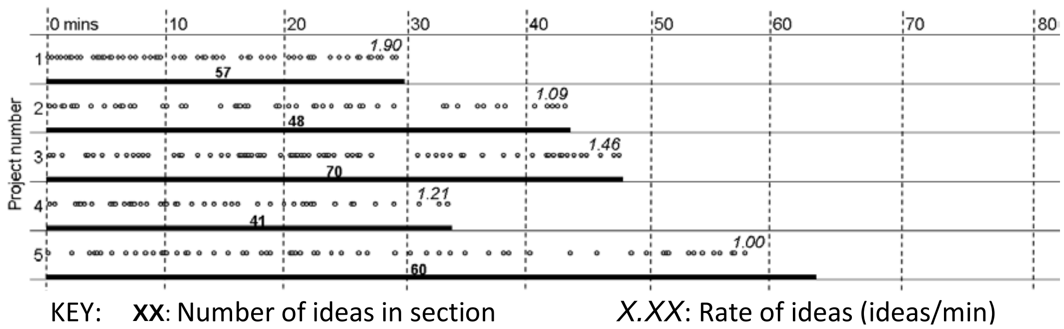


Figure 5. Time-line showing alpha-idea production in free-thinking part of brainstorm sessions

Appropriate ideas produced

Figure 6 illustrates which of the ideas displayed in figure 5 were deemed appropriate (becoming part of a stage-gate concept) and are notated by the circles along the timelines. The plot sheds new light on the findings displayed in figure 5. As suggested in RQ2, there is a general influx of appropriate ideas during the early stages. However, where the ideas plot (figure 5) suggests idea generation performance stays roughly constant, it can be seen that producing appropriate ideas becomes more and more difficult with time. Over the five cases, ~75% of the **appropriate** alpha-ideas in the first 30minutes occurred before 15 minutes. Using a paired T-Test this showed to have a two-tailed significance value of p=0.162.

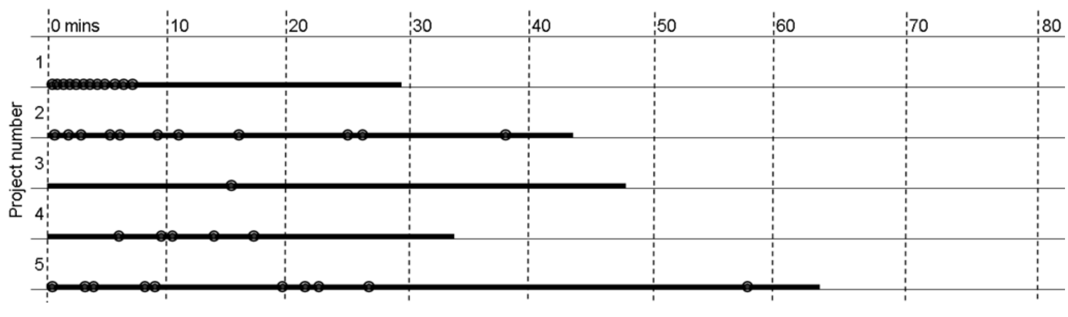


Figure 6. Time-line of appropriate alpha-ideas in free-thinking part of brainstorm sessions

Stage-gate concept breakdown

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

To give an idea of how important the free thinking brainstorm is in terms of the overall process, an average of 64% of stage-gate concepts contained alpha ideas (generated within the free thinking brainstorming session) suggesting that it is a vital phase of the innovation process. This is regarded by the authors as a revealing statistic suggesting that only one third (approx) of stage-gate concepts can be attributed to ideas generated outside the 'free thinking' brainstorm.

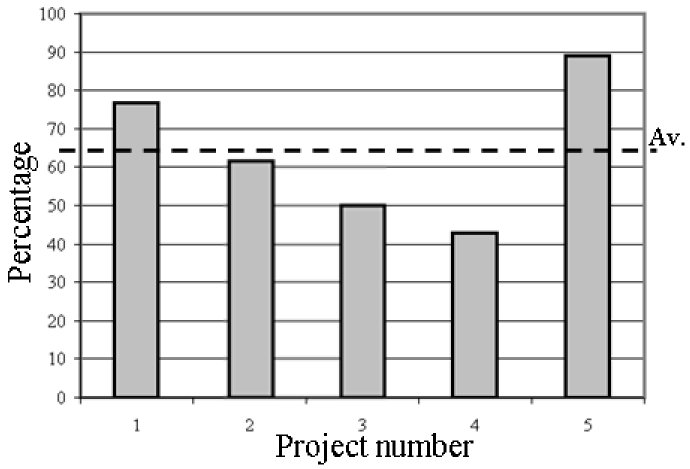


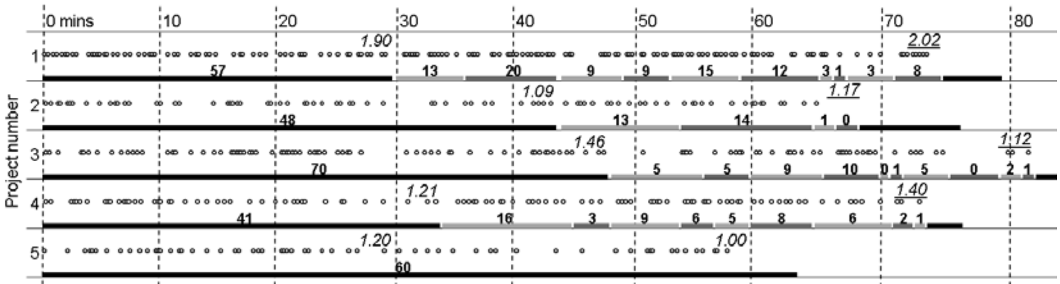
Figure 7. Percentage of concepts containing at least some alpha-ideas.

Ideas produced under the influence of stimuli

This section displays results regarding the rate of beta-idea generation, the appropriateness of the beta-ideas and an assessment of the how the beta-ideas relate to the stage-gate concepts.

Rate of beta-idea generation

Figure 8 shows the brainstorming timelines of the five projects. The first black line of each project represents the free thinking brainstorm session which begins after the project briefing. Each section of grey line represents the introduction of a new stimulus to help inspire new ideas. The final shorter dark line represents the closing discussion. Each small circle represents an idea. The bold figures give the total number of ideas produced for the particular section, and the italic figures provide the rates of idea production. The underlined figure represents the rate of idea production from the point of introduction of the first stimulus.



KEY: **XX**: Number of ideas in section *X.XX*: Rate of ideas in section (ideas/min) *X.XX*: Rate of ideas under use

Figure 8. Time-line showing alpha- and beta-idea production over complete brainstorm sessions

It is clear, both from both experimental observation and the plot in figure 8 that the stimuli helped to maintain the rate of idea generation, agreeing with previous research (Nijstad et al. 2002). Using a Kolmogorov-Smirnov test, normality was found for all 5 groups. By using a Mann-Whitney test it was shown that there was no significant differences between the rates of idea generation from before and after the stimuli was used. However, group 5 (the control group) showed a significant (p=0.041) reduction in frequency of ideas from 1.2 ideas/minute to 0.7 ideas/minute from before to after the first 30 minutes of brainstorming.

During the later stages of the brainstorm session, it is likely that the rate of idea generation was maintained by added interest and motivation experienced by the group from using the stimuli. However, there were more direct effects from the stimuli, where elements of the stimuli directly inspired ideas. These observations were backed up by feedback from the participants. For example: "The segmentation one certainly sparked a few ideas”. The stimuli also provided a starting point for participants to begin discussion and lateral thinking: “secondary conversation that was quite productive actually".

Appropriateness of beta-ideas produced

Figure 9 shows which of the ideas displayed in figure 8 turned out to be appropriate, (becoming part of a stage-gate concept). Each of these appropriate ideas are represented by the circles along the black and grey time lines in figure 9.

It is clear that, in general, the stimuli had a positive effect on the ideas being generated, with a higher proportion of appropriate ideas being produced under the influence of stimuli than could be expected at the particular late stage of the brainstorm session. As for the number of ideas, a Kolmogorov-Smirnov test was used showing normality for all groups. The Mann-Whitney test was then used showing that groups 1-4 had no significant differences between before and after the stimuli were introduced. However, group 5 had a significant (p=0.008) reduction, where the rate of appropriate ideas produced after 30minutes was roughly 10% of the rate before 30minutes. This would suggest the use of stimuli in general helps to produce appropriate ideas as predicted in the hypothesis for RQ5.

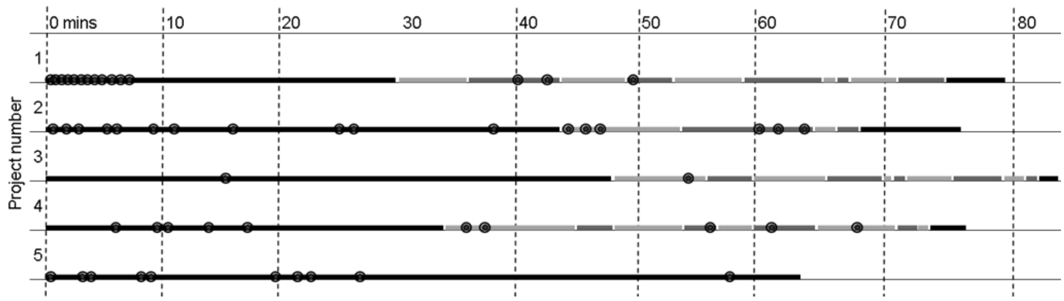


Figure 9. Time-line highlighting all the appropriate ideas over the complete brainstorm sessions

Stage-gate concept breakdown

Figure 10 shows how the appropriate beta-ideas are spread over the stage-gate concepts for the four projects provided with stimuli. The total number of appropriate beta-ideas is represented by the white columns. This consists of original ideas and developmental ideas. The total number of different concepts containing beta-ideas is represented by the hatched columns, giving some idea as to how diverse the ideas are. Arguably the most valuable measure is that of the original beta-ideas, represented by the grey column. An original beta-idea can be classed as heterogeneous and is the first idea to be associated with a new stage-gate concept.

From figure 10 it can be seen that on average only 1 original idea is produced as a result of the prescribed stimuli. This did not entirely support the hypothesis that the diversity of the stimuli would lead to more original beta-ideas, instead suggesting that the stimuli aid the development of concepts, based on creative thoughts of: ‘how to…’ rather than ‘what else…’. It appeared that the groups given the guided stimuli (projects 2 and 4) performed better, producing on average more appropriate beta-ideas; though most of the ideas proved to be developmental ideas rather than original or heterogeneous ideas.

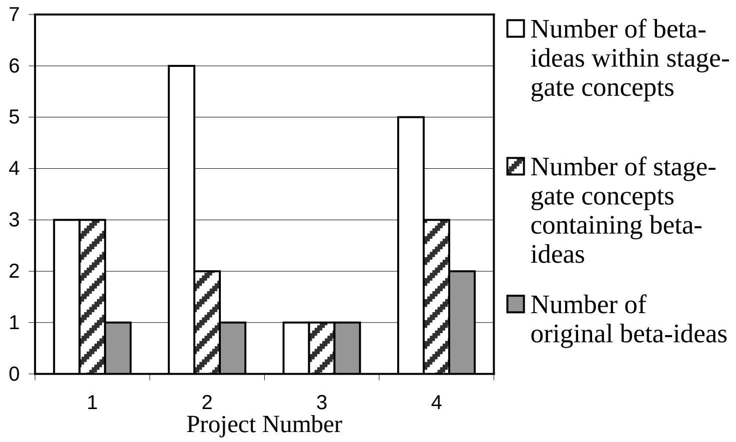


Figure 10. beta-idea to concept breakdown

Discussion

The following section will discuss the results and their implications, shedding light upon the research questions posed in the introduction.

Analysis of the free thinking brainstorm

Regarding RQ1, this research showed that the rate of idea production appeared to be roughly constant throughout each session until around 30 minutes. The rate of ideas was then shown to significantly reduce after 30minutes without intervention.

By following an industrial innovation process for real projects, the evaluation of how ‘appropriate’ each idea was, could be assessed in an objective manner: i.e. those early brainstorm ideas that are ‘appropriate’ are the ones that make it through to be part of a stage-gate concept. The results show that in total,75% of the appropriate alpha-ideas are produced within the first 15 minutes of the first 30minutes of brainstorming (see figure 6). Significant reductions in the number of ideas being produced was observed after 30minutes. In light of this, one recommendation would be that more time should be spent towards the end of brainstorming session on linear development of the ideas already produced (thus not wasting time producing inappropriate ideas). This recommendation would also be promoted by previous research (Mulet and Vidal 2008) which suggests adding behaviours and structure (which they consider developmental ideas) to functions during early stages of design will increase the ‘efficiency’ of the design process.

To address RQ3, figure 7 provides a revealing insight into how the ideas produced within the free thinking brainstorm session (alpha-ideas) influence the concepts at the stage-gate; where roughly two-thirds of the concepts produced for each project were initiated by ideas produced within the free thinking section of brainstorming.

The influence of the prescribed stimuli

From experimental observation it would appear that the stimuli prescribed to the brainstorming groups were well received. This was substantiated by the following quotes captured during the cool-down period of each brainstorm: "They were all quite good I thought"; "The stimuli at the end were very good"; "Very useful actually"; "If we'd have gone through those at the beginning we would have probably got these ideas quicker". It was quite evident at the time and during the video analysis that following a lull in performance, the stimuli aided the group in terms of motivation. It can be seen from the timelines (in figure 8) that the brainstorms with prescribed stimuli lasted longer. Furthermore, the rate of idea production remained higher even at the later stages of the sessions when using the prescribed stimuli answering RQ4.

From the analysis of figure 6, it was suggested that the rate of appropriate idea generation reduces significantly with time throughout the brainstorm session. It can be seen from figure 9 that the introduction of prescribed stimuli helped to counteract this in all cases. The hypothesis from RQ5 was therefore supported and recommendations to the case company have now been implemented based on this finding.

The originality of the ideas produced (RQ6) was not significantly increased, with more homogeneous appropriate ideas being produced than ideas that generated new concepts (original ideas). This could have been due to the group trying to incorporate the principles taken from the stimuli into the existing ideas, or simply just a natural characteristic of these latter stages of the brainstorming sessions where ideas are developed into complete concepts rather than generating completely separate heterogeneous ideas.

The nature of creative stimuli

In previous work (Howard 2008) it has been suggested that stimulative ideas are generated by means of direct transfer from the stimuli to the new design situation. Suppressative ideas arise when the stimuli help to remove mental blocks in order for new ideas to be created (Howard 2008). These mechanisms were not validated during this study, although some stimuli were observed to “spark secondary conversation that was quite useful” and “new and interesting trains of thought”. Thus, although some ideas produced were not connected to the stimulus (producing anomaly type ideas) this should not suggest that the stimulus was of no use.

In other previous research, different authors have suggested categorisation schemes for different types of stimuli (see related literature section for examples). However, few have suggested mechanisms showing how these different stimuli are used to prompt new ideas. Mak and Shu (2008) have suggested that there are four categories of mechanism for idea generation using biological stimuli: *literal implementation*, *biological transfer*, *analogy* and *anomaly*. While these categories provide distinction between the types of mechanism, a framework for describing the differences is not shown. In a paper from the domain of cognitive psychology, Thagard (1997) suggests that there are 4 stages to what he terms as the ‘generation model’ of analogical transfer for ‘stimulative’ ideas:

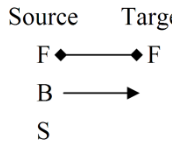
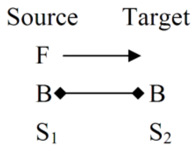
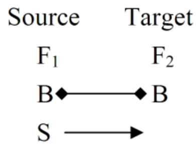
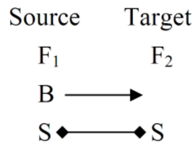
1. Start with a target problem.
2. Retrieve or encounter a very approximate analog.
3. Fill out the approximate analog by looking at the target and identifying aspects of the constructed analog that need identification. Fill these in.
4. Transfer from the newly constructed source to target.

Within this description, Thagard describes the stimulus to be the source, and the task or problem as the target. If we consider both the target and source to be either partially or fully formed concepts (a proposition which has at least one function (F), behaviour (B) and structure(S)) new insight can be gained to analogical transfer. This would give a modified series of stages:

1. Start with a target problem.
2. Retrieve or encounter a source that has at least one similar and one different F, B or S.
3. Identify which F, B or S is the same for the source and the target and whether the F, B or S that is different may be useful in the target domain.
4. If deemed useful, transfer and modify the new F, B or S from the source to the target.

This gives rise to 4 different forms of stimulative mechanisms described in table 1

Table 1. The four stimulative mechanisms of analogical transfer

1. Fb analogy	2. Bf analogy	3. Bs analogy	4 Sb analogy
			
Same function different behaviour	Same behaviour, different function	Same behaviour different structure	Same structure different behaviour

Because there are 2 'behaviour' analogies this may provide explanation as to why Benami and Jin (2002) concluded that 'behavioural' stimuli produce more ideas than functional or structural stimuli. During this study the stimuli provided had functional, behavioural and structural elements which may have added to the quality of the stimuli. In other previous research into case based reasoning and design-by-analogy (McAdams and Wood 2002), analogical transfer has primarily concentrated on problem solving using mechanisms 1 and 3. However, product design is different to problem solving and is perhaps better described by C-K theory (Hatchuel and Weil 2009) where concepts are non proven propositions whose functions, behaviours and structures morph through the design process abiding to set theory. If correctly identified, the above mechanisms may help to prescribe the most appropriate forms of stimuli for a given design task or activity.

Conclusion

This research has a variety of implications for engineering design practice and research. It has been shown in an industrial context through quantitative and qualitative observations that prompting designers with stimuli during brainstorm sessions is of benefit both to the frequency and quality (in terms of increased appropriateness) of the ideas produced. The researchers would recommend that facilitators have stimuli ready prepared when conducting brainstorm sessions in order to introduce them to the group after an observed lull in performance after roughly 30-40 minutes of idea generation.

The results of this study also have important implications for design research. It has been shown that prompting brainstorm groups with stimuli is of benefit to idea generation, even when the stimuli are randomly sourced and retrieved. From this we may conclude that showing designers any information is generally better for idea generation than no information. Thus designers may find it easier to relate information/ideas to the design task then to propose new related information/ideas. This may be an explanation why 'ambiguity' of the stimuli is a useful characteristic (Benami and Jin 2002) as it allows the designers to suggest the purpose or use for the stimuli/information presented. It is therefore advised that all research regarding the procurement of information for use as creative stimuli must be evaluated not against a control group using no stimuli, but against a placebo group (Adair et al. 1990) in which the stimuli used is randomly retrieved (see Jones et al. (2001) for example method). It is also of extreme importance for future studies that both the type of design task, the designer participating, and the type of stimuli must in turn be investigated as independent variables with the ideas generated assessed as the dependent variable. This should be conducted through a series of controlled experiments by design psychologists and comparative industry based studies. The authors believe that analysing each of these variables in terms of function, behaviour and structure will help characterise the types of ideas produced and may be the key to matching the correct types of stimuli to the different design activities or tasks.

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