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ICDC 2012

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PROCEEDINGS

Design Creativity 2012

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Editors

Design Creativity 2012

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Preface

Design Creativity is a challenging but core topic of study in design. It encapsulates the essence of originality of new concepts and the evolution of our society. A simple search on the World Wide Web for "design creativity" returns around 520,000 hits and about four thousand articles. Since the year 2000, when the Design Society was originally established as a formal body, listed articles have grown on average of over 16% per year from just over 700 to just under 4,000. A steady increase, year on year, of scholars and researchers focussing their interests and publishing their findings in this fundamental and critical field of study.

These proceedings present articles of the second conference on Design Creativity (ICDC 2012), with the first being held in Kobe, Japan (http://www.org.kobe-u.ac.jp/icdc2010/). ICDC 2012 was held on the 18th to 20th September 2012 in Glasgow, UK. The aim of the biennial conference is to provide an international forum to present and discuss the latest findings in the nature and potential of design creativity from both theoretical and methodological viewpoints. ICDC is an official conference promoted by the Design Creativity Special Interest Group (SIG) of the Design Society. The SIG was established in 2007; since then, its ambit has expanded to include engineering design, industrial design, artificial intelligence, linguistics, and cognitive science. Along with the SIG's International Journal of Design Creativity and Innovation the proceedings of the conference will form a continuing archive of the contributions to design creativity.

All papers received were blind reviewed by at least two referees drawn from an international programme committee. They all deserve special thanks for their time, effort, pertinent comments and recommendations. 31 podium papers were accepted for final publication. The topics and themes of the conference and corresponding proceedings included, but were not limited to the following:

- Creativity and emotion
- Cognition in creative design
- Creative design processes, methods and techniques
- Design thinking and education
- Design creativity practice
- Creativity and innovation
- Creative design assessment and evaluation
- Collaborative creativity

The organisers are grateful for the contributions of Strathclyde University, Scottish Engineering, Tunnocks and Barr.

Alex Duffy and Andrew Wodehouse
University of Strathclyde

On behalf of the ICDC 2012 Organising Committee
August 2012

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Cognition I

[Design Cognition Differences When Using Structured and Unstructured Concept Generation Creativity Techniques]
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DESIGN COGNITION DIFFERENCES WHEN USING STRUCTURED AND UNSTRUCTURED CONCEPT GENERATION CREATIVITY TECHNIQUES

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Abstract: This paper presents the results of measuring and comparing design cognition while using different creativity techniques for concept generation in collaborative engineering design settings. Eleven design teams, each consisted of two senior mechanical engineering students, were given the same two design tasks, respectively using an unstructured concept generation technique (brainstorming) and a structured technique (TRIZ). A protocol analysis was carried out where the designing activities were audio-visually recorded and analysed using the FBS ontologically-based coding scheme. Preliminary results indicate that the students' design cognition differed when designing with different concept generation creativity techniques. The inter-technique differences were mainly noticeable in the early stages of designing. Specifically, designers tend to focus more on problem-related aspects of designing, i.e., design goals and requirements, when using the structured technique of TRIZ. Alternatively, when using the unstructured technique of brainstorming, designers focused more on solution-related aspects of designing, i.e., a solution's structure and behaviour.

Keywords: *creativity techniques, design cognition, FBS ontology, protocol analysis*

1. Introduction

The creativity of engineering product design is primarily determined in the conceptual design activity, in which design concepts are generated to largely define fundamental characteristics of design outcomes (French, 1999; Keinonen, 2006). Due to the importance of conceptual design, numerous concept generation techniques have been developed to stimulate creativity in engineering design (Cross, 2008; Smith, 1998). These creativity techniques fall into two broad categories, unstructured/ intuitive techniques and structured/logical techniques (Shah, Kulkarni, & Vargas-Hernandez, 2000). Unstructured techniques aim to increase the flow of intuitive ideas and facilitate divergent thinking.

Brainstorming is a well-known unstructured intuitive technique. It is a group creativity technique developed and popularized by Alex Osborn (1963). The essential principle underlying this technique is to remove mental blocks and increase the chance of producing creative ideas by suspending judgment and criticism during the idea generation process. The main objective of brainstorming is to produce as many ideas as possible. The solution space produced as a result of idea generation can be further expanded by amalgamating and refining the ideas while judgment is still deferred.

In contrast to unstructured techniques, structured concept generation techniques provide a defined direction for the concept generation process, e.g., applying a systematic approach to analyse functional requirements and generate solutions based on engineering principles and/or catalogued solutions from past experience (Moon, Ha, & Yang, 2011). TRIZ is a well-developed structured creativity technique. TRIZ, which is the acronym in Russian for the theory of inventive problem solving, was developed by Genrich Altshuller (1997, 1999). Based on critical analyses of historical inventions, a set of fundamental design principles was derived aiming to discover and eliminate technical and physical contradictions in solutions (Silverstein, DeCarlo, & Slocum, 2007; Terninko, Zusman, & Zlotin, 1998).

The creativity techniques of brainstorming and TRIZ have both been widely applied in industry. The research reported in this paper focuses on the effects of brainstorming and TRIZ on design cognition when given tasks of similar levels of complexity. If a significant difference is identified, future studies will further investigate the relationship between the cognitive differences identified here and the creativity of design outcomes.

Compared with brainstorming, TRIZ prescribes an “abstraction” procedure of defining the contradiction (Silverstein et al, 2007), which requires designers to formulate their generic question in terms of requirement, function and expected behaviours. This study thus hypothesizes that designers using the TRIZ concept generation creativity technique have a relatively higher focus on understanding the problem than when using the brainstorming technique.

Design theories usually assume that there is “a regularity in designing that transcends any individual or situation” (Pourmohamadi & Gero, 2011). In particular, the designing process generally commences with an articulation of design problems before moving to the generation and evaluation of solutions. Therefore, the second hypothesis for this study is that designer’s focus on the problem decreases along with the progress of designing, independent of which particular concept generation creativity technique is used.

2. Research design

This study consisted of two design experiments, performed by eleven small design teams of two persons. Each team was given the same two design tasks, whose complexities were set at the same level, as judged by design educators and expert designers. Participants were then asked to apply brainstorming and TRIZ techniques respectively in these two tasks.

2.1. Participants

Twenty-two mechanical engineering students participated in this study voluntarily. They were recruited from the first semester of a capstone design course at a large land grant university. As seniors, the students’ prior design education was a cornerstone experience in a first-year engineering course and a sophomore-level course that focused on exposing students to engineering design and design methods at an early stage of their professional development. In this capstone sequence, student teams would work with a faculty mentor on a year-long design project. The students' primary goal for this first semester is to scope their given design problem, generate several potential solutions, and select an alternative to embody during the second semester. It is in this initial semester where the students received instruction on different concept generation creativity techniques that are explored in this study.

2.2. Design Experiments

Before each experiment, there was a lecture elucidating and detailing one of the creativity techniques. The brainstorming lecture covered the fundamental principles that contribute to intuitive concept generation, e.g., delaying judgement, production for quantity rather than quality of ideas, welcoming strange and unusual ideas, and inter-connection and cross-pollination on the basis of the generated ideas. The TRIZ lecture focused on the concept of contradiction and a simplified TRIZ procedure. Hardcopies of the 40 inventive principles and contradiction matrix were provided during the lecture and design experiment.

During the experimental sessions, the students were asked to collaborate with their team members to generate a design solution that meets the given design requirements within 45 minutes. All the design activities (including conversations and gestures) were audio and video recorded for later analysis.

3. Ontologically-based protocol analysis

The video record of design activities were analysed by protocol analysis using an ontologically-based protocol segmentation and coding method (Gero, 2010; Pourmohamadi & Gero, 2011).

3.1. The function-behaviour-structure ontology

The FBS ontology (Gero, 1990; Gero & Kannengiesser, 2004) models designing in terms of three classes of ontological variables: function, behaviour, and structure. The *function* (F) of a designed object is defined as its teleology; the *behaviour* (B) of that object is either derived (Bs) or expected (Be) from the structure, where *structure* (S) represents the components of an object and their compositional relationships. These ontological classes are augmented by *requirements* (R) that come from outside the designer and *description* (D) that is the document of any aspect of designing, Figure 1.

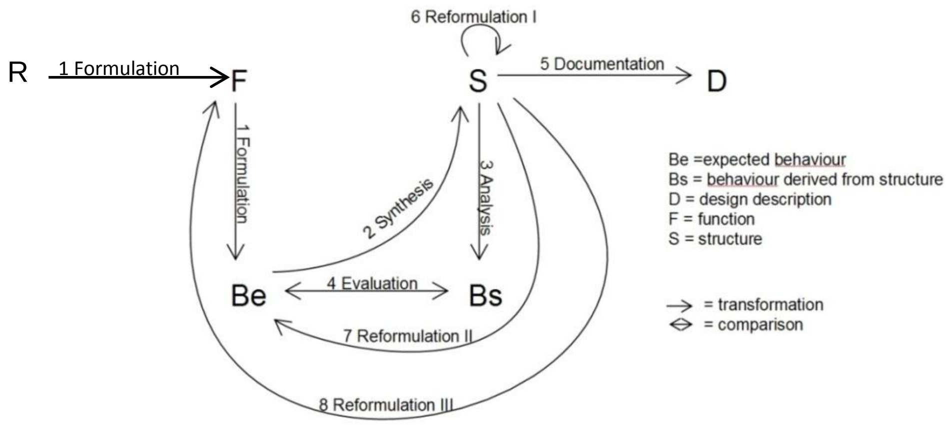

Figure 1. The FBS ontology (after Gero & Kannengiesser, 2004)

In this ontological view, the goal of designing is to transform a set of requirements and functions into a set of design descriptions. The transformation of one design issue into another is defined as a design process (Gero, 2010). As a consequence, there are 8 design processes that are numbered in Figure 1.

3.2. Integration of the FBS-based coding scheme with problem-solution division

The analyses reported in this paper use an integration of the FBS ontologically-based coding scheme with a Problem-Solution (P-S) division (Jiang, Gero & Yen, 2012). The designing process is often viewed as constant interactions between two notional design "spaces" of the problem and the solution (Dorst & Cross, 2001; Maher & Tang, 2003). This paper uses the P-S division to reclassify design issues and syntactic design processes into these two categories, as presented in Table 1Table . The FBS-based coding scheme does not specify description issues with the P-S division. Description issues and the process of "documentation" are thus excluded in the analysis using the P-S division.

Table 1. Mapping FBS design issues & processes onto problem and solution spaces

Problem/solution Space	Design Issue	Syntactic Design Processes
Reasoning about Problem	Requirement (R) Function (F) Expected Behaviour (Be)	1 Formulation 7 Reformulation II 8 Reformulation III
Reasoning about Solution	Behaviour from Structure (Bs) Structure (S)	2 Synthesis 3 Analysis 4 Evaluation 6 Reformulation I

Utilizing the problem-related issues/processes and solution-related ones, this paper examines the students' design cognition from both a meta-level view (i.e., a single-value measurement) and a dynamic view (i.e., taking the sequential order of design issues/processes into consideration).

3.2.1. Problem-Solution index as a single value

The P-S index, which helps to characterize the overall cognitive pattern of a design session, was calculated by computing the ratio of the total occurrences of the design issues/processes concerned with the problem space to the sum of those related to the solution space, as shown in Equations (1) and (2). Compared with the original measures of design issues and syntactic processes using a set of measurements, the P-S indexes with a single value can facilitate comparisons across multiple sessions and across sessions involving different technique usage in an effective way.

$$\text{P-S index(design issue)} = \frac{\sum(\text{Problem}-\text{related issues})}{\sum(\text{Solution}-\text{related issues})} = \frac{\sum(R,F,Be)}{\sum(Bs,S)} \quad (1)$$

$$\text{P-S index(syntactic processes)} = \frac{\sum(\text{Problem}-\text{related syntactic processes})}{\sum(\text{Solution}-\text{related syntactic processes})} = \frac{\sum(1,7,8)}{\sum(2,3,4,6)} \quad (2)$$

3.2.2. Sequential P-S index as a time series

Designing is a dynamic process. A single-value P-S index for the entire session will collapse any time-based changes into a single value. This paper proposes a further measurement: the sequential P-S indexes across different sections of a design session. A fractioning technique (Gero, 2010) was used to divide the whole design session into 10 non-overlapping deciles each with an equal number of design issues or syntactic processes. It then computed P-S indexes for each decile, and used a sequence of temporally ordered P-S indexes to represent the cognitive progress during the designing process.

4. Results

4.1. Design issues and syntactic processes

After the FBS ontologically-based protocol segmentation and coding, the video records of designing were converted into sequences of design issues and, consequently, sequences of syntactic design processes. Due the varied lengths of design sessions, the occurrences of design issues and syntactic processes were respectively normalized as the percentages of the total issues/processes in each session, Figure 2.

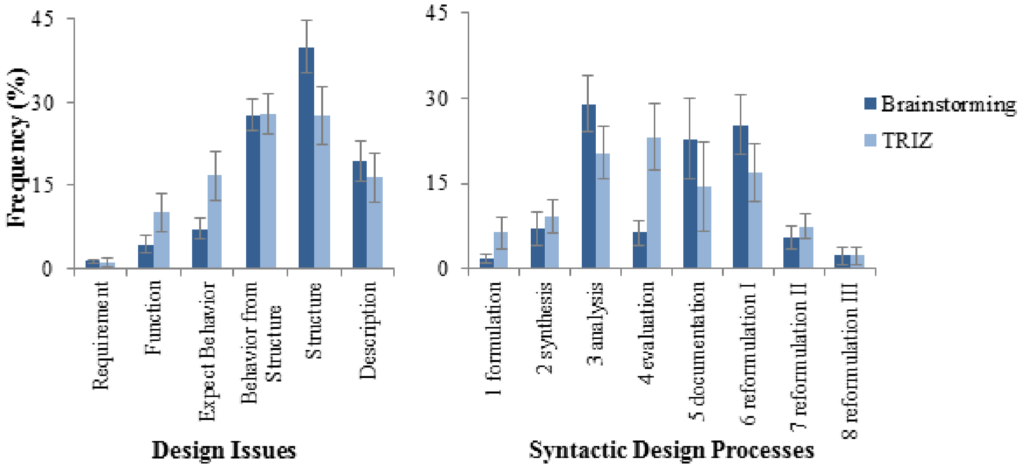

Figure 2. Frequency distribution of design issues and syntactic design processes (%)

Compared to the sessions using TRIZ, the brainstorming sessions have higher percentages of structure design issues, and "analysis", "documentation" and "reformulation I" syntactic design processes. When using TRIZ, students' cognition was significantly more focused on the design issues of function and expected behaviour, and on the syntactic design processes of "formulation" and "evaluation". These design issues and syntactic processes are then categorized using the P-S division.

4.2. Inter-session comparisons between brainstorming and TRIZ

Comparisons of P-S indexes between brainstorming and TRIZ sessions are presented in Figure 3 and Table 2 for the full protocol as a single activity and for each session divided into two sequential halves. These results indicate that the TRIZ sessions had a significantly higher P-S index (in terms of both issue index and process index) than brainstorming sessions, for the entire design session and for the first half of the design sessions. For the second half of design sessions, though the issue index is significantly different, the inter-technique difference (mean) was reduced from -0.66 to -0.16. Paired-sample *t*-test shows that there was no statistically significant difference in terms of the two syntactic process indexes in the second half of design sessions' protocols, $t(9)= -0.195$, $p>0.05$.

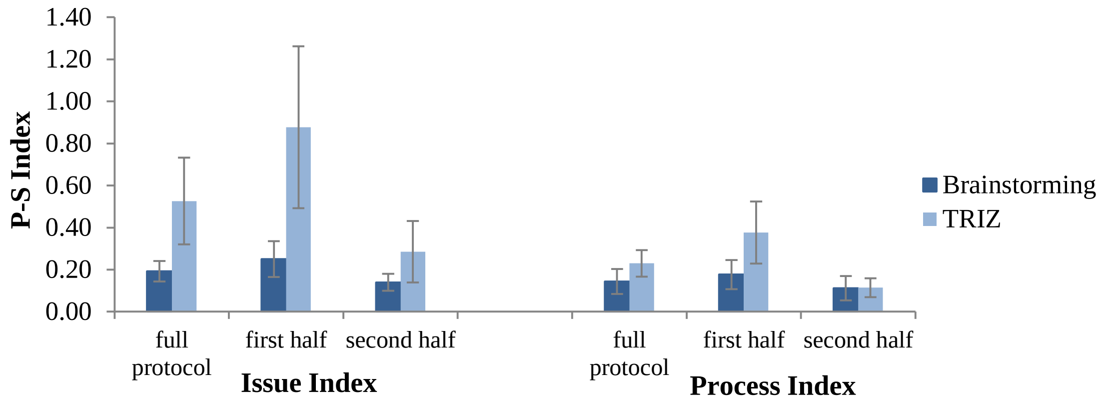

Figure 3. Comparison of P-S indexes between brainstorming and TRIZ sessions

Table 1. Comparison of P-S indexes between brainstorming and TRIZ

Fractioned protocols	Design Issue Index				Syntactic Process Index			
	Brainstorming	TRIZ	Comparison		Brainstorming	TRIZ	Comparison	
	Mean (SD)	Mean (SD)	*t*-score	*p* value	Mean (SD)	Mean (SD)	*t*-score	*p* value
Full protocol	0.192 (0.049)	0.526 (0.206)	-4.892	0.001***	0.144 (0.060)	0.230 (0.063)	-3.441	0.009**
First half	0.251 (0.085)	0.877 (0.385)	-4.704	0.002***	0.177 (0.069)	0.377 (0.147)	-4.267	0.003***
Second half	0.140 (0.040)	0.285 (0.146)	-3.252	0.012*	0.111 (0.058)	0.114 (0.045)	-0.195	0.850

* $p<0.05$, ** $p<0.01$, *** $p<0.005$

4.3. Dynamics of design cognition

The dynamics of design cognition are examined using two analytic methods. Single-value P-S indexes are compared between the first and second halves of design sessions for each concept generation techniques via paired-sample *t*-tests. The nuances of designing dynamics are then illustrated by sequential P-S indexes over time.

Table 2. Intra-session comparison of P-S indexes

Creativity Technique	P-S Index	First half	Second half	Within-session comparison	
		Mean (SD)	Mean (SD)	*t*-score	*p* value
Brainstorming	Issue Index	0.251 (0.085)	0.140 (0.040)	4.100	0.003*
	Process Index	0.177 (0.069)	0.111 (0.058)	4.323	0.002*
TRIZ	Issue Index	0.877 (0.385)	0.285 (0.146)	6.022	0.000**
	Process Index	0.377 (0.147)	0.114 (0.045)	6.485	0.000**

* $p<0.005$, ** $p<0.001$

4.3.1. Intra-session Comparisons between First and Second Halves

Intra-session comparisons of the P-S indexes between the first and second halves of design sessions are presented in Table 3. They indicate that, regardless of the concept generation technique employed and the measurements of issue/process index, the first half of the design sessions have a significantly higher P-S index than the second half of the design sessions.

4.3.2. Sequential P-S Index over Time

The intra-session differences of design cognition are further explored using sequential P-S indexes that divide the entire design session into 10 successive non-overlapping sections, i.e., into deciles. Design cognition here is measured by both a sequential issue index, Figure 4, and by a sequential process index, Figure 5. Both figures showed a decreasing trend across the design sessions for both measurements. The TRIZ session had a relatively larger decreasing rate, as it started with a greater focus on the problem than the brainstorming session did.

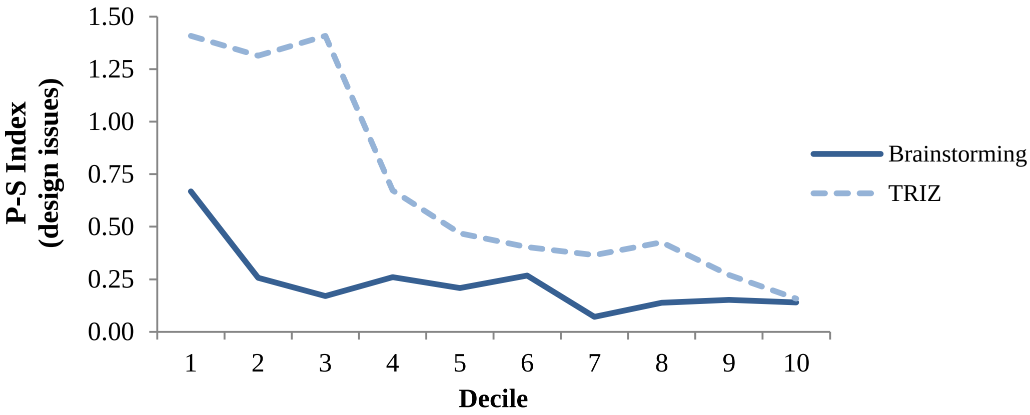

Figure 4. Sequential issue index in ten sections of design protocols

Comparing sequential P-S indexes between the brainstorming and TRIZ sessions, the inter-session differences were mainly in the early stages of designing. In the first 4 deciles, the TRIZ sessions' P-S indexes (both in issue index and process index) were more than twice the index values in the brainstorming session. In the last two deciles of design sessions, there were no statistically differences found in terms of either issue index or process index.

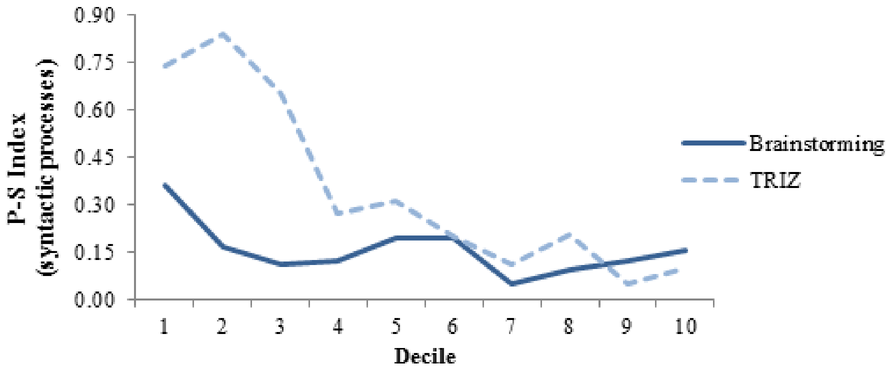

Figure 5. Sequential process index in ten sections of design protocols

5. Discussion & conclusion

This paper examines the effects of unstructured/intuitive and structured/logical concept generation creativity techniques on the design cognition of senior students in a collaborative engineering design setting. The analyses and discussions are undertaken in response to the two hypotheses presented in the Introduction.

(1) designers using the structured creativity technique of TRIZ have a relatively higher focus on the problem than when using the unstructured technique of brainstorming, and

(2) designers commence with a relatively higher focus on the problem and this focus decreases as the design session progresses, independent of which particular creativity technique is used.

5.1. Designing with TRIZ is more focused on problem than brainstorming

Results from this experiment provide evidentiary support for the first hypothesis that students spent more cognitive effort reasoning about design problems when using the structured concept generation technique of TRIZ than they did when using the unstructured brainstorming technique. This applied to almost the entire design session for the P-S design issue index and to the first half of the design session for the P-S design process index, Figure 3. This qualitative assessment is confirmed with paired-samples *t*-tests applied in the protocols of the entire design sessions, as well as those of the two halves of the design session, Table 2. Statistical results confirm that statistically significant differences occur between the brainstorming and TRIZ sessions in terms of overall issue and process indexes characterising the entire design session.

The fractioning technique further indicated that the cognitive differences between the two creativity techniques were primarily observed in the early stages of designing, Figures 4 and 5. It suggests that using brainstorming and TRIZ may mainly affect the students' design cognition during the initial problem framing and concept generation phases of designing, and that they have relatively less influence on their design cognition related to the further development of design concepts.

This cognitive difference corresponds with the manner in which the two concept generation creativity techniques are formalized. In order to use the TRIZ and its 40 inventive principles and contradiction matrix, a designer must first formulate the design problem into an abstract contradiction. This explicit, structured instruction requires students to engage in cognitive exercises pertaining to the requirement, function and expected behaviour of the design problem. Brainstorming, in comparison, offers no structured direction for the designer, thus students tended to jump straight to activities related to solutions without fully scoping the design problem.

5.2. Focus on the problem decreases while designing progresses

The second hypothesis concerning the independence of overall design behaviour from any particular concept generation creativity techniques employed, i.e., a "regularity" of designing, was qualitatively shown with the line charts of the sequential P-S indexes in Figures 4 and 5, and statistically validated by the intra-session comparison of the P-S indexes between the two halves of design sessions, Table 3. Figures 4 and 5 both show the decreasing slopes against the ascending order of decile number. Irrespective of which particular creativity technique is used, the issue index and process index measured in the first half of design sessions' protocols were significantly larger than those in the second half of the design sessions' protocols as presented in Table 3, providing evidentiary support for the hypothesis. As both concept generation creativity techniques are oriented towards the goal of generating a solution to the design task, it is not surprising that a design team's cognition is more focused on structure issues towards the end of the designing process.

5.3. Conclusion and future research

This paper compares senior mechanical engineering students' design cognition when designing with two concept generation creativity techniques of brainstorming and TRIZ. The protocol analysis used two novel measurements on the basis of an integration of the FBS ontologically-based coding scheme with a P-S division. Preliminary results indicate that using different concept generation creativity techniques may induce different behaviours in designers, and the technique-specific differences are within an overall "regularity" of designing. Specifically, designers using the structured technique of TRIZ tend to focus more on the problem-related aspects of designing than when using the unstructured technique of brainstorming.

The next step of this study aims to assess how using different concept generation techniques affects the creativity of design outcomes, as well as whether the cognitive differences are correlated to the creativity difference of design outcomes.

Understanding and measuring the design cognition of students and designers as they utilize different concept generation techniques provides a foundation for educational interventions that target desired behaviours.

The findings of this paper are limited by the sample size of this study and the specifics related to the research setting. Confirmative studies with a larger sample size, as well as including other types of designers, are needed to generalize the influence of brainstorming and TRIZ on design cognition. It requires examining more concept generation creativity techniques in order to generalize the findings beyond brainstorming and TRIZ techniques to other unstructured and structured techniques.

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CREATIVE PROCESSES IN GROUPS – RELATING COMMUNICATION, COGNITIVE PROCESSES AND SOLUTION IDEAS

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Abstract: In technical product development group creativity sessions are performed to develop new and unobvious solution ideas. Different factors, e.g. creativity methods, influence the creative process and consequently the created solution ideas. The analysis of the communication within the group in addition to the evaluation of the solution ideas provides a deeper understanding of the impact of these influencing factors. In this work, we develop an approach to analyse the communication process in group creativity sessions. We relate communication elements to cognitive effects such as production blocking known from psychology research. This approach allows for the detailed analysis of the development of solution ideas – from their emergence to their documentation or rejection.

Keywords: *creative process, solution search, communication*

1. Introduction

Creativity plays an important role for solving tasks and problems in daily life. Correspondingly, in technical product development, engineers also ask for creativity to solve problems. Particularly for the phase of generating solution ideas, a number of methods and recommendations to increase creativity exist. One controversial recommendation is to perform group creativity sessions to combine the individuals' knowledge for creating "better" solutions (Lindemann 2009, Nijstad & Stroebe 2006, Pahl et al. 2007).

Figure 1shows a model of the creative process in group creativity sessions. Several participants of the group creativity session develop solution ideas based on their previous knowledge and cognitive processes. They communicate these ideas to the other participants. The communication has an influence on the participants' cognitive processes and the development of the solution ideas. Additionally, influence factors such as methods, the composition of the group etc. have an impact on the development of solution ideas. With regards to the documentation of solution ideas, we observed in previous work that groups given the instruction to document all solution ideas, did not document about 50% of the communicated solutions ideas (Hashemi Farzaneh et al. 2012).

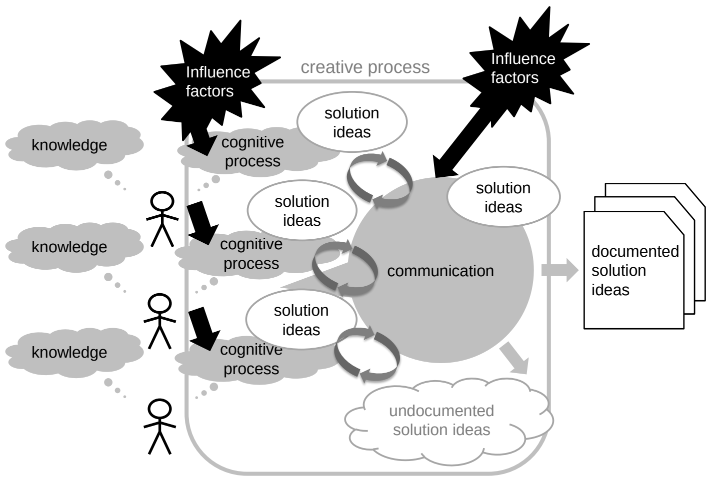


Figure 1. The creative process in group creativity sessions

In order to evaluate the impact of influence factors, the creative process can be regarded in addition to the developed solution ideas. In the creative process, the cognitive processes remain invisible to the observer. However, Stempfle & Badke-Schaub (2002) state, *"communication provides a prime access to the thinking and problem-solving process of the design team".*

Therefore, this work focusses on the analysis of the communication in group creativity sessions in order to integrate the developed solution ideas into the context of the creative process. By this means, the development of specific solution ideas can be regarded in detail, from the emergence to the documentation or rejection.

To start with, we give an overview of literature on the creative process in groups in the disciplines of psychology and in technical product development. Then, we introduce an approach to break protocols of verbal communication into communication elements and to relate them to cognitive effects. As an example, we analyse the communication involving one solution idea in detail.

2. Literature review: analysis of the creative process

Analysing and understanding the creative process is a research field that has been regarded from multiple perspectives according to different areas of research. However, Cross (2001) reviewed protocol studies of design processes in different disciplines and found "a number of striking similarities". He identifies *problem framing*, *co-evolution* and *conceptual bridging* as distinctive characteristics related to the generation of creative solutions (Cross 2001).

In this section, we start with an overview on psychology research relevant to understand basic cognitive effects that influence creative processes. Then, we focus on the technical product development perspective.

2.1 Psychology

In psychology, researchers have closely observed and analysed creative processes, particularly in laboratory experiments. With regards to group creativity, several cognitive effects have been identified which influence the creativity of the participants of the group negatively.

One of the negative cognitive effects is *social inhibition* (also called *evaluation apprehension*) (Diehl & Stroebe 1987), the fear of the participants that their idea will be considered unfavourably by the others.

Social loafing and *matching* are negative cognitive effects attributed to the individual participant's tendency to reduce the efforts in a group. *Social loafing* (also called *free riding*) describes the reduction of productivity because the individual participant is not held responsible for the creative output of the group (Diehl & Stroebe 1987). *Social matching* is the adaption to the least productive participant of the group creativity session (Paulus & Dzindolet 1993).

Another negative cognitive effect is *production blocking* which is explained by the fact that participants of a group creativity session cannot express their idea when it occurs to them. Instead, they have to wait for their turn to speak and are detracted by the other participants' ideas (Gallupe et al. 1991, Diehl & Stroebe 1987). Nijstad and Stroebe (2006) explain *production blocking* by stating that only one idea at a time can be processed in the individual participant's working memory which is "forgotten" as soon as he or she is distracted. *Production blocking* is considered to be particularly relevant for unsuccessful brainstorming (Nijstad and Stroebe, 2006). Methods such as electronic brainstorming or brainwriting that allow participants to document their ideas continuously have been developed to prevent *production blocking* (Gallupe et al. 1991).

2.2 Technical product development

As in technical product development "creative" solutions search is often recommended to solve technical tasks, the complexity of the tasks plays an important role. To that effect, Shah & Vargas-Hernandez (2003) state that the evaluation of the creativity process as a cognitive process is complicated by the fact that cognitive models developed by psychologist are based on relatively simple laboratory experiments and not on experiments with technical tasks. Therefore, in technical product development a number of studies focus on the evaluation of the documented ideas, solutions or products (Shah & Vargas-Hernandez 2003). Still, a number of researchers regard the (undocumented) solution ideas which are developed during the creative process. For example, Srinivasan & Chakrabarti (2010) regarded individual designers and include their utterances asking them to "*think aloud*" for the assessment of the novelty of concepts at various levels of abstraction. Hashemi Farzaneh et al. (2012) analysed group creativity sessions by considering all solutions mentioned by the participants.

In addition to the research centred on solution ideas, there is a research focus on product development or design process models and their stages. The creative process can be analysed and mapped to the stages of different process models. Stempfle & Badke-Schaub (2002) examined group creativity sessions identifying four basic proposed cognitive operations *generation*, *exploration*, *comparison* and *selection* and map them to design process stages. Gero et al. (2011) developed a software tool to assign verbal communication in group creativity sessions to elements of the design process. As an outcome, these researchers regard the amount of time spent on specific stages of the process which allows for conclusions on the validity of the product development or design processes for real group creativity processes.

3. Communication elements and cognitive effects in creativity sessions

In technical product development, one research focus is the development of metrics to evaluate the creativity of the solution ideas generated in creativity sessions (Shah & Vargas-Hernandez 2003, Sarkar & Chakrabarti 2011). As described in section 2.2, another research focus is the creative process in group creativity sessions (Stempfle &Badke-Schaub 2002, Gero 2011).

To assess the impact of different factors on group creativity sessions, the analysis of the creative process in addition to the analysis of the solution ideas allow for a more detailed assessment. Particularly interesting are two questions:

- Which processes in creativity sessions lead to creative solution ideas?
- What triggers groups to document some of these ideas and to "forget" others?

To answer these questions, the evaluation of the creativity of solution ideas has to be combined with an analysis of the creative process. As shown in Figure 1, the creative process includes the cognitive processes of the individual participants of the creativity sessions and the communication. As we can only observe the communication, we have to relate it to cognitive processes for a better understanding of the overall creative process.

The goal of this work is to develop an approach to analyse the communication of group creativity sessions and relate it to cognitive processes. Figure 2 illustrates the approach. In a first step, the verbal communication is divided into elements el_1 to el_n. These communication elements are assigned to several cognitive effects ef_1 to ef_n known from psychology research described in section 2.1. In a next step, the development of solution ideas s_1 to s_n can be regarded. We can analyse which communication elements and cognitive effects act on the development of a solution idea from its emergence until the documentation or its rejection. This is done exemplarily for a documented solution idea in section 4.

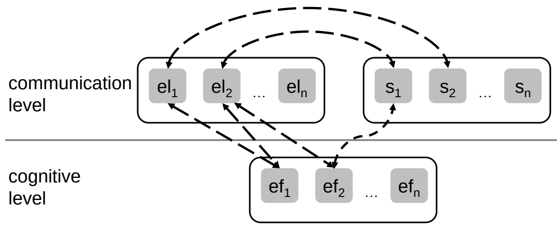


Figure 2. "Mapping" of solution ideas to communication processes

3.1 Communication elements

To analyse the communication process recorded in protocols, we define communication elements, i.e. utterances about a certain topic. On the basis of Stempfle & Badke-Schaub (2002), process-related elements and content-related elements are defined. In groups, organisation-related communication is necessary to organise the group process. An example is the assignment of tasks to specific participants of the creativity session. The organisation-related communication can be divided into elements such as *planning*, *analysis*, *evaluation*, *decision* and *control* (Stempfle & Badke-Schaub 2002). We define content-related elements according to the Munich Procedure Model (Lindemann 2009) into *goal analysis*, *goal planning*, *task structuring*, *generate solution ideas*, *properties assessment*, *decision making* and *ensuring goal achievement*. For completeness, these elements include all stages of the technical process development. Despite this, the assumption is that in a group creativity session for *generating solution ideas*, the focus of the communication is mostly on the first elements and not on *decision making* and *ensuring goal achievement*.

To allow for a more detailed analysis of the *generation of solution ideas*, we further divide the element *generating solution ideas*. Following Nijstad and Stroebe (2006), when a succession of ideas are generated, they can be in one ore different "categories". In a cognitive process, two ideas from one category are based on the same image in the working memory of an individual; a change of category is equivalent to the activation of a new image in the working memory. It is not possible to observe the cognitive process, but it is possible to identify ideas of one category by their semantic relation in the communication (Nijstad and Stroebe, 2006).

The following elements are used for the *generation of solution ideas*:

- *solution idea – new category*: a solution idea which is in another semantic category than the previous idea
- *solution idea – variation*: a solution idea which is semantically related to the previous idea (same category) and represents a variation of the idea
- *solution idea – concretization*: a concretization of the previous solution idea (same category)
- *solution idea – expansion of the scope*: an expansion of the scope of the previous solution idea (same category)
- *solution idea – repetition*: a repetition of a solution idea that has been developed previously
- *classification of solution ideas*: one or several solution ideas are classified, i.e. put into context, in relation to other solution ideas

As the positive, negative statements and questions for the *properties assessment* of the solution ideas are critical for the group's decision to document them, this communication element is further divided into:

- positive statements/ questions
- neutral statements/ questions
- negative statements/ questions

A verbal communication contains utterances that are neither process- nor content-related. An example is the replication of another participant's statement or jokes and laughter. We use the communication elements *replication*, *jokes and laughter* and *other verbal communication*, i.e. all utterances that cannot be assigned to any of the other elements. *Documentation* is added as an element, to explain the participants' actions such as *sketching* even though this is no verbal communication.

3.2 Cognitive effects

As explained in section 2.1 a number of cognitive effects have been identified in psychological research. In laboratory experiments, researchers have shown that particularly the cognitive effects *social inhibition*, *social loafing* and *production blocking* diminish the number of solution ideas generated by groups that use creativity methods such as brainstorming (Nijstad and Stroebe, 2006). Therefore, we choose these three cognitive effects as examples and relate them to communication elements. We depict the relation on excerpts of protocols from a group creativity session.

This group creativity session was performed with three mechanical engineering students (different semesters, age: 20-25, no personal relationships). The task was to *"design a way that allows people parking and leaving their bike secured".* The students were asked to generate as many solution ideas as possible and to document them by means of sketches with textual descriptions. The duration of the creativity session was thirty minutes. The students were not asked to follow a specific procedure or to use a creativity method.

3.2.1 Social loafing

Social loafing can be recognised in a creativity session if one or several participants do not contribute solution ideas for a noticeable period of time or if they do not participate at all in the discussion. In relation to communication elements this corresponds to

- a period of time in which a participant does not make utterances belonging to the communication elements *solution idea - new category, - variation, – concretization, – expansion of the scope*
- a period of time in which a participant does not make any utterances

The excerpt depicted in Figure 3 shows an example of participants not making any utterances. Two participants of the creativity session observed the third participant sketching a solution idea and agreed that they would not sketch an idea (communication element *planning*). This resulted in a delay of 20 seconds, in which both of them remained passive before one of them started talking about a solution idea that had been mentioned before.

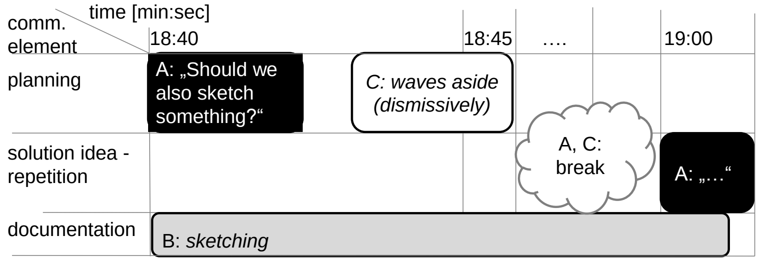


Figure 3. Social loafing (A: participant A, B: participant B, C: participant C)

3.2.2 Social inhibition

Social inhibition is triggered by the fear of participants that their ideas will be judged negatively by the other participants. This cannot explicitly be observed in the communication elements, because in most cases the participants do not express this feeling. Still, if their fear is confirmed by negative criticism as shown in Figure 4, this can increase *social inhibition*. In this excerpt, participant C suggested to *spray tear gas*, a *solution idea in a new category*. The solution idea is immediately criticised by both other participants. Negative criticism corresponds to

- utterances belonging to the communication element *negative statements/ questions*
- the communication element *jokes and laughter*

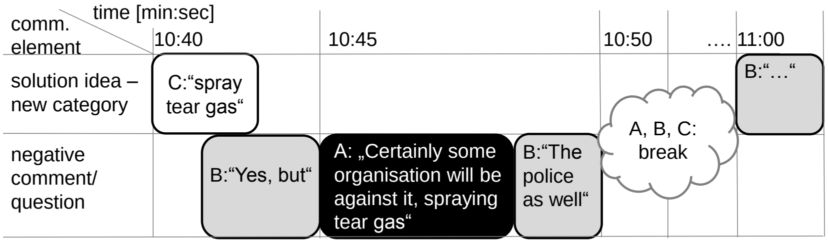


Figure 4. Social inhibition (A: participant A, B: participant B, C: participant C)

3.2.3 Production blocking

Production blocking means that the participants do not mention all solution ideas they have because they are distracted when they are waiting for their time to speak. This cognitive effect is explicit when several participants mention semantically different ideas in a short period of time as shown in Figure 5: Participant C suggests one solution idea and participant B suggests a semantically different solution idea. Then participant C "jumps" to one more semantically different solution idea. This solution idea is then pursued and concretized by participant B. Both previous solution ideas are "forgotten".

Another example of *production blocking* is that one participant concentrates on one aspect of a solution idea and is "interrupted" by a participant who broadens the idea or inversely. As to the communication elements, this corresponds to

- many utterances belonging to the element *solution idea – new category* in a short period of time.
- change from the element *solution idea – concretisation* to *solution idea – expansion of the scope* or inversely.

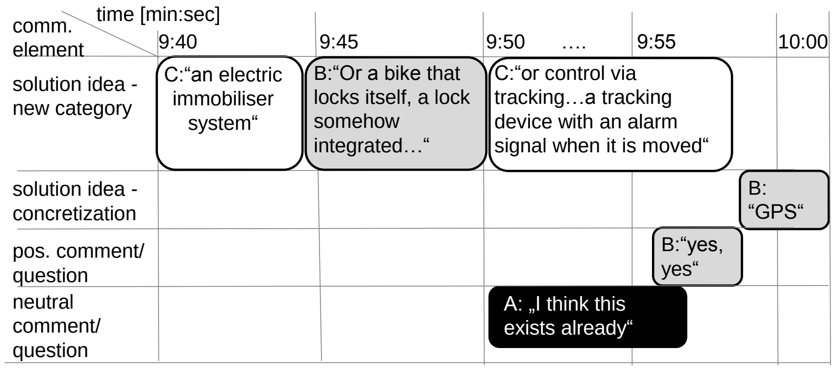


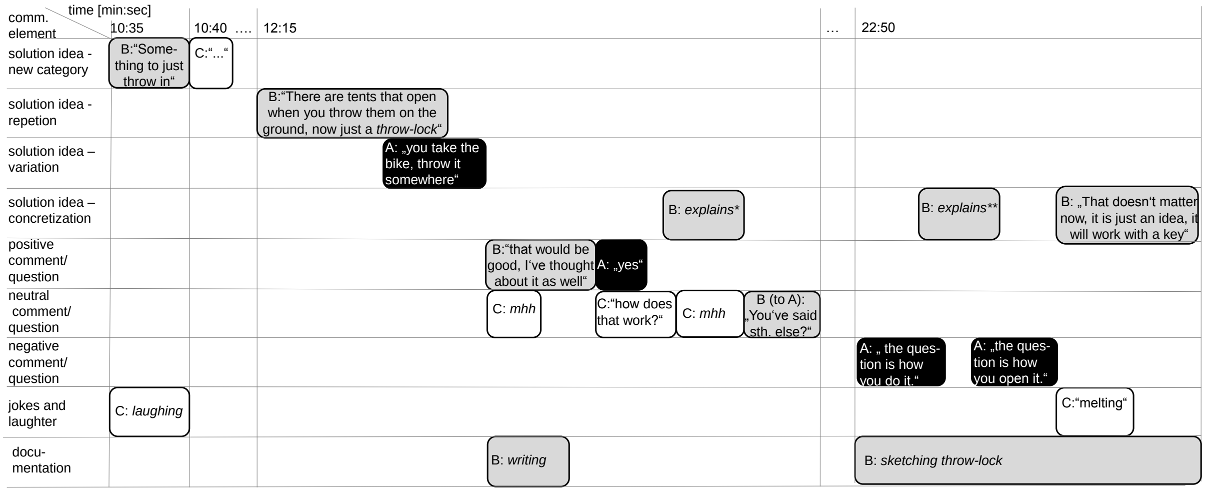
Figure 5. Production blocking (A: participant A, B: participant B, C: participant C)

4. Detailed analysis of the development of a solution idea

In this section, the communication with regards to the solution idea *throw-lock* is shown exemplarily. This solution idea was documented in a sketch with textual descriptions. Examples for undocumented solution ideas can be taken from Figure 4 (*tear gas*) and Figure 5 (e.g. *electric immobiliser system*). To start with, we explain the solution as it was documented in the group creativity session: It is described by the group as a lock consisting of a steel cable and two magnets. The lock can be "thrown" at the bike and the object to which the bike should be fixed. The magnet force actuates as a locking mechanism. The group stated that the difficulty of this solution idea is the opening mechanism. Based on the initial questions, we examine the process of the solution idea's emergence and development until its documentation in a sketch. Figure 6 depicts the communication elements involving the solution idea. The communication elements include the following utterances:

Participant B mentioned in minute 11 *throwing* a device. After other utterances, he mentions the idea of the *throw-lock* in minute 13. Participant A varies the idea by suggesting throwing *the bike somewhere*. Participant B gives positive feedback to this, but he returns to his initial idea when participant C asks about the functionality. Participant B explains it by referring to bracelets with a bistable functionality that "snaps" around the arms. Subsequently he passes on to other solution ideas.

In minute 22, he sketches the solution idea despite the negative questions of participant A and the joke of participant B.



*: “It has to be secured somehow. Do you know these bracelets? They are curved and you can snap them around your arm. They stay like this until you open them with your finger or like this. You snap them on your bike.” (*gestures with his hands*)

**: “There are two ends that join each other. You throw it; it wraps itself around the bike.” (*points at the sketch*)

Figure 6. Solution idea casting lock (A: participant A, B: participant B, C: participant C)

The analysis of the process of this solution idea’s development shows its emergence out of the image of *throwing* that participant B has in his mind. This image and the analogies to other products (tent, wristlet) endure the emergence and development of *solution ideas in new categories* so that participant°B continues developing it afterwards. Participant B is so convinced of this solution idea that he sketches it even though the other participants express their criticism with utterances belonging to the communication elements *negative comment/ question* and *jokes and laughter*.

In conclusion, this example shows that the participants of creativity sessions can pursue solution ideas despite the impact of the communication element *solution ideas – new category*. This does not necessarily distract the participants from one idea and cause the cognitive effect *production blocking*. In addition, utterances of the communication element *negative comments/ questions* do not inevitably trigger the cognitive effect *social inhibition*.

5. Discussion

The analysis of communication in group creativity sessions allows for several observations: To start with, the communication elements were defined according to process elements concerning the organisation of the group and content. We observed that not all of the defined communication elements were used by the observed groups. The duration of the creativity sessions (30 minutes) can be a limiting factor at this point. As to the cognitive effects, three negative cognitive effects were taken as examples and related to communication elements by the authors. There are a number of other, positive and negative cognitive effects which can also be regarded. In addition, the analysis performed in section 4 shows that the communication elements associated with certain cognitive effects do not necessarily trigger these cognitive effects: This does not prove that there is no relation between cognitive effects and elements, it depicts that there is no causal relation.

6. Conclusion and outlook

In this work, we analyse communication in group creativity sessions performed for solution search. We fragment the communication into utterances and assign them to communication elements depending on their topic. These communication elements are then related to cognitive effects such as *production blocking*. Communication elements and cognitive effects can positively or negatively affect the development of solution ideas. With this approach, a specific solution idea can be set into the context of the creative process so that the emergence, development or rejection of the solution idea can be analysed. This research provides a number of starting point for future work:

More cognitive effects can be regarded, especially positive cognitive effects. As to relating utterances, communication elements and cognitive effects, the inclusion of more evaluators in addition to the authors can give a broader view. Then, the analysis of the communication can be related to the evaluation of the solution ideas. Specific solution ideas evaluated as creative or not, can be regarded in detail. Referring to the questions asked at the beginning of section 3, we can detect the communication elements and cognitive effects preceding and possibly triggering their creation. Then, the influence of communication elements and cognitive effects on the process of developing or changing the solution idea can be regarded. We can analyse which communication elements and cognitive effects have an impact on the documentation or the rejection of the idea.

As a next step, the influence factors depicted in Figure 1 can be analysed, such as the creativity methods recommended in technical product development: How do they influence the communication and its elements? Which cognitive effects do they trigger? How is the development of solution ideas influenced? This approach supports a more differentiated view on influence factors such as creativity methods and can help to improve them.

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PHYSICAL EXAMPLES IN ENGINEERING IDEA GENERATION: AN EXPERIMENTAL INVESTIGATION

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Abstract: Design fixation is a major concern in engineering idea generation because it restricts the solution space in which designers search for their ideas. For designers to be more creative, it is essential to mitigate fixation. The majority of studies investigate the role of pictorial stimuli in design fixation. The role of examples presented in other formats, including physical prototypes, is largely unknown. This paper presents a study that compares design fixation, in novice designers, caused by pictorial and physical representations. The effects of defixating materials are also investigated. The results show that both formats cause the same magnitude of fixation; however, participants utilizing physical examples produce a greater quantity of complete ideas. The defixation materials do not facilitate novice designers' mitigation of their fixation.

Keywords: *Design Fixation, Examples, Idea Generation, Physical Representations*

1. Introduction

Design fixation has been a subject of concern in engineering design research. It can be defined as a blind, counter-productive adherence to a designer's own initial ideas and example solution features (Jansson and Smith, 1991). This confines the solution space where designers look for their ideas, decreasing creativity. Most of the fixation investigations involve pictorial stimuli (Jansson and Smith, 1991; Chrysikou and Weisberg, 2005; Purcell and Gero, 1996; Linsey, et al., 2010). These investigations show that both experts and novices can fixate in the presence of pictorial examples. The effects of examples presented in other formats, especially three-dimensional physical models, are not well understood. In more realistic design situations, the examples from a designer's physical world can influence idea generation. In fact, most of these systems are three-dimensional and can act as idea generation physical examples. The fixation aspects of such examples need to be studied in detail. The difference in the capability of these representations in conveying relevant information also remains unknown. In the end, the study presented in this paper aims to clarify these issues.

This study seeks to compare design fixation caused by pictorial and physical examples. The authors hypothesize that physical examples can cause the same level of design fixation as pictorial examples. A controlled, between-subject experiment evaluates this claim. The subsequent sections in this paper present a brief background, the experimental method, relevant results, further discussion and the final conclusions.

2. Background

Examples are useful in engineering idea generation because they help designers identify new solutions via analogical reasoning. Analogical reasoning is considered a very powerful tool to invoke designer creativity (Pahl and Beitz, 2003). In this process the most challenging task is the identification of source analogy (Alterman, 1988; Markman, 1997). Numerous research efforts in the literature attempt to simplify the identification of source analogies (Linsey, et al., 2012; Chakrabarti, et al., 2005; Nagel, et al., 2008; Sarkar, et al., 2008). When designers receive examples, the examples act as source analogies, eliminating that difficult step. Unfortunately, analogies from domains very close to the design problem can fixate designers (Dugosh and Paulus, 2005; Perttula and Sipilä, 2007).

A number of studies show that, when designers are given example solutions, they fixate (Jansson and Smith, 1991; Chrysikou and Weisberg, 2005; Purcell and Gero, 1996; Linsey, et al., 2010). Jansson and Smith show that when designers receive examples, they blindly copy features even if those features violate the problem requirements. As a follow-up, Purcell and Gero (Purcell and Gero, 1996) show that industrial designers fixate less to examples compared to mechanical engineers. Linsey et al. (Linsey, et al., 2010) find that even experts with years of experience solving open-ended design problems fixate to examples. Interestingly, these experts can successfully mitigate their fixation via the use of alternate representations of the design problem. A majority of these studies use hand sketches to present their examples. Complimenting these efforts, Cardoso et al. (Cardoso, et al., 2009) use richer pictorial stimuli, in the form of photographs, in their study. Ultimately, they observe that the photographic format fixates designers to the same extent as hand sketches. Efforts to replicate these results with higher fidelity representations, including three-dimensional virtual models and physical models, are scarce.

Based upon the background literature, the following hypothesis is formulated and further investigated in this paper:

Hypothesis: Designers fixate to both pictorial and physical examples to the same extent.

The following sections present a controlled experiment investigating this hypothesis along with the key results and a discussion of these results.

3. Method

A between-subject experiment with novice participants was conducted to investigate the hypothesis. This experiment was designed based upon the prior experiments by Linsey et al. (Linsey, et al., 2010) and Viswanathan and Linsey (Viswanathan and Linsey, 2012; 2011a). Participants generated ideas to solve a design problem in four different groups: No Example Group, Pictorial Example Group, Physical Example Group and Physical Example Defixation Group. In each group, the participants solved the same design problem. The occurrence of example features in their solutions was studied to identify the extent of their fixation to the example.

All the participants solved a "peanut sheller" design problem (Linsey, et al., 2010; Linsey, et al., 2012; Linsey, et al., 2011). This problem asked participants to generate as many ideas as possible for a device that can quickly and efficiently shell peanuts without the use of electricity and with minimum damage to the peanuts. None of the participants were familiar with the design problem before the experiment; but they all had experienced the routine task of shelling peanuts.

The four experiment groups differed in both the type of additional materials provided and the manner in which the example was presented. The No Example Group received only the design problem statement and no supplemental material. The Pictorial Example Group received an example solution, in the pictorial form, as shown in Figure 1, along with a short description. The description detailed the operation of the example solution. The exact statement was the following: "This system uses a gas powered press to crush the peanut shell. The shell and peanut then fall into a collection bin". The Physical Example Group received the same example solution in the form of a physical model (Figure 1Figure). This physical model was not functional; but the participants were not informed of this. They were told that it could function with a gas powered motor. The Physical Example Defixation Group received the same physical model and the defixation materials used in prior experiments (Linsey, et al., 2010; Viswanathan and Linsey, 2012; 2011a). The defixation materials consisted of a brief functional description of the problem along with some back of the envelope calculations, lists of energy sources and analogies that could help solve the problem. These defixation materials were effective in mitigating design fixation in experts (Linsey, et al., 2010), but not in novices (Viswanathan and Linsey, 2012; 2011a).

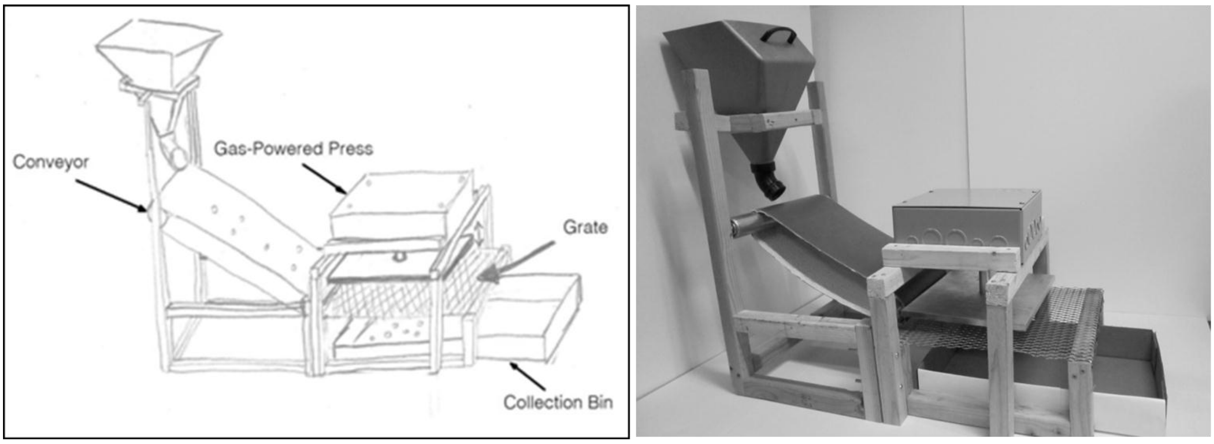

Figure 1. Pictorial example given to the Pictorial Example Group (left) and physical example provided to the Physical Example and Physical Example Defixation groups (right).

Senior undergraduate and graduate students from the Mechanical Engineering Department at Texas A&M University participated in this study. There were a total of 29 participants (21 undergraduate students and 8 graduate students). Six were in the No Example Group, seven in the Pictorial Example Group and eight each in the remaining two groups. The graduate students were equally distributed across the conditions. Six participants were female, and the average age of the participants was 23. None of the participants possessed more than six months of industrial design experience.

As the participants entered the experiment room, they were directed to their workspaces. Up to four students participated at a time, and their workspaces were separated by dividers. As the experiment began, they received the design problem statement along with the appropriate supplemental materials as determined by their experimental group. They were given five minutes to read and understand the design problem. The participants utilizing the physical example were also allowed to inspect it. The physical model was displayed on a table in front of them. These five minutes were followed by a 45 minute idea generation. They were instructed to generate as many ideas as possible. To encourage their participation, they were told that the participant with greatest number of solutions would receive a prize. To ease logistics, this prize was given to all participants, but the participants did not know this prior to the experiment. The examples were available to the participants throughout the session. The participants were asked to sketch their ideas and supplement those sketches with labels and short descriptions of each part. At the end of the experiment, a survey asked the participants about their prior exposure to the design problem and any relevant industrial experience.

4. Metrics for evaluation

To measure fixation, five metric are used: number of repeated example features, percentage of reused example features, quantity of non-redundant ideas, number of ideas for energy sources and percentage of ideas using a gas engine. These metrics are employed by Linsey et al. (Linsey, et al., 2010) in their study on fixation and its mitigation in experts. The number of times example features appear in a participant's solution is counted. To ensure reliability, a second independent reviewer blind to the experimental conditions analyzes 52% of the data. An inter-rater agreement of 0.95 (Pearson's correlation) is obtained for this metric. This high value indicates that the metric is reliable. Another metric involves the percentage of features reused from example. This is calculated as the ratio of the number of utilized example features to the total number of ideas within each example solution. An inter-rater agreement of 0.86 is obtained for this metric, showing that the metric is reliable.

Building from the procedure proposed by Shah et al. (2000), the quantity of non-redundant ideas metric was developed by Linsey et al. (2011). For this experiment, an "idea" is defined as a component that solves at least one function in the functional basis (Stone and Wood, 2000). A non-redundant idea is a unique, non-repeated idea not present in the example. Even when participants do not see the example, the ideas from the example are also counted to find the number of non-redundant ideas. The quantity of non-redundant ideas is calculated by a functional break down of all solutions. Also, the authors obtain an inter-rater agreement, a Pearson's correlation of 0.87, showing that this measure is reliable.

Two metrics measure the level of fixation to the example energy source: the number of energy source ideas in each participant's solutions and the percentage of solutions utilizing gas power. To calculate the percentage of solutions using gas power the authors take the ratio of the number of solutions using gas power to the total number of solutions generated by that same participant. Inter-rater reliability scores of 0.88, for the number of energy source ideas and 0.89, for the percentage of ideas utilizing a gas engine, are obtained. Said scores indicate that the measures are reliable.

5. Results

5.1. Number of Repeated Example Features and Percentage of Reused Example Features

The results from the number of repeated example features and the percentage of reused example features indicate that the three groups with examples fixate to the example features (Figure 2). Compared to the No Example Group, all other groups replicate more example features. Since the example contains common solutions to the requisite functions, the No Example Group utilizes some example features in their ideas. Still, the level of utilization is relatively small compared to the other groups. A one-way ANOVA indicates that the mean number of repeated example features varies significantly across the conditions ($F(4,25) = 3.38$, $p<0.03$). Pair-wise a-priori comparisons show that the No Example Group generates significantly fewer example features compared to all other groups (No Example vs. Pictorial Example: $p<0.08$; No Example vs. Physical Example: $p<0.001$; No Example vs. Physical Defixation: $p<0.04$). As expected, all other pair-wise comparisons are not statistically significant. The percentage of reused example features follows the same trend (Figure 2). Across the conditions, the data shows an overall significant difference (using one-way ANOVA: $F(4,25) = 5.92$, $p<0.001$); moreover, a lower percentage exists in the No Example Group as compared to the other groups (No Example vs. Pictorial Example: $p<0.001$; No Example vs. Physical Example: $p<0.001$; No Example vs. Physical Defixation: $p<0.01$).

These results strongly support the hypothesis. Examples in both the pictorial and the physical model formats fixate participants. The mean number of repeated example features is slightly higher for the Physical Example Group as compared to the Pictorial Example Group, but this difference is statistically insignificant. Interestingly, the defixation materials do not help novice participants mitigate their fixation. These results are consistent with the prior studies. Linsey et al. (2010) show that expert designers successfully mitigate their fixation to pictorial examples; but a follow-up study (Viswanathan and Linsey, 2012; 2011a) shows that these materials are not effective for novice designers.

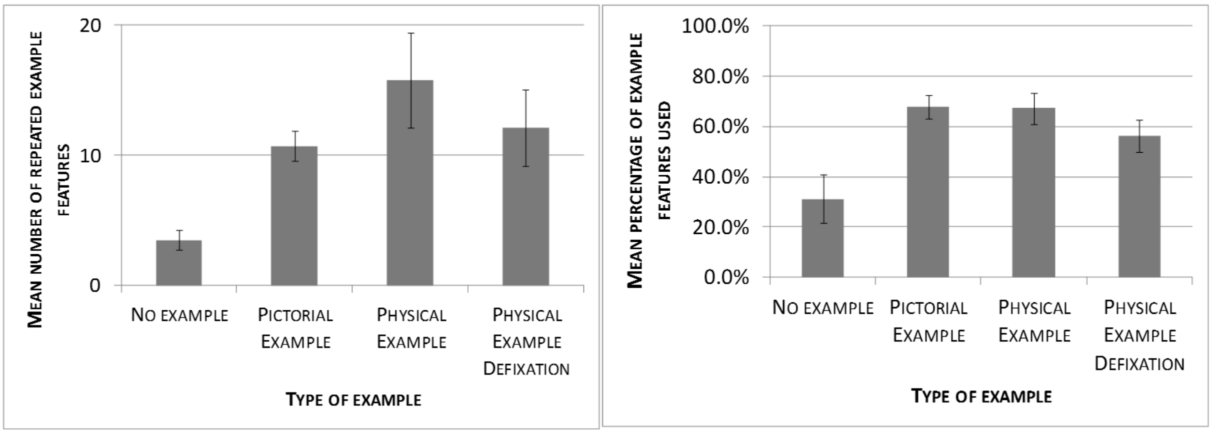

Figure 2. Variation of mean number of repeated example features (left) mean percentage of example features used (right) and across the conditions. Error bars show (±)1 standard error.

5.2. Quantity of non-redundant ideas

The quantity of non-redundant ideas varies across the four groups (Figure 3). A one-way ANOVA shows statistically significant variation of this metric across the groups ($F(3, 25) = 2.41$, $p<0.09$). Pair-wise a-priori comparisons show that the Pictorial Example Group produces significantly less ideas than the other groups (Pictorial Example vs. No Example: $p <0.09$; Pictorial Example vs. Physical Example: $p< 0.02$; Pictorial Example vs. Physical Example Defixation: $p< 0.05$). Other pair-wise comparisons are statistically insignificant.

These results highlight extremely interesting trends in the data. As expected, participants with the pictorial example generate a lower quantity of novel ideas, an indication of fixation. Conversely, the Physical Example Group does not follow this pattern. In fact, they generate the same mean quantity of non-redundant ideas as the No Example Group. This indicates that, though the Physical Example Group replicates many example features in their solutions, they can generate a greater quantity of novel ideas than the Pictorial Example Group. The Physical Example Defixation Group does not show any improvement in the mean quantity of non-redundant ideas. Said fact indicates that the defixation materials do not significantly help the participants. Additionally, the data seems to reveal that, though the Physical Example Group does repeat features from the example, said fixation does not appear to limit their ability to generate a high quantity of ideas. Contrasting this with prior studies measuring design fixation (Jansson and Smith, 1991; Chrysikou and Weisberg, 2005; Purcell and Gero, 1996), it is essential to consider quantity of ideas as a measure for fixation, in order to get a complete picture.

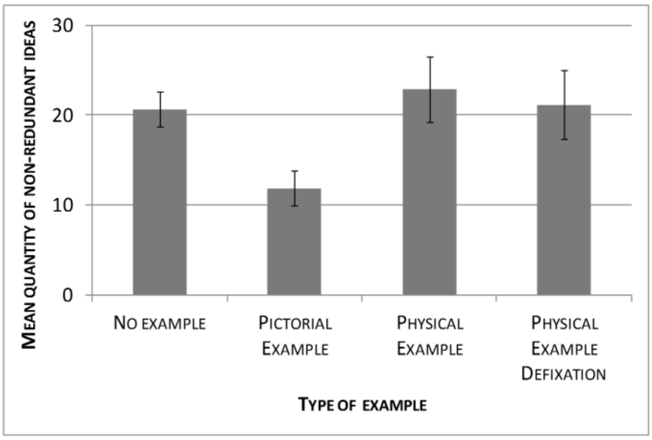

Figure 3. Variation of mean quantity of non-redundant ideas across the experiment groups. Error bars show (±)1 standard error.

5.3. Energy sources fixation

The mean number of energy sources and the mean percentage of solutions using gas as the power source do not vary much across the conditions (Figure 4Figure). A one-way ANOVA indicates that both metrics do not significantly vary across the conditions (Number of energy sources: $F(4,25) = 1.42$, $p = 0.26$; Percentage of solutions with gas powered press: $F(4,25) = 0.21$, $p = 0.88$). Still, the Pictorial Example Group produce a lower mean number of energy source ideas as compared to other groups. Said result is consistent with the prior study by Viswanathan and Linsey (2012).

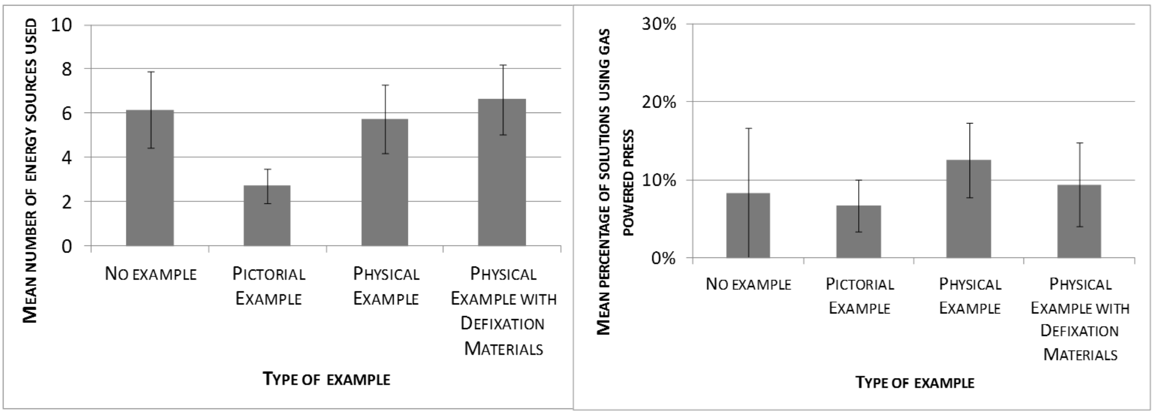

Figure 4. The variation, across the conditions, of the mean number of energy sources (left) and the percentage of solutions using a gas engine (right). Error bars show (±) 1 standard error.

Consistent with prior studies, the Pictorial Example Group produced a lower mean number of ideas for energy sources. The Physical Example Group produced the same mean number of ideas for energy sources as the No Example Group, indicating no fixation. In this study as well, defixation materials did not have any effect on novice designers. Interestingly, the percentage of solutions using a gas powered press remains constant across all the conditions.

6. Discussion

The results indicate that the participants fixate to features of the pictorial example. They replicate many features from the example in their solutions resulting in a higher mean number of repeated example features as compared to the No Example Group. The Pictorial Example Group produces less energy source ideas as compared to other groups; still, the percentage of solutions utilizing a gas engine remains constant across the conditions. These results are consistent with prior studies which demonstrate that designers fixate to pictorial examples (Jansson and Smith, 1991; Chrysikou and Weisberg, 2005; Purcell and Gero, 1996; Linsey, et al., 2010).

Participants utilizing physical examples fixate to the example solution features to the same extent as those utilizing the pictorial example. This result strongly supports the hypothesis. Also, the Physical Example Group produces significantly more non-redundant ideas as compared to the Pictorial Example Group. In fact, the quantity is comparable to that of the No Example Group. The mean number of solutions remains the same across all the conditions. Said observation indicates that, for a given solution, the Physical Example Group produces more ideas satisfying the requisite functions. In the No Example and the Pictorial Example groups, participants generate many partial solutions which satisfy only some of the necessary functions of the peanut sheller (for example: a solution contains ideas to only shell peanuts but does not include ways to separate the broken shells). Though some of the ideas are replicated from the example, the Physical Example Group tends to produce a greater quantity of complete solutions. In this case, the physical example may be acting as provocative stimuli through example exposure, which needs further investigation. The presence of fixation is not observed in the use of energy sources in solutions. These results possess extremely important implications for engineering design. More specifically, the results indicate that, though examples in the form of physical models can lead to design fixation, they can also lead designers to more complete solutions. The presence of a physical model during idea generation might lead designers to consider each feature of the model and subsequently generate solutions for the function each example feature fulfils.

Pictorial examples containing the same amount of information fail to have the same effect. This indicates designers might derive different magnitudes of information from these two types of examples. As a consequence, physical representations might play an important role in the design process because designers might extract a greater amount of information from them. This argument requires further investigation in future work.

Existing literature provides conflicting guidelines concerning fixation caused by the building of physical models during engineering idea generation. Kiriyama and Yamamoto (1998) observe that novice designers building physical models during idea generation fixate to variations of their initial ideas. A similar observation is made by Christensen and Schunn (2005) in their study on practicing designers. A controlled study by Viswanathan and Linsey (Accepted), with a simple design problem, fails to detect fixation from working with physical models. In a follow-up controlled study (Viswanathan and Linsey, 2011b), they show that the design fixation observed in prior studies occurs because of the Sunk Cost Effect; in other words, fixation is not an inherent part of the building process. The Sunk Cost Effect entails an adherence to a chosen course of action after significant investment is devoted to that path (Arkes and Blumer, 1985; Kahneman and Tversky, 1979). During idea generation, if designers spend a large amount of time, money or effort solving design problems, they tend to fixate to variations of their initial ideas. When designers build their own physical models, they fixate as demonstrated by the prior studies (Kiriyama and Yamamoto, 1998; Christensen and Schunn, 2005). In this study, designers do not fixate to the physical example any more than to the pictorial one because they receive the physical model, and the sunk cost associated with building is low. Similar results are reported by Youmans in a recent study (Youmans, 2011). These results reinforce the argument that the Sunk Cost Effect is a major factor in causing design fixation.

The results also show that the defixation materials do not help novice designers mitigate their fixation to example solutions. This result also validates the study by Viswanathan and Linsey (2012; 2011a), which shows that the same defixation materials do not help novice designers mitigate their fixation to pictorial examples. Linsey et al. (2010) show that expert designer can use the resources provided to them, in the form of defixation materials, and significantly mitigate their fixation to the example features. Unfortunately, novice designers fail to utilize these materials in either pictorial (Linsey, et al., 2010) or physical form.

7. Conclusions

This paper investigates the effects of physical examples on design fixation. The study presented hypothesizes that designers fixate to physical examples to the same extent as to pictorial. A between-subject controlled experiment evaluates this hypothesis. In the experiment, participants generate ideas for a design problem with the help of either pictorial or physical examples. The occurrence of example features in their solutions is studied to identify fixation. The results support the hypothesis. The participants fixate to physical examples to the same extent as to pictorial examples. Still, participants with physical examples generate a greater quantity of complete solutions. These results also strongly support the argument that, during idea generation, design fixation is caused by the Sunk Cost Effect and fixation is not an inherent aspect of working with physical models. Due to these reasons, quick prototyping techniques such as rapid prototyping need to be encouraged during engineering design. Designers can also employ separate technicians to build prototypes of their ideas. Said strategy might reduce the Sunk Cost Effect and resultantly lead to a greater quantity of novel ideas.

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COGNITIVE LOAD MANAGEMENT AND ARCHITECTURAL DESIGN OUTCOMES

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Abstract: The aim of this study was to analyze the link between the way designers manage cognitive load during the process of architectural design and the outcome of this process, that is, the quality of the creative designs they produce. To this end, we quantitatively measured cognitive load by asking 36 architecture students to perform a secondary task while they were using three classic design media (hand sketch, physical model and Sketch-Up, a modelling program). Then, the students' designs were qualitatively assessed by eight architects acting as judges (four teachers and four professionals). No correlation was found between cognitive load and project quality for any of the three media.

Keywords: *cognitive activity, design media, evaluation*

1. Introduction

Design is a complex task composed not only of a single problem, but of several, multifaceted ones (Lebahar, 2007). According to the cognitive approach to creativity and design activities, architecture is a dynamic and iterative process of looking for a "satisfactory" solution that is both original and functional. This iterative process of exploration-generation-evaluation relies on representations, which can be either internal (resulting from cognitive activities or processes) or external (depending on the design medium). These representations are essential to any creative act, as well as in every phase of the design process, as a means of projecting the architect's thinking and know-how.

The activities and cognitive strategies implemented by architects during ideation may consist of (re)interpretation, combination, restructuring, or analogical reasoning (Visser, 2009), and require significant cognitive resources. However, as mentioned by several authors (Bilda & Gero, 2008; Wickens, 2000), cognitive resources are limited, and designers need to externalize their ideas to free up their working memory (Baddeley, 2007). Moreover, the manipulation of design media also requires cognitive resources. We therefore decided to examine whether any particular types of design medium impose additional cognitive load on the designer during the design process, and whether the design outcome is affected.

We begin by defining the concepts evoked above – namely cognitive load and its role in the design process, as well as the assessment of creative productions resulting from this process – before detailing the current experimental method and results.

2. Theoretical background

2.1 Cognitive load and the design process

Owing to its inherently complex nature, the design task is reliant on working memory resources. However, in the field of architectural design, few studies have focused on the management of cognitive load. After defining cognitive load, we look at how it can be measured and its role in architectural ideation.

2.1.1. Cognitive load definition

There are almost as many definitions of cognitive load as there are research areas. Thus, in the field of cognitive ergonomics, Wickens and Holland (2000, p.128), define it as "the difference between the cognitive demands of a particular job or task, and the operator's attention resources" - a definition reiterated by Cegarra and Chevalier (2008). In educational psychology, for Sweller, who developed the theory of cognitive load in the 1980s, working memory accumulates the information being processed, and it is this that constitutes its cognitive load. By inducing less cognitive load, we can allow more information to be processed, and thus support and enhance learning potential. Following this logic, Eggemeier (1988) asserts that any increase in task difficulty leads to a deterioration in performance.

For the purposes of the present study, we adopted the general definition by Chanquoy et al. (2007, p. 58). According to these authors, cognitive load is "a quantity, a measure of the intensity of cognitive processing engaged by a particular individual, with certain knowledge and resources, to achieve a certain task, somehow, in some environment".

2.1.2. Cognitive load measurement

Cognitive load measures can be classified as either qualitative or quantitative.

- Qualitative measures

These measures or tests are used to collect participants' thoughts and feedback on their performance. De Waard (1996) prefers the term "self-assessment measure" (self-report measure), as some physiological measurements can also be subjective. Three tests are particularly widespread in the literature: the Workload Profile (Tsang & Velazquez, 1996), the Subjective Workload Assessment Technique (SWAT; Reid & Nygren, 1988) and the NASA Task Load Index (TLX; Haart, 1988).

- Quantitative measures

The first category of quantitative measures relies on physiological indicators to measure cognitive load, such as a pupil dilation, eye movement, electrocardiography (blood pressure, blood volume, etc.), electroencephalography (rhythms in the brain associated with cognitive demands), and brain imaging (functional magnetic resonance imaging, fMRI). These physiological indicators are useful because they allow us to measure cognitive load during task performance, but they are both intrusive and expensive. Another quantitative method consists of administering primary tasks (PTs) or secondary tasks (STs), also referred to as behavioural or performance-based measures. In PTs, cognitive load is measured in terms of response times to the PT. STs however, are more widely used (see, for instance, Bonnardel & Piolat, 2003, in the context of design activities). The basic principle is that a more demanding PT leaves fewer cognitive resources available for the ST, which is then reflected in ST performance.

2.1.3. Cognitive load and design media

Few studies have investigated the cognitive load management in the field of architectural design (Côté et al. 2011). Bilda and Gero (2008; see also Bilda, Gero, and Purcell, 2006, and Dorta, 2008) sought to establish whether mental imagery or medium type impose additional cognitive load on designers, using mainly qualitative or subjective methods. Results suggested that the externalization of cognitive activities (e.g., visuospatial information processing) is needed to free up WM so that other tasks can be carried out effectively. For this reason, external representations (i.e., design media) play a key role in architectural design. Hand sketches and ideation are two inseparable acts for most architects. The use of sketches has always been considered a medium of choice for the externalization of visual mental images: "designing involves the interplay of sketching and imagery" (Goldschmidt, 1995, p.3). However, there has been little empirical research on ideation using 3D digital tools such as Sketch-Up, which allows objects to be manipulated in 3D and interactions to take place in realtime. Thus, cognitive load, which is a measure of designers' cognitive activities, depends on several factors, both including the cognitive strategies and the media used by designers to represent their ideas. No studies in the field of architectural design have made the connection between the management of cognitive resources by designers engaged in the architectural design process and the resulting quality of creative designs.

2.2. Design assessment

Assessing creative productions (here, architectural designs outcomes) is a complicated objective, because it is essentially based on the judges' subjectivity. Howard et al. (2008) investigated the creativity measures used in several studies. Allthough the precise semantics varied from one author to another, Howard et al. (ibid). found that two key characteristics of creative products were generally emphasised: novelty and adaptability or functionality, While it seems feasible to explore the adaptability or functionality of creative works by establishing objective criteria (compliance with prescribed constraints, such as surface area and number of rooms, planning regulations, disabled access, etc.), the judges' subjectivity comes to the fore when examining the innovative or original aspects of designs. In the field of architectural design, studies addressing the assessment of architectural solutions in academic or professional contexts have always been based on "qualitative" methods since they rely upon expert assessments (Bilda & Gero, 2008; Casakin, 2008; Yukhina, 2008). Amabile (1983) has theorized about and empirically documented this method for over thirty years, calling it the "Consensual Assessment Technique" (CAT) when applied to the field of creativity. The CAT is based on the idea that the best measure of the level of creativity of a work, a theory, or an artefact, results from a combination of expert assessments in this area. According to Hennessey (2003), researchers using this technique must meet four criteria: (1) the judges must have expertise in the field, even if their levels of experience vary; (2) judges must assess the designs/artifacts independently, without being influenced by the experimenter; (3) judges must assess productions by comparing them and not by measuring them against a standard; and (4) each judge must assess the artifacts in random order, to avoid any order effects. The main advantage of the CAT is that it is not based on any theory of creativity, and its validity was established empirically (Baer et al., 2004).

Assessment criteria vary, depending on the domain and the judges assessing the creative products. In the field of industrial design, Wojtczuk and Bonnardel (2011) asked a panel of 20 experts to assess creative productions (computer mice) according to criteria of aesthetics, originality, functionality, and marketing. In the field of architectural design, Yukhina (2008) submitted participants' products to three experts, who rated their compliance with a number of prescribed constraints (12 design criteria), as well as criteria of originality, complexity, flexibility, functionality and sketch quality. Similarly, Yukhina(2008) and Casakin (2008) based their earlier assessment on prescribed constraints, as well as criteria of usefulness, originality and aesthetics.

To our knowledge, there has not been any research in the architectural design field on the possible connection between the cognitive load experienced by designers and the quality of creative designs generated.

3. Experiment

Can cognitive load potentially influence the outcome of the design process, that is, in a general sense, the quality of the design? If a designer has too few cognitive resources to develop visual mental images and externalize ideas, does he or she produce poorer-quality designs? If a design medium requires more cognitive resources and thus increases the designer's cognitive load, does it influence the quality of the resulting design? To answer these questions, we conducted a study across two academic semesters with architectural students. We adopted a mixed methodology to determine the participants' cognitive load, and took care to respect the ecological validity of the architectural design process. Inspired by experimental psychology, we used a combination of quantitative and qualitative measures. However, whereas experimental psychology studies are generally conducted in the laboratory, we believed it was crucial to take the dynamic and complex nature of architectural design into account. Thus, although we could not analyze all the interactions involved in such a process, we were able to ensure a degree of ecological validity by creating a minimally intrusive protocol for a "traditional" design environment.

We adopted a repeated-measures design for our data analysis, as there is only a limited pool of students in architecture, and this design allowed us to compare the use of three design media: hand sketch (HS), physical model (PM) and Sketch-Up (SK). To avoid order and practice effects, the participants had to randomly produce three different designs using the three design media.

3.1. Participants

Thirty-six architecture students took part in this study. We chose to undertake accidental (nonprobabilistic) sampling, one of the most widespread and least expensive sampling techniques. The sample consisted of 22 men and 14 women, with a mean age of 24 years (SD = 3.03). Moreover, to ensure that all participants had some experience of undertaking small design projects, only students who had completed at least four academic semesters were recruited. In addition, on a five-point Lickert scale, all participants rated themselves as proficient in the use of the three design media, especially the modelling software (SK) (Mean responses: PM = 3.88; HS = 3.48; and SK = 3.97; N = 36).

3.2. Procedures and materials

The experiment comprised two phases:

1. The first one concerned the production of three designs in three experimental sessions, during which each participant used a specified design medium. Each experimental session took about 30 minutes. First, the participants had 3 minutes to come up with a design of their own choice, to allow them to become accustomed to wearing headphones (needed for the ST). Then, after reading the guidelines and the criteria for the design project (±5 minutes), each participant had 22 minutes to complete the main (or primary) design task on a drawing board that allowed them to sit in an upright posture. For each medium, the participants performed randomly a task to design either a bus station (BUS), a recycling station (RS) or a public restroom (WC).

   To measure cognitive load, we administered an ST (performance-based task) to participants. This task was tested in a previous design context (Bonnardel & Piolat, 2003) and it seemed appropriate to working conditions in design activities.This task was conducted as follows. Throughout the 22-minute design period, numbers ranging from one to five were played randomly over the headphones, at a rate of one every five seconds. The participants' task was to press on a foot pedal as quickly as possible whenever there were two consecutive ascending digits. The use of a foot pedal minimized interference with the main design task that required the use of both hands. Before each experimental session, participants received a list of written instructions that clearly indicated that the design project took priority. We analyzed the percentage of correct responses (CR) and mean response times (RT).

The second phase consisted of the assessment of the participants' designs. A panel of four professional architects (at least five years' experience) and four architecture teachers assessed these projects on four criteria: overall assessment, aesthetics, originality and functionality. A definition of these criteria was given to the judges in order to reduce differences in interpretation. In addition, as recommended by Amabile (1996), the judges assessed the projects independently and in random order.

4. Results

4.1. Secondary task results

As some participants completed the design task in less than 22 minutes, in order to compare their results with those of the other participants (and given that there was a maximum of 25 correct responses), we computed the following ratio: % of correct responses (for x minutes) = (no. correct responses/25 - no. of missing responses) x 100.

Two one-way ANOVAs were run on correct responses and response times (Fig. 2). The assumptions of normality, homogeneity of variance, and sphericity were met. The results for the correct responses showed that there was no significant difference between the three media, $F(2, 65) = 2.068$, $p = .138$ (see Fig. 1). Concerning response times, no significant difference was observed between the three media, $F(2, 56) = 1.983$, $p = .155$.

The results of these quantitative measures showed that none of the media imposed a relatively higher cognitive load than any other. This result is in contrast with the theoretical assumption that hand-sketching, with its potential for generating alternative solutions faster, induces less cognitive load.

To find out whether there was a link between CR and RT, whatever the medium used, we performed a correlation analysis between the CR and RT measures. Results indicated negative correlations between CR and RT for HS ($N = 36$, $r = -0.456$, $p < 0.005$), PM ($N = 36$, $r = -0.467$, $p < 0.006$) and SK ($N = 36$, $r = -0.607$, $p < 0.001$). Thus, participants who took longer to respond also made more errors, regardless of the medium used. The next section will allow us to determine whether cognitive load has an influence on the quality of projects generated, depending on the medium used.

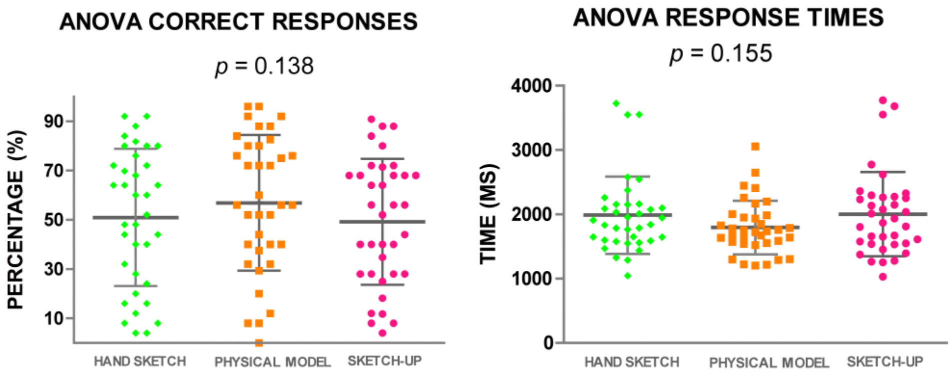

Figure 1. Scatterplots of correct responses (%) and response times
Legend: The scatterplots illustrate the data clustering based on three statistics: lower quartile, mean and upper quartile.

4.2. Design assessment results

The 8 judges had to assess all the participants' final productions, such as the ones presented in Figure 2.

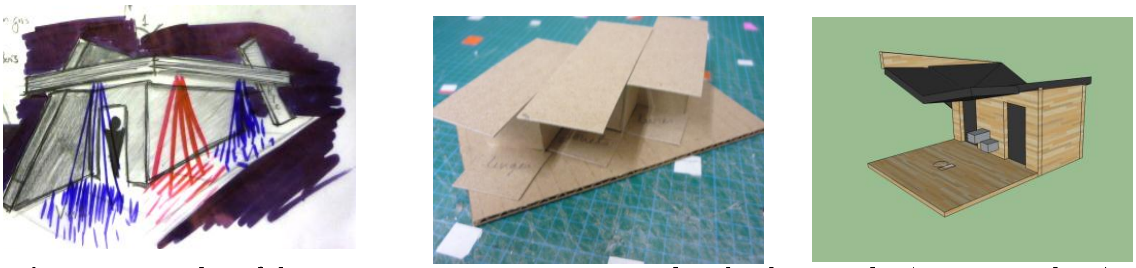

Figure 2. Samples of three project outcomes represented in the three media (HS, PM and SK)

The descriptive statistics performed on scores attributed by the judges showed that for overall quality and aesthetics, SK seemed to have better ratings than the other two media. For originality, PM received the best ratings; while for functionality, HS came top (see Table 1).

Table 1. Means and *SD*s of assessment scores

Assessment (*N* = 36)	Hand sketch	Physical model	Sketch-Up
Overall	2.12 (σ=.70)	2.20 (σ=.48)	2.23 (σ=.62)
Aesthetics	1.85 (σ=.79)	1.99 (σ=.57)	2.09 (σ=.71)
Originality	1.77 (σ=.86)	1.90 (σ=.76)	1.83 (σ=.76)
Functionality	2.52 (σ=.67)	2.44 (σ=.67)	2.37 (σ=.62)

To look for statistically significant differences between the assessments, four one-way repeated-measures ANOVAs were run on each assessment criterion: overall, aesthetics, originality and functionality. The assumptions of normality, homogeneity of variance, and sphericity were met.

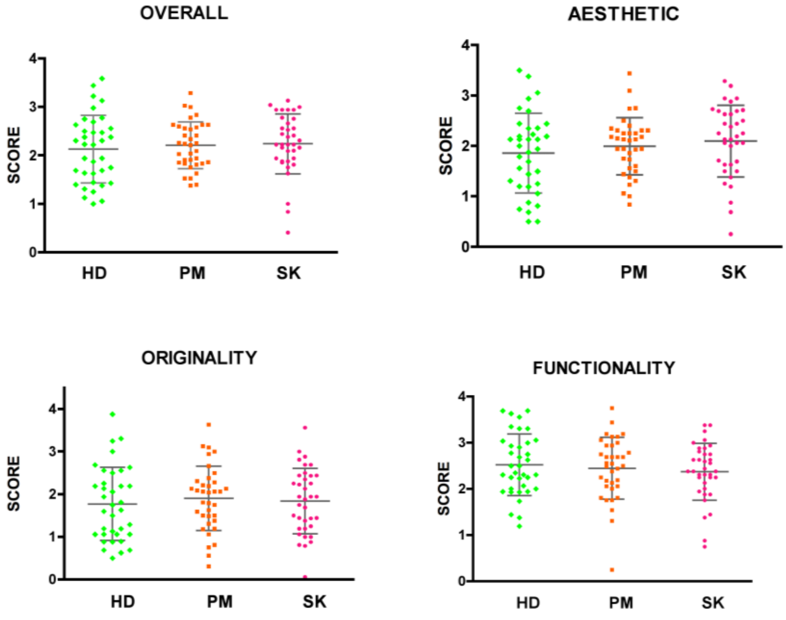

Figure 3. Scatterplots of project evaluations (%)

The results for the overall assessment showed that there was no significant difference between the three media, $F(2, 65) = 1.34$; $p = .607$ (Fig. 3). Concerning aesthetics, originality and functionality, there was again no significant difference between the three media, $F(2, 64) = 0.57$, $p = .231$), $F(2, 69) = 1.56$, $p = .707$, and $F(1, 35) = 0.145$, $p = .494$.

4.3. Correlation between cognitive load and design assessments

Correlation analyses were performed between the two measures of cognitive load (CR and RT) and the four assessment criteria (Overall, Aesthetics, Functionality and Originality) for each of the design media. Results did not indicate any significant relationship between these variables, regardless of the medium used (see Table 2). This means that the quality of the participants' designs was not related to reductions or increases in cognitive load.

Table 2. Correlations between cognitive load measures and design assessments

		Hand Sketch				Physical Model				SketchUp			
		Over.	Aesth.	Origi.	Funct.	Over.	Aesth.	Origi.	Funct.	Over.	Aesth.	Origi.	Funct.
Corrrect responses	Pearson cor.	*.265*	*.202*	*.201*	*.107*	*.182*	*.096*	*.209*	*.102*	*-.138*	*-.182*	*-.159*	*.031*
	sig.	*.119*	*.238*	*.239*	*.536*	*.289*	*.578*	*.222*	*.553*	*.423*	*.288*	*.356*	*.858*

Response times	Pearson cor .	*.091*	*.100*	*.090*	*.159*	*-.045*	*.068*	*-.021*	*-.112*	*.246*	*.228*	*.314*	*.067*
	sig.	*.599*	*.562*	*.600*	*.353*	*.798*	*.698*	*.905*	*.521*	*.149*	*.181*	*.062*	*.696*

5. Discussion and conclusion

The major goal of this exploratory research was to analyse certain aspects of the cognitive activities of novice architects during conceptual phase as well as to illustrate the impact of design media on their performances. Borrowed from experimental psychology and human factor studies, a mixed methodology was proposed to document the link between the use of design media, the design process and the results of creative design process.

The present study yielded three findings: (1) none of the design media has imposed an additional cognitive load on the designer, in contrast to the literature, which suggests that the hand sketch is the ideal tool for the design process; (2) the quality of the design did not depend on the medium used; and finally, (3) there was no relation between cognitive load and design quality. These different kinds of observations can be commented more precisely.

Firstly, historically, hand sketch seemed to be the designated medium for the architectural design. Indeed, the studies comparing traditional (hand sketch) and digital media criticize the fact that modeling software slowed down the externalization of the designer's mental imagery (Bilda, 2006). In contrast, our results show that these digital media do not impose additional load compared to other media. Furthermore, the current widespread use of digital media, offers multitude potentials, which can become a strong complement to other media at all stages of the design process. Thus, usages of complementary media could be investigated with regard to the stages of the design activities.

Secondly, the overall quality of generated projects was not influenced by the medium used. Thus, our results suggest that each tool may provide the same potential for representing and externalizating the designer's mental imagery. Future works will aim to detail these potentials.

To conclude, the results of this research suggest that each design media offers opportunities for design. The dialogue that ensues between the designers and their representations, contibute to the emergence of opportunities specific to each medium. For example, using primitives (cube, cylinder, pyramid, etc..), applying geometric transformations, manipulating them with a software (such as Sketch-Up) and obtaining complex volumes or spaces, definitely creates opportunities and promotes ideas that the designer probably would not have developed as easily with a drawing or model. As highlighted by Keehner et al. (2008), the properties of external representations influence how we interact with them, they structure and anchor the cognitive and metacognitive strategies used to develop mental images. Therefore, depending on the context and the stage of the design process, each designer should be able to choose the tool(s) that are appropriated with regard to his or her knowledge and metacognitive strategies, in order to facilitate as much as possible his or her creative activity.

Acknowledgement

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Creativity

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USING AI TO EVALUATE CREATIVE DESIGNS

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Abstract. Many have offered criteria for judging a design as creative. Among these criteria have been *novelty*, *value*, and *surprise*. We offer a unique perspective and synthesis of these three criteria with the goal of giving agents – be they artificial, human, or collectives thereof – a common model to judge the creativity of their own designs and the designs of others, and ultimately to inform computational modelling of creative design. We illustrate an AI approach to judging creativity using an example of sustainable design -- the Bloom laptop.

Keywords: *evaluating creativity, novelty, value, surprise, clustering, sustainable design*

1. Introduction

There is increasing interest in computational systems that model creative processes and generate creative designs, yet we still rely on humans to evaluate whether a specific design is creative. In parallel there is increasing interest in computational systems that encourage and enhance human creativity; these latter systems make no claims about whether the computer is being creative, but do make claims that the human/computer pairing is more creative than the human alone.

As the boundary between human creativity and computer creativity blurs, we are interested in evaluating creativity that makes no assumptions about whether the creative entity is a person, a computer, or a (potentially large) collective intelligence of human and computational entities. We desire a "Turing Test" for creativity that is not biased by the form of the entity that is doing the creating. Ultimately, such tests will imbue artificial agents with an ability to assess their own designs, informing computational models of creative reasoning. Such tests will also inform the design of cognitive assistants that are effective collaborators with humans in sophisticated socially intelligent computational systems.

This paper takes steps towards assessing creativity by considering formalizations of three criteria for creativity that are often referenced in the literature, though not always together and often by different names; these are *novelty*, *value* and *surprise*. We believe that our treatment of these criteria goes beyond earlier treatments, in part because we synthesize across them, suggesting and formalizing relationships between the three. Our paper begins with a survey of relevant creativity research;

followed by targeted surveys of novelty, value and surprise; formalizations of each of the three in terms of distance measures; and illustrate these measures with laptop designs, to include the Bloom laptop. We end with the relevance of machine learning for assessing creativity and to other future work.

2. Creativity research

When describing and evaluating creative processes and products, there is a "conceptual space" (Boden, 2003) of possibilities that structures, constrains and otherwise biases thought. Boden (2003) describes combination, exploration, and transformation as ways in which the conceptual space is traversed when generating a creative design: *combination* finds novel ways of combining ideas within the conceptual space; *exploration* finds parts of the space that were not discovered previously; and *transformation* extends the space to include novel ideas. Much work on creative thought has focused on processes of individuals (Mumford, Mobley, Uhlman, Reiter-Palmon, and Doares, 1991). Recently there has been interest in understanding individual and team cognition in creative processes, and the role of shared mental models (Reiter-Palmon et al 2008). From a computational creativity perspective, Gero (2000) presents combination, transformation, analogy, emergence, and first principles as processes for generating creative designs. Maher et al (1995) presents a framework to characterize different computational processes in terms of transformation and exploration and describes a zone of creativity to evaluate their potential for generating creative designs. Brown and Chandresekaran (1989) distinguish routine, innovative, and creative design in terms of existing knowledge of decompositions and plans for generating the design. A similar distinction between routine, innovative and creative design is made in Goel (1997) and Gero (1994), showing how creative designs result in a new, often expanded conceptual space.

Often, we cannot observe the creative process directly. Rather, people often judge the design (or artefact, product, idea, etc) that results from a process instead of judging the process directly. Judgements of designs can serve as a "Turing Test" of the underlying process that produced the design. Though a Turing Test approach is imperfect, we continue in this tradition, and speak of "creative designs."

Most descriptions of creative designs, including dictionary definitions, include novelty as an essential characteristic. However, psychologists, computer scientists, and engineering designers suggest creativity goes beyond novelty. Csikszentmihalyi and Wolfe (2000) define creativity as an idea or product that is original, valued, and implemented. Amabile (1996) claims an outcome or result is interpreted as creative if it is both novel and appropriate. Runco (2007) summarizes several researchers who claim that creativity results in something new and useful, and others who claim creativity is more than that. Boden (2003) claims that novelty and value are the essential criteria and those other aspects, such as surprise, are kinds of novelty or value. Wiggins (2006) defines novelty and value as different factors of creativity, yet often uses value to indicate all valuable aspects of a creative product. Cropley and Cropley (2005) propose four broad properties of products that characterize their creativity: effectiveness, novelty, elegance, and genesis. Besemer and O'Quin (1987) define a Creative Product Semantic Scale of products along three dimensions: novelty (the product is original, surprising and germinal), resolution (the product is valuable, logical, useful, and understandable), and elaboration and synthesis (the product is organic, elegant, complex, and well-crafted). Horn and Salvendy (2006) report on consumer perception of creativity along three dimensions: affect (our emotional response to the product), importance, and novelty. Goldenberg and Mazursky (2002) report that creativity in products includes "original, of value, novel, interesting, elegant, unique, surprising." From the engineering design perspective, Oman and Tumer (2009) combine novelty and quality to evaluate engineering designs. Shah, Smith, and Vargas-Hernandez (2003) associate creative design with ideation and develop criteria for novelty, variety, quality, and quantity of ideas.

Amabile (1982) summarizes the social psychology literature on the assessment of creativity: while most definitions of creativity refer to novelty, appropriateness, and surprise, current creativity tests or assessment techniques are not closely linked to these criteria. She further argues that “There is no clear, explicit statement of the criteria that conceptually underlie the assessment procedures.” In response to an inability to establish criteria for evaluating creativity that is acceptable to all domains, Amabile (1982, 1996) introduced a Consensual Assessment Technique in which creativity is assessed by a group of judges that are knowledgeable of the field. Since then, several scales for assisting human evaluators have been developed, such as Besemer and O'Quin's (1999) Creative Product Semantic Scale; Reis and Renzulli's (1991) Student Product Assessment Form; and Cropley et al’s (2011) Creative Solution Diagnosis Scale.

In sum, the two most-widely endorsed factors in the literature that contribute to creative designs are novelty and value. Surprise is articulated much less often, but we nonetheless believe it is an important factor, different from but related to both novelty and value. While these factors have been discussed to varying extents, and have informed the development of computational systems to generate designs that were then judged by humans to be creative, we know of no work that quantifies these factors so that an artificial agent can use them collectively to assess creativity.

3. AI models of novelty and surprise

Computational models of novelty and surprise have been developed for various purposes in AI and these models inform our understanding of these concepts for evaluating creative design. A clustering approach based on Self-Organizing Maps (Kohonen, 1993) is the basis for a real-time novelty detector for mobile robots (Marsland et al. 2000), using Stanley’s model of habituation (1976). Habituation and recovery imbues a novelty filter with the ability to forget, which for design, allows novel designs that have been seen in the past to be considered again as potentially creative using a new value system. Saunders and Gero (2001) drew on the work of Berlyne (1996) and Marsland et al (2000) to develop computational models of curiosity based on novelty, using sigmoid functions to represent positive reward for the discovery of novel stimuli and negative reward for the discovery of *highly* novel stimuli. Negative rewards reflect that designs that are too different are not considered creative, perhaps because they were perceived as violating constraints or norms that help establish the value of a new design. This suggests that a creative design should be sufficiently different to be considered novel, but similar enough to be “in the ballpark”.

Horvitz et al (2005) develop a model of surprise for traffic forecasting. They generated probabilistic dependencies among variables, for example linking weather to traffic status. They assume a user model that states that when an event has less than 2% probability of occurring, it is marked as surprising. They use a temporal model of the data, grouping incidents into 15 minute intervals. Surprising events in the past are collected in a case library of surprises. Itti and Baldi (2004) describe a model of surprising features in image data using a priori and posterior probabilities. Given a user dependent model M of some data, there is a P(M) describing the probability distribution. P(M|D) is the probability distribution conditioned on data. Surprise is modeled as the distance d between the prior, P(M), and posterior P(M|D) probabilities. Ranasinghe and Shen (2008) develop a model of surprise as integral to developmental robots. In this model, surprise is used to set goals for learning in an unknown environment. The world is modeled as a set of rules, where each rule has the form: Condition → Action → Predictions. A condition is modeled as: Feature → Operator → Value. For example, a condition can be feature1 > value1 where "greater than" is the operator. A prediction is modeled as: Feature → Operator. For example, a prediction can be "feature1 >" where it is expected that feature1 will increase after the action is performed. Comparisons can detect the presence (%) or absence (~) of a feature, and the change in the size of a feature (<, <=, =, >=, >). If an observed feature does not match its predicted value, then the system recognizes surprise.

The models of surprise and novelty provide different approaches to recognizing creativity using clustering and distance, probability and expectations, and generalized rules based on previous experience. In the remainder of this paper we focus on clustering and distance, while acknowledging that other AI models may be part of a larger toolbox for evaluating creativity.

4. An AI approach to evaluating factors of creativity

A "Turing Test" for creativity presupposes that characteristics of a design tell us something about the process that created it. To develop such a test we elaborate on two principles: (1) creativity is a relative measure in a conceptual space of possible and existing designs and (2) novelty, value, and surprise capture distinct characteristics of creative design within that space. We illustrate these principles using the laptop domain, describing the conceptual space initially of Mac laptops only, and consider the addition of a new laptop to this set: The Bloom laptop (Figure 1), which was designed by mechanical engineering students at Stanford University and Aalto University (Bhobe et al, 2010). The laptop was designed for ease of recycling with design requirements including minimum number of parts and types of material, modular construction and disassembly, ease of disassembly, minimum disassembly time and has an unexpected value-adding feature of a removable keyboard during use.

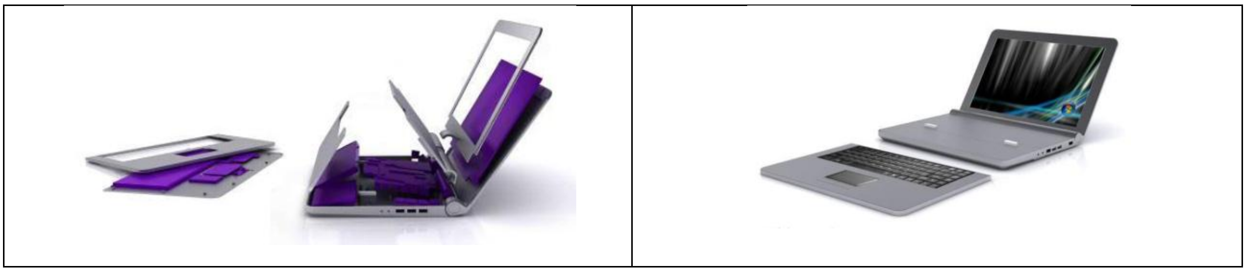

Figure 1. Bloom laptop modular design and removable keyboard; images from (Bhobe et al 2010); available under CC BY-SA licence (http://creativecommons.org/licenses/by-sa/3.0/)

4.1 Relative measures in a conceptual space

Novelty, value and surprise for a new design are measured in a conceptual space of existing and possible designs. We assume a representational schema in which a design is described by attribute-value pairs, though relational schemas are possible and often preferable. For measuring novelty and value, we suggest different aspects of the conceptual space: a description space for measuring novelty and a performance space for measuring value. For example, we characterize the description space of laptops as a set of attributes including Processor Speed (GHz), Height (in), Display size (in), Memory (GB), Storage (GB), HD Graphics Processor, Resolution-x (pixels), Resolution-y (pixels); and the value space to include Battery life (hours), Price (min US$), Weight (lbs). Note that there is subjectivity, stemming from the preferences of users – an elderly person using the laptop for email and Web surfing may care very much about weight, price and battery, and may not even know that processor speed is a characteristic, much less having a preference on it. So, while Csikszentmihalyi (1996) suggests that value is a social construct and determined by the "gatekeepers," these gatekeepers and preferences will, of course, vary among observers, as will the attributes that these observers associate with preferences. We have not specified aesthetic and affective features of creativity as a separate factor since these are domain dependent and therefore may be included in what we call value. For example, in many areas of design, people correlate the aesthetic of increasing complexity of images or ideas with creativity; in such cases, complexity is a characteristic that would be included in the measurement of value.

In this initial work on assessing creativity quantitatively, we use distances as relative measures within the design space. For example, given two designs, $X^{(1)}$ and $X^{(2)}$ each described along numeric attributes, $X_i^{(K)}$, the Euclidean distance is the square root of the sum of squared differences in the corresponding attributes (after normalization) of each design: $\sqrt{\sum(X_i^{(1)} - X_i^{(2)})^2}$. Even when we commit to distance as a means of measuring novelty, there are multiple ways to operationalize this approach.

- As above, we can measure the distance of a design in terms of its distances to other *specific* designs in the conceptual space; for example, equating novelty of design X as the distance to its *nearest neighbor* in the conceptual space is an example of a individual-link approach.
- However, if we were to measure novelty of X by the ratio of X's distance to its nearest neighbor, divided by the average of nearest-neighbor distances of all other designs (excluding X), then this would be an example of a family-link measure, since information about ALL designs, through the average of nearest neighbor distances, would be taken into account.
- Yet another family-link strategy is to measure the distance between X and the *centroid* of designs in the conceptual space. The centroid is a theoretical point in the space, created by averaging the attributed values across all designs in the space. X's novelty could be operationalized as its distance to the centroid, or some ratio involving the centroid.
-

Continuing along these lines, it is natural/desirable for cognitive agents to organize their observations into rich conceptual structures. When new designs are observed, they are not (necessarily) assessed relative to an unorganized collection of previous designs, but against a backdrop of conceptual structures over these designs. Clustering has been proposed and used as an organizing principle for an autonomous agent's conceptual structures (e.g., Fisher, 1996; the use of SOMs in Marsland et al., 2000). We will use the well-known K-means clustering algorithm, using Euclidean distance and centroids, to organize the known designs. When a new design is observed, its distance to the nearest cluster centroid will inform assessments of novelty, value and surprise.

4.2 Measures of novelty, value and surprise in a conceptual space

Novelty, value and surprise are distinct perspectives on the location of a new design in a conceptual space of possible designs. We treat novelty and value as arising from different perspectives of the conceptual space (as noted in 4.1); novelty stems from a comparison (e.g., based on distance) in a *descriptive space*, and value is based on attributes that have utility preferences associated with them.

Importantly, while novelty and value are assessed in different (descriptive and performance) spaces, we assume that both can be assessed through distance – distance in descriptive space and distance in performance space. In addition, of course, value not only has a magnitude component (distance), but a directional component too. We don't address the directionality component here other than to note that a measure like Euclidean distance cannot capture it per se; and just as there were choices in how to use distance (e.g., centroid vs neighbour), choices in directionality must also be addressed (e.g., is positive score in one performance dimension more important than others).

It is possible for something to be novel and valuable, but not be surprising. Surprise is a feature that is based on expectations, which can themselves be represented as a subspace of possible designs – thus, surprise is based on anticipating patterns or trends in the space of both actual designs and possible designs, leading to violated expectations.

We illustrate our approach to evaluating these three characteristics for the Bloom laptop, relative to a space of previous Mac laptops (i.e., MacBook, 11-inch MacBook Air, 13-inch MacBook Air, 13-inch MacBook Pro, 15-inch MacBook Pro, 17-inch MacBook Pro). The values for descriptive and performance attributes for the Mac laptops were taken from the apple.com technical specifications, and the values for the Bloom laptop were found in Bhobe et al (2010). The laptops have been conceptually organized using the K-means algorithm (with K=2, with attribute normalization). Distances between the Bloom and nearest centroids inform measures of novelty, value and surprise.

Novelty: Table 1 shows the full set of descriptive attributes (column 1), the cluster number (second to last row), and the distance from each design to the centroid of its cluster (last row). The Bloom's (rightmost column) Euclidean Distance to the centroid of its cluster is an order of magnitude larger than the distance of the Mac designs to the centroid of their respective clusters. This larger distance indicates that the Bloom is novel with respect to the other designs in this space, in large part because of the large differences in Body Parts (row 1), Removable Trackpad (row 2), and Removable Keyboard (row 3). In fact, there was no variance on these three variables before Bloom's introduction, and they would likely not have been used in descriptive analyses at all – Bloom's introduction added these variables in effect.

Value: Table 2 shows the performance attributes (again, a matter of subjectivity, but our example illustrates the point), the cluster number (second to last row), and the distance from each design to the centroid of cluster 1 (since the Bloom laptop is in a cluster of 1 and the distance to its centroid is 0). When comparing the Bloom to existing laptops, this distance is 2 orders of magnitude higher than the other designs, due to differences in the first three attributes/rows of Table 2.

Surprise: The large distance between the Bloom and the centroids of the 2 clusters in the description space suggests that in a 3-cluster space, the Bloom would be placed alone, and indeed K-means (K=3) places the Bloom in its own cluster. In value space, even in the 2-cluster solution, the Bloom is placed alone. We interpret surprise as a difference so great that the new design is effectively creating a new cluster in the conceptual space, and thereby changing expectations for new designs.

Table 1. Description space for laptop design (Data from apple.com and Bhobe et al, 2010)

	MacBook	11-inch MacBook Air	13-inch MacBook Air	13-inch MacBook Pro	15-inch MacBook Pro	17-inch MacBook Pro	Bloom Laptop Design
Body Parts	1	1	1	1	1	1	14
Removable Trackpad	0	0	0	0	0	0	1
Removable Keyboard	0	0	0	0	0	0	1
Processor Speed (GHz)	2.4	1.6	2.13	2.7	2.3	2.3	2.4
Height (in)	1.08	0.68	0.68	0.95	0.95	0.95	1.08
Display size (in)	13.3	11.6	13.3	13.3	15.4	17	13.3
Memory (GB)	4	4	4	8	8	8	4
Storage (GB)	500	128	256	500	750	500	256
HD Graphics Processor	0	0	0	0	1	1	0
Resolution-x (pixels)	1280	1366	1440	1280	1440	1920	1280
Resolution-y (pixels)	800	768	900	800	900	1200	800
Battery life (hours)	7	5	7	7	7	7	7
USB ports	2	2	2	2	2	3	2
Cluster	1	1	1	1	2	2	1
Distance to Centroid	0.14	0.16	0.12	0.18	0.03	0.03	1.8

Table 2. Value space for laptop design (Data from apple.com and Bhobe et al, 2010)

	MacBook	11-inch MacBook Air	13-inch MacBook Air	13-inch MacBook Pro	15-inch MacBook Pro	17-inch MacBook Pro	Bloom Laptop Design
Disassembly (min)	45	45	45	45	45	45	2
Removable Trackpad	0	0	0	0	0	0	1
Removable Keyboard	0	0	0	0	0	0	1
Price (min US$)	1000	1000	1300	1200	1800	2500	1000
Weight (lbs)	4.7	2.3	2.9	4.5	5.6	6.6	4.7
battery life (hours)	7	5	7	7	7	7	7
Cluster	1	1	1	1	1	1	2
Distance to Centroid	0.0148	0.0524	0.0175	0.005	0.0164	0.0094	2.167

Before closing, we draw from Boden (2003) and Gero (2000), who note that there are several ways in which a new design can be creative: a previously unknown value for an attribute is added (which the Bloom did in the case of several attributes), a new attribute is encountered in a potentially creative design (again, with the Bloom), or a sufficiently different combination of attributes is encountered. In all of these cases, a creative design changes the organizational structure of existing designs in a conceptual space, which we show using clustering and relative distance. The Bloom illustrates *transformational* creativity in that it triggers a realignment of conceptual structures. There are many interesting questions that need to be addressed as we design a cognitive artificial agent that can learn (cluster) designs and assess novelty, value and surprise (and creativity generally) of new designs relative to learned concepts, particular issues of how the agent is motivated to transform the conceptual space. Our point here is to sketch how clusters of designs in a conceptual space might be learned and used to assess creativity.

5. Conclusions

This paper presents an AI approach to evaluating creative designs that is independent of the design discipline and of the source of creativity. The AI models operate in a conceptual space, thereby contextualizing the evaluation and providing a relative measure of creativity rather than a binary judgment. Formalizing the criteria for evaluating creativity facilitates comparisons of computational systems that are themselves creative, as well as computational systems that enhance human creativity. The three criteria for evaluating relative measures of creativity described here are novelty, value and surprise. With metrics for these we have a common ground for evaluating creativity in human, computer, and collectively intelligent systems.

Our next steps are to evaluate our method for evaluating creative designs, which will involve first collecting attribute-value representations of successive designs in a domain such as the laptop illustration used here, and measuring how successive laptops compare to previous ones along our metrics. Ultimately we are interested in how our distance-based assessments compare with judgments by humans when presented with the same ordering of designs. In addition to having to elaborate on some smaller, but important issues, such as directionality (as well as magnitude) in assessing value, we have alluded to larger issues of conceptual *organization* of conceptual spaces that undoubtedly bias human judgements and that will ultimately guide computer judgements of creativity as well. Unsupervised machine learning approaches, while often viewed as data analysis tools, are also approaches for organizing a cognitive agent's memory of designs, products and processes (Fisher, 1996; Fisher and Yoo, 1993), creating the backdrop against which an agent can make more sophisticated assessments of creativity.

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DUBIOUS ROLE OF FORMAL CREATIVITY TECHNIQUES IN PROFESSIONAL DESIGN

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Abstract: Formal problem-solving and creativity techniques have repeatedly been promoted to designers by consultants and scholars. However, there has been little research about the adoption and usefulness of these techniques among practitioners. In this paper, we investigate the prominence of different design methods among design companies in Europe and North America. We interviewed 17 professional designers from companies of different orientation. We inquired about working practices and the significance of different methods and practices in everyday design work. We found that designers from industrial design as well as engineering design backgrounds relied mostly on established design methods – generally characterized as "design thinking" skills – rather than on specific creativity tools. Sketching, rapid prototyping and in-house testing were typical ways for the designers to invent. We suggest that the emphasis in design creativity studies with pragmatic goals should be on studying *design practice* and *everyday situated creativity* rather than on examining isolated creative techniques per se.

Keywords: creativity techniques, brainstorming, design practice, design thinking

1. Introduction

The term *design creativity* can be seen as a construct that captures the essence of designer's work. It refers to the constant need for creativity in the designer's profession. This is implied by the realities of design work, in which designers are required to produce insightful and feasible ideas constantly. It is therefore only natural that creativity in design has gained significant attention over the years both within academic research, and within educational and professional literature. The scientific studies on design creativity have focused primarily on the following aspects; design processes, cognitive behavior, and interactions (Gero, 2010). As such, the interest is not new. The creative aspect of design has been well acknowledged since the studies of design thinking as a subject of scientific study of design research began (e.g. Thomas & Carroll, 1979; Akin, 1986).

However, it has been recently argued that research on design has not sufficiently addressed issues of practical value, or the needs of the design practice (Liikkanen, Laakso & Björklund, 2011). Design research fails to be relevant for design practitioners and it has been unsuccessful in its core mission: establishing a sustainable discourse between research and practice (Jung, Sonalkar, Mabogunje, Banerjee, Lande, Han & Leifer, 2010). So what could be a potentially more fruitful direction for research on design creativity? Alternative approaches for studying design creativity might involve the study of creativity support tools (Shneiderman, 2007) and how designers interact with them (Gero, 2010) or systematic methods utilized in design industry to create new designs (Lindemann, 2010).

In this paper, we explore a research direction that considers both approaches suggested in the cited literature. Putting our focus on design practices of present day designers, we present some findings from interviews focusing on the working methods, practices, and approaches of 17 professional designers from 7 different organizations in the US and in Finland. The interviews were conducted with the aim of building a foundation for longitudinal, observational field studies to be conducted at design companies. The interviews covered the working approaches, practices, tools, and methods utilized by the interviewees and within their organizations. The purpose was to identify themes and issues that have been left unattended or are underrepresented in present-day design creativity research from the viewpoint of design practice. Our interview results suggest there might be a misleading emphasis on structured creativity techniques, such as ideation methods, which overlook the daily practices related to "routine creativity" in professional design, and hence make it difficult to have an impact on the design practice with academic research.

We begin our treatment by discussing the existing research on design creativity in terms of creativity practices and ideation and move on to describing the research methodology. Next, we present the results of the interviews, and conclude with a discussion about the implications of the findings for future research.

2. Background: studies of creative design practices

We see that that an important part of research on design should concern practice; the behavior and thinking of design professional operating in the real world. These types of studies are rather rare in design research, maybe with the exception of the seminal work by Schön (1983) on professional development and reflective design. Recently published studies of design practice have revealed some interesting characteristics of professional design. Hinds & Lyon (2011) studied cross-cultural differences in design practices. Their report describes the different challenges of practicing design in Asia, Europe and North America. They have found that design practices are influenced by different regional client expectations. For example, in the US, the relations are seen as more collaborative, whereas in Europe and particularly in Asia, the professional designers' sole responsibility in design decisions and deliverables is emphasized. This reflects a difference that re-emerges with prototype presentations. European and Asian designers prefer to display polished and detailed prototypes where as the American clients were seemingly satisfied with rougher sketches.

A study by Nov and Jones (2006) investigated the creative practices in an advertising agency by means of interviews and observations. The investigation yielded a model of the organizational roles contributing to ad design. Formal creativity techniques, such as Brainstorming originate from advertisement industry, were surprisingly marginal in the discussion. Brainstorming was considered as a method to utilize different types of knowledge existing in the company. They also mapped the creative influences into a circular model of creative practice. They identified six "inner circle" organizational principles and activities contributing crucially to overall creativity. These included knowledge distillation, task focus, feedback functions, accountability, recognition, and career development. The outer circle of the model included less central, but influential factors that aim to maintain the creative atmosphere of the work place. They concluded that creativity in the studied advertising agency hinged upon a delicate balance of formal processes and informal practices, which together feed the progress.

Petre (2004) documented an extensive field study. She studied design activities over the span of two years in twelve engineering consultancies. Although not presented in full detail, she identified fourteen practices, aimed mainly at knowledge gathering by either considering more potential solutions or broadening the definition of the problem. Petre notes, that although seemingly contradictory, deliberate and systematic practices foster inspiration and innovation in the studied firms. She gives an account of why exceptional performance in design and development is rare by highlighting the complex balance among contributing factors. Specifically she draws attention to the reliance of the identified practices on expertise (particularly expert skills) and a reflective, supportive, and collaborative culture and communication among design professionals.

Hargadon and Bechky (2006) identified interactions that precipitate moments of collective creativity in organizations in a field study of six professional consulting firms (four product design and development consultancies and two management consultancies). Their evidence, collected through ethnographic methods, suggests that while some creative solutions can be viewed as the products of individual insight, others are clearly the products of a momentary collective process. In essence, their study illuminated how the locus of creative problem solving shifts between individuals and the collective. Hargadon and Bechky present and discuss four sets of interrelating activities that play a role in triggering moments of collective creativity: help seeking, help giving, reflective reframing, and reinforcing. In summary, based on the review of the literature, we find little documents addressing the presumably heterogeneous ways in which designers in the early 21st century work. Thus we see that there is a motivation to investigate the situated creative design practices further.

3. Research methods

To understand the realities of design practice with regards to different types of designers and companies, we conducted 17 interviews in Finland and the US. The interviewees represented seven different organizations, five of which were design and development consultancies and two were companies that manufacture their own products. Six of the interviewees were based in the US in three different consultancies and the remaining twelve interviewees were from four different organizations in Finland; two design consultancies and two manufacturing firms. The intention was not to be representative of any specific branch of design, but rather than to get a rich sample of different types of organizations and designers.

Typical job titles or backgrounds of the interviewees were industrial designers and mechanical engineers. However, especially in the case of small design consultancies the job descriptions or titles were not clear, with descriptions of employees such as “mechanically-inclined designer”. Majority of the interviewees had worked as designers or design engineers in two to four companies during their career and they had been working as professional designers from 2 to 25 years, averaging at 11 years. Designers working as consultants for external clients and those working as in-house designers have both been included. Information on the interviewees is depicted in Table 1 on the following page.

The interviews were semi-structured. They were built around open-ended questions probing both the working habits and the utilized tools and methods of both the individuals and the companies. The focus was on the present, but reflection across the working career was also urged. The interviewees were asked to reflect on their entire career and not to focus solely on the organization they were currently employed in. The background and working history of the interviewees and the practices of the companies in terms of team composition and hierarchy were inquired. In order to stimulate recall and avoid a too abstract or generalized level, the interviewees were asked to discuss specific examples of projects they had taken part in recently or were currently involved in. The open-ended question format of the interviews served the purpose of probing the realities and real-life practices of the designers on a tangible level.

The interviews lasted between 25 and 120 minutes, averaging at 76 minutes. They were conducted at the designer's native language (English or Finnish). Straightforward content analysis was used to analyze the data. The interview transcripts were screened for reported actual, concrete practices, ways of working and utilized methods or tools. For this paper, specific attention was paid to references to social and individual activities related to idea problem-solving and framing activities. We avoided including subjects' own generalized statements or interpretations on their approaches or practices.

4. Results

In this section we describe the interview findings. We focus on the prominent practices and approaches to everyday design work, including generation of ideas and creative problem-solving. The main findings can be classified into three categories:

1) *Knowledge acquisition*,

2) *Informal and spontaneous problem framing and solving* activities as routine practices, and

3) The significance of *external representations* (i.e. models and prototypes) of the design challenge.

Table 1. Interviewee profiles

Interviewee #	Background/title	Professional work experience (years)	Country	Consulting or In-house design
1	Engineering design	7	FI	IH
2	Engineering design	25	FI	IH
3	Engineering design	7	FI	IH
4	Industrial design	13	FI	CO
5	Industrial design	14	FI	CO
6	Industrial design	7	FI	CO
7	Industrial design	10	FI	CO
8	Industrial design	11	FI	CO
9	Engineering design	16	FI	CO
10	Engineering design	13	FI	CO
11	Engineering design	17	FI	CO
12	Industrial design	2	US	CO
13	Industrial design	2	US	CO
14	Industrial design	23	US	IH
15	Industrial design	10	US	IH
16	Industrial design	7	US	IH
17	Industrial design	10	US	IH

4.1. Knowledge acquisition

The interviewees independently gather knowledge relevant to design. Knowledge acquisition was described both as an ongoing routine activity apparently driven by the designer's intrinsic motivation. The need to learn about the latest developments in the domain was taken as an integral part of practicing design profession. This activity was not always directly associated with any company or project specific goal in a contrast to more deliberate and purposeful action driven by the needs of ongoing design and development projects.

Typical sources for knowledge acquisition were the *internet*, *professional magazines*, and *books*. Designers described constantly following design websites and blogs (e.g. Core77), designer portfolios, and technology websites and blogs. A few interviewees also mentioned trade fairs or exhibitions, but this was not focal.

The motivations to learn fell into two categories: *goal-oriented* and *inspirational* search. The latter, inspirational information gathering occurred without a very specific focus and appeared mostly as maintaining and developing personal skills. Goal-oriented searches were usually motivated by pressing needs, such as the form factor of a product or mechanical solutions suitable for the project at hand. Certain phases of projects demanded more intensive knowledge acquisition. This included benchmarking relevant solutions or related products.

Internet searches were the most typical form of information gathering and inspiration. In this context, several interviewees described design in a classical way as getting inspiration from something already existing and transferring it into a new context. As an example, interviewee 8 describes his practices of knowledge acquisition at the start of a project:

> *"I end up using quite a lot of time - hours if not days - just going to the library of the university and browsing through all kinds of magazines and books they have with no specific focus. I have my notepad and pen with me and I make notes of ideas I have, like, maybe there could be something like this in the product"* Interviewee 8

None of the interviewees described any company-driven, formal knowledge acquisition practices, such as tracking patent databases. However, if the company held a patent portfolio, it was considered to be a significant constraint in their work. Exceptions to this, however, were the methods used for gathering user requirements, in which some interviewees described a disciplined use of user research methodologies (interviewees 5, 17). Other interviewees however, had a more informal approach to user research.

4.2. Informal and spontaneous problem framing and solving

Informal interactions between designers were important for idea generation, problem framing, and creative problem solving. These occur spontaneously without a prior agreement. They typically take place at the desk of an employee or in the the immediate vicinity of the work stations. A clear majority of the interviewees (interviewees 1, 2, 3, 5, 6, 7, 8, 9, 10, 13, 14) unpromptedly described a highly informal and spontaneous style to ideation and problem framing either as typical approach to or the preferred way of doing design. In addition to spontaneous discussions taking place at the work desks, informal routine gatherings, such as going out for a cigarette and coffee breaks were reported as venues for ideation and problem-solving. The following was described by interviewee 7:

> *"The method I use is going out for a cigarette. That's where the problem crystallizes and the solution appears. Sometimes I go alone, but if I bump into any of the other smokers on the way, I ask for them to join me"* Interviewee 7

Structured idea generation methods were mainly to be used when working with clients or other external stakeholders. These sessions were typically organized at the start of the project or at major decision points. However, even in these cases the satisfaction level to the structured approach was not very high. Some interviewees described ideating with clients highly challenging because the client representatives were cautious and not in the right mode for creative ideation (e.g. interviewee 7). Interviewee 11, a project manager, described the ideation sessions with clients at the project initiation phase to be aimed mainly at collecting the relevant initial and background information on client needs and constraints, rather than generating new solutions. This view was supported by other interviewees who also initially focused on problem framing.

The use of structured methods or formal approaches of creative design (ideation, rapid prototyping etc.) was scarce. None of the interviewees reported actively using structured methods internally. Furthermore, more than one of the interviewees explicitly pointed that structured group idea generation methods were poorly suited for internal idea generation needs (interviewees 1, 5, 7, 11). Structured methods were seen to at times compromise the natural flow of the ideation and hinder the dynamics of building on others ideas (interviewees 1 and 5). Attempts of utilizing structured methods had in some cases been clearly rejected by the working community. Interviewee 5 who tried to inspire colleagues by providing them with commercially available methodology cards:

> *"For about a week I tried giving everybody one card each day, but nobody went for them. I immediately got them back like 'you can keep your cards' (laughs) and I didn't bother pushing it for very long"* Interviewee 5

In addition to idea generation, none of the interviewees brought up utilizing structured methods for problem framing and solving unprompted. When directly asked about using them, singular instances in which light-weight methods such as scoring attributes of different concepts to develop a concept combining the best possible set of most desirable attributes.

4.3. The importance e of external representations

The traditional skills of design, or craft, played a crucial role in creativity. The creative design practices were often initiated or facilitated by concrete representations of the idea under development. For instance sketches, visualizations, 3D CAD, and different types of physical models and prototypes. These representations were described as key means of approaching the task at hand individually and collaboratively. This often took the form of a single designer creating representations which then acted as a catalyst for collaborative work (interviewees 2, 3, 4, 5, 6, 7, 8, 9, 12, 13, 14, 15). Interviewee 8 specifically describes how these representations spark conversation and ideation:

> *"It's like a magnet when you model, draw or render something so it's visible on your screen or desk. It always attracts the others… …it always creates discussion and debate about the possible approaches and solutions"* Interviewee 8

The role of early prototyping and a hands-on approach is highlighted by the interviewee 15, who describes how a certain employee is often taken in to the process early on due to his ability to approach problems in a tangible fashion, which the whole team can build and reflect upon:

> *"So, if it's early on and it needs to be kind of just, he usually gets it really early on. And he's more of a tinkerer, so he'll just tinker with it."* Interviewee 15

The need for quick external realization of ideas was wide spread. This was also intimately tied to the technology that augmented designers' abilities. The important creativity-support tools included different computer visualization tools (Photoshop, Illustrator, and CAD) but also sophisticated hardware such as 3D printers for rapid prototyping of 3D product mock-ups.

5. Discussion

In this paper we presented findings from interviews conducted with a number of professional designers globally concerning their everyday working practices. Our approach to creativity in design has been that of "nothing special" perspective (Weisberg, 2006; Ward, Smith & Finke, 1999), treating creativity foremost as a property of the output received from the design process. In this study of creative design practice, we intended to map which aspects of design creativity would be potential focal points for research on design creativity and might in future have a high relevance to design practice. We grouped our central insights from the interviews into three categories: *knowledge acquisition practices, informal and spontaneous problem framing and solving practices, and practices related to producing external representations of design*.

Our findings reveal that there are multiple practices and tools that contribute to design creativity. Some are design domain specific, some more general. The role of supporting tools seems tremendous in professional design. The long debate on the influence of CAD to creativity seems pointless. It seems that designers are ready to adapt any new technologies that will help to improve their output, facilitate the process, and improve means of communication. What's more, these creativity support tools are not only inventions specific to design, such as Wacom tablets or 3D printers, but generic tools (blogs, Google search) which facilitate knowledge acquisition. In some respect, the technologies are simple if not even dumb. They are clearly tools to be used according to the designers' best intention, not active agents in the creative process, hardly reaching the level of "nanny" in the taxonomy of Lubart for computational support tools of creativity (Lubart, 2005)

One clear finding is that for many of our interviewees, design remains independent work. There might be more demand for structured, formal creativity techniques in assignments demanding extensive group collaboration and in converging knowledge from relevant stakeholders in projects involving a large number of people. But as long as there are individual responsibilities in design, there does not seem to be a great demand for formal measures among the professionals.

Formal creativity techniques, such as Brainstorming, did not surface often in the interviews. Their role seems thus be rather subdued. However, the professionals we interviewed did indicate benefits of using brainstorming, such as the function of gathering information from clients. This suggests that even though the formal methods have been used in professional design, the purpose of their use might have been different from what has commonly been assumed.

We also found that the studied organizations did not have a structured or a formal approach to knowledge acquisition. This is somewhat in contrast with the results of Petre (2004) whose field research in engineering consultancies documented active programs of knowledge acquisition including patent searches, technical literature reviews, and analysis of legislative requirements and regulatory standards. Interestingly, we did not observe notable differences between designers working on different regions in the three dimensions we observed.

5.1. Conclusions and future directions

Many studies of creative design have adopted a specific perspective of drilling into creative techniques (e.g. Jansson & Smith, 1991; Shah, Vargas Hernandez & Smith, 2003). This has left the overall picture of design creativity somewhat fuzzy and produced findings contradictory to design practice. For instance, research has repeatedly found brainstorming to be less efficient in producing ideas than if the individuals were working separately (e.g. Mullen, Johnson & Salas, 1991). However, by ignoring the complicated social context surrounding brainstorming in professional design, these approaches disregard some apparent benefits related to it. For instance, Sutton and Hargadon (1997) found a different reality in work place ethnographic research. They studied brainstorming as a part of the larger scale operation in the design agency IDEO. Their approach provided insights in to the factors that make brainstorming popular among practitioners that the traditional studies of brainstorming have disregarded. They found that designers were highly motivated in team work; teams allowed effective utilization of knowledge and dissemination of ideas, and working in teams supported social bonding. (ibid.) This can be taken to indicate that design companies may benefit from systematic "creativity" techniques once they are adequately modified to match the organizational requirements and adopted into everyday "routines".

The initial findings from our study of research practices show that the established methods of design (skills of design thinking in the modern vernacular) prevail. On the other hand, designers do opt in new techniques and methods as well as the general public. For instance, knowledge acquisition methods have been quit transformed since the internet sources have become available. Product designers also highly value new prototyping tools such as 3D printers.

One could ask whether formal techniques redundant in professional design? The answer is yes, sometimes. The character of design work requirements changes. Previously people have needed help to collaborate within large design teams and to work with external stakeholders. One could ask is the current information overflow presented by the internet soon overtaking individual work? Maybe some specific tools to facilitate this will emerge. Lindemann argued that creativity supporting methods and procedures should be generic (2010, p. 28). Based on the reports from our informants, it seems that there is likely demand for both specific creativity-support tools and techniques (e.g. 3D printing equivalent for electric prototyping) and generic tools such as easily utilizable electronic brainstorming tools (see Liikkanen, Kuikkaniemi, Lievonen & Ojala 2011). There would seem to be plenty of possibilities to study the utilization of different creativity-support tools, such as electronic magazines and blogs that designers utilize to update their expertise. It would be interesting to find out how the transition from printed sources and trade fairs to constant stream of digital information influences the creative output of designers.

Our findings encourage further explorations among real designers. It would seem that the studies of particular design methods, for instance ideation techniques, conducted in isolation from their real-life application context provide a biased sight on design creativity. We prefer a future orientation to creative design research in which rests on the association of research with practice. An example study in this vein is Hargadon & Bechky (2006); a study which revealed interactions between people that precipitate the moments of collective creativity. We hope to see research development in empirical and theoretical directions which can help us to advance the state-of-the-art in that line of research. Since this initial report is on the major commonalities in design, in future we hope to find and show key differences between designers and their organizations using the data we have already gathered and are currently gathering, maybe shedding light on why some design are more creative than others.

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TOWARD A CONSTRATING ORIENTED PRAGMATISM UNDERSTANDING OF DESIGN CREATIVITY

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Abstract: This paper explores the potentials of pragmatist philosophy to enrich the discourse on design creativity in general and the concept of constraints specifically. The concept of constraints is central in vanguard creativity research, and recent contributions have begun to explore constraints as nuanced and situated phenomena. In this paper, we argue that pragmatism can inspire and inform the study of constraints in design creativity by offering a coherent and well-developed frame of understanding how designerly inquiry unfolds as a complex interplay between the designer and the resources at hand in the situation, which may continuously alternate between constraining and enabling roles, or even take on both roles simultaneously. Through this, pragmatism can lead to a more situated, dialogical approach to constraint management and manipulation, thus facilitating new insights into design creativity.

Keywords: *design creativity, pragmatism, constraints*

1. Introduction

Since Guilford's seminal inaugural APA address in 1950 (1950), research into creativity has evolved at a remarkable pace with work spanning several academic disciplines. As one such, design research is now an expansive field with contributions from psychology, engineering, management, HCI, AI, and informatics, among others. Much scholarly work in design concerns tangible artefacts and their contextual appropriation by users, not least within interaction design. Although at the core of most of such studies, *design creativity* as a particular phenomenon displayed by skillful practitioners still appears somewhat impalpable. We have been intrigued by the evasiveness of this fundamental concept as a seemingly consensually understood term that nevertheless turns out to be a conceptual challenge when explored in depth. What Johnson-Laird (1988) notes on creativity, that it is often most beneficial to define it *a posteriori*, seems to apply to design creativity as well, as it is typically conveyed as a part of a concluding summation of concrete project findings. Rather than follow that avenue of thought, we deem it more fruitful to contribute to advancing the understanding of *design creativity* by extracting the concept and considering it in the light of John Dewey's seminal work on *pragmatism*. As we will argue, Deweyan pragmatism has influenced the development of design theory so a natural step, we claim, is to look at design creativity in a pragmatist perspective. To ensure the topicality of this analytical stance, we turn toward vanguard creativity research based on psychology and philosophy. There, we find a growing interest in the complex role of constraints as both enablers and restrainers of creative agency, and, notably, a conceptual shift toward a more situated, even dialogical understanding of constraints that mirrors key thoughts within pragmatism. In itself, pragmatism sheds light on key issues in current design research, however, the pragmatist concept of *inquiry* seems especially potent for understanding design creativity when the latest work on the complex role of constraints as a creative resource in design processes is taken into account as well.

To ensure the concept of design creativity comes to the fore of the paper, we begin (2.) by presenting key aspects of ongoing constraints research, not least the aforementioned shift toward a more situated understanding of constraints as elements open to creative manipulation by the agents involved. We then proceed to introduce the pragmatism of John Dewey (3.), which leads to our discussion (4.) of how pragmatism, informed by constraints research, may enrich the concept of design creativity, especially with regard to design as an inherently technological mode of inquiry and the understanding of design creativity as an emergent, situated, reciprocal, and distributed phenomenon. Finally (5.), we end the paper by briefly considering paths for future work. In order to ensure a satisfactory treatment of the core aspects of the paper, our focus is primarily theoretical. We are hopeful that the contraint-oriented pragmatist understanding of design creativity presented here will form the basis for in-depth case studies in future work.

2. From problem-solving to creative manipulation of constraints in design

As argued by (Gross, 1986), most design-related disciplines emphasize the presence of constraints as vital to an understanding of the creative process itself. Some take the argument even further by stating that: *"[formally], all design can be thought of as constraint satisfaction, and one might be tempted to propose global constraint satisfaction as a universal solution for design*" (Chandrasekaran, 1990, p. 65). Breaking away from seminal work in problem-solving, notably (Simon & Newell, 1972), recent attempts to reframe processual design creativity have looked toward metaphors to advance the concept (Casakin, 2007). Other theory contributions address the topic generically (Weisberg, 2006), or conceptualize it as 'requirements engineering' (Maiden et al., 2010) or as a question of 'balance-seeking' (Salustri, Eng & Rogers, 2009), to name a few examples. As noted by Johnson-Laird (1988, p. 202): *"to be creative is to be able to choose among alternatives"*, which is in alignment with many observations by Boden (2004). A key aspect of any creative activity is the agent's ability to handle the constraints presented by the given situation in a constructive, innovative manner that ensures creative progression, regardless of whether the aim be a final design, a cake recipe, or a haiku poem. At a basic level of definition, 'constraints' may be considered more or less synonymous with 'requirements', e.g. (Nuseibeh & Easterbrook, 2000), or in a practice-oriented scope as: *"limitations on action [that] set boundaries on solutions"* (Vandenbosch & Gallagher, 2004, p. 198). Advancing beyond such brief expoundings, however, entails terminological diffusion and conceptual opacity as no comprehensive, cross-disciplinary theory of creativivity constraints has yet been introduced.

Theory contributions to constraints research feature mainly three disciplines: architecture, psychology (seasoned with artistic experience), and philosophy (practical rationality). These contributions range from cubic typologies of design constraints (Lawson, 2006, p. 106), to strategies for allegedly creating artistic breakthroughs by merging dichotomies, e.g. by combining a horizontal and vertical perspective in a visual work of art (Stokes, 2006; 2009). The latter of the three contributions does not focus on creativity, but presents an array of useful, conceptual clarifications such as the basic distinction between *intrinsic* (primarily immanent in the material itself such as bulk density), *imposed* (by agents, clients etc. in the form of budgets, deadlines, and other demands), and *self-imposed constraints* (self-restraint brought into the situation by the agent herself in expectance of a beneficial, more creative result) (Elster, 2000, pp. 175-269). Although each of these contributions have helped advance research into the relation between constraints and creativity, the disciplinary gaps and lack of shared scope and terminology remain significant.

Rather than taking the constraints 'at face value', recent meta-studies (Onarheim & Wiltschnig, 2010) and cross-domain explorations (Biskjaer, Onarheim & Wiltschnig, 2011) specifically targeting design research have shown a consensual understanding of the complex, dual role of constraints as being both restraining *and* enabling for creative agency. The complexity of this *both-and* characteristic by which the same creativity constraint such as the choice of a particular design material may simultaneously open/enlarge *and* close/reduce the problem/solution space (Dorst & Cross, 2001), has been represented in various ways, e.g., via divergence/convergence (Löwgren & Stolterman, 2004, pp. 29-30; Biskjaer, Dalsgaard & Halskov, 2010). Other theorizations aim to show this dual role by asserting distinctions of constraints such as hard vs. soft (Elster, 2000, p. 190), essential vs. incidental (ibid., p. 4), fixed vs. flexible, or strong vs. weak (Stacey & Eckert, 2010, p. 249).

What is important in order to help optimize creative performance on the path toward highly original results regardless of domain is the reflective approach of the creative agent. This means that current research into constraints has yielded an important, gradual change through which the very properties of the constraints themselves, not least how they affect creative agency, has been brought to the fore. No longer considered unmalleable by definition, recent theory suggests that even the most rigid, inviolable constraints such as the essential need for medical equipment to be sterile (aseptic) may be – and in fact not rarely is – ignored during the design process if it thereby helps yield a more innovative, final design (Onarheim, 2012). The four strategies of constraint manipulation outlined in this study are blackboxing, removal, introduction (of new constraints), and revising (of existing ones). Inspired by a cross-domain study displaying four patterns of similitude based on analyses of the role of constraints in experimental filmmaking and industrial design in plastic pharmaceuticals (Biskjaer et al., 2011), we wish to further argue for scaffolding a new, more refined conceptualization of constraints emphasizing the agent's unbound, personal, creative decision-making as well as the practical outcome and concrete usefulness of such decisions. We are currently taking steps in that direction in an attempt to advocate not only an increased alertness toward the active role and empowerment of the creative agent in the design process, but also a more pronounced emphasis on her ability to engage more experimentally in the design situation itself exactly by way of manipulating and playing with the constraints at hand, be they fixed or flexible, voluntarily chosen, or imposed by colleagues or clients. Such a reflective, yet open-minded approach to the design situation itself based on skillful management of constraints and evident domain knowledge seems a promising path to follow in order to better grasp the impalpability of design creativity. This conceptual shift toward a more situated or dialogical understanding of and engagement with even the most rigid constraints bears resemblance to key aspects of a *Deweyan pragmatist design philosophy*, and it is our contention that such a constraint-oriented, pragmatist stance on design can help shed light on and qualify design creativity, which is at the core of design practices. To be able to present this view, we now proceed to give…

3. A brief introduction to the pragmatism of John Dewey

Pragmatism is a school of thought that emerged in the United States toward the end of the nineteenth century. There have been a number of different and to some extent incongruent interpretations of basic assumptions in the field from the very beginning, see e.g. (Talisse, 2002). However, the different perspectives are joined by a series of basic tenets. Chief among these tenets is the pragmatic maxim, which is the proposition stating that the meaning of our conceptualizations of the world must always be evaluated based on their consequences and implications in practice: our experience in practice-based action precedes doctrines. This is a tenet that unites pragmatism in opposition to rationalist philosophy. Here, we will address one specific strand of pragmatism, that of John Dewey, to scaffold our discussion of the potentials of employing pragmatism as a perspective for understanding design creativity. Due to the scope of the paper, we have selected a set of four central concepts from Dewey's rich oeuvre, which are particularly salient for our discussion of design creativity in general and constraints in particular, namely the concepts of *situation*, *inquiry*, *transformation*, and *technology*.

Situation

Deweyan pragmatism posits that all human activity is situated to the extent that neither the subject, nor phenomena in the world, can be understood outside of the situation. A situation is constituted by the subject and the surrounding environment, including others, artifacts and physico-spatial surroundings as well as social constructs. Our thoughts and actions, as well as the meaning of events and ojects, must be understood in the context of the situation of which they are part. The situation is therefore not something that can be described without taking into account the subject(s) who are part of it. Nor can we understand the subject without looking at the situation in which he/she is placed. In other words, the subject and the situation are reciprocally co-constitutive (Dewey, 1998, pp. 66-67).

Inquiry

Situations may be experienced to be more or less stable and comprehensible. Dewey employs the term *determinate* to denote a stable situation in which the subject has a firm understanding of things; in contrast, *indeterminate* situations present themselves to subjects as instable and unpredictable. When we face indeterminate situations, we may label them as being problematic for us, in which case we will often embark upon a process of inquiry in order to bring an end to the instability, either by getting a better understanding of them, or by actively changing the situation: "*Inquiry is the controlled or directed transformation of an indeterminate situation into one that is so determinate in its constituents distinctions and relations as to convert the elements of the original situation into a unified whole"* (ibid., p. 108). Dewey describes the process of inquiry as progressing through states of 1) recognizing that a situation is problematic, 2) identifying the aspects or components of a situation that causes it to be problematic, 3) forming conceptualizations of how the situation may be resolved, and 4) experimenting with and carrying out actions based on these conceptualizations in order to resolve the situation and make it determinate. As an extension of the pragmatic maxim, this implies that the conceptualizations must prove their worth in practice by helping the subject resolve the situation. In this way, Deweyan pragmatism moves beyond the theory-practice dichotomy and instead views knowledge and theories as active phenomena that are formed and reformed through experimental action in the world. It must be stressed that Dewey views the stages of inquiry as highly intertwined and iterative, rather than a fixed model for problem-solving; e.g., later stages of the process may reveal to the subject that the initial understanding of the situation and the problems at hand were improper and thus instigate a new line of inquiry on the basis of a revised understanding of the situation.

Transformation

The goal of inquiry is transformation. As Deweyan pragmatism considers the situation the assemblage of subject, physical surroundings and things, other human actors, and social constructs, the transformation may apply to one, several, or all of these entities and their relations: *"Situations are an intimate, interconnected functional relation involving the inquirer and the environment. The resolution of a problematic situation may involve transforming the inquirer, the environment, and often both. The emphasis is on transformation"* (Dewey, 1925-1953, X, p. 33). Transformation can thus be construed as quite non-disruptive when the subject learns something new about the situation, which causes him to see it in a new, determinate way, whereas transformation may be highly disruptive in cases where all entities of the situation and their interrelations are altered through the course of designerly inquiry.

Technology

The final concept we will treat is technology. In Deweyan terms, technology is a broad, and inclusive concept that denotes the use of resources, means, or instruments to reach an intended result. In this understanding, technology is thus deeply connected with the three preceding concepts: technologies are almost always already part of a given situation. They scaffold the process of inquiry, and they help us transform the situation and may in turn be transformed, since they are co-constitutive components of the situation. Given our focus on constraints and design creativity, one of the central understandings that Dewey's notion of technology brings us is that technologies have a complex, reciprocal nature. Firstly, technologies help us see certain things in a situation, they act as lenses through which we perceive certain phenomena in the world, all the while concealing or obscuring other phenomena. Secondly, technologies can serve as extensions of our faculties for thought and action, enabling us to understand and act in ways that were not possible without them. Thirdly, technologies that become integrated into our lives can guide our thoughts and actions in ways that we may not be consciously aware of. And fourthly, technologies themselves change over time as they are developed.

4. How can constraint-oriented pragmatism enrich insights into design creativity?

Having outlined a rough sketch of these tenets of Deweyan pragmatism, the obvious question of how it can enrich our understanding of design creativity and constraints arises. We shall answer this in two tempi: firstly, by looking at how pragmatism resonates with design in general; secondly, and more extensively, by offering a more specific discussion of how pragmatism may inform and inspire our understanding of creativity and constraints in design.

Regarding the coupling of pragmatism and design, the notion of *inquiry* – understood as the mode of action and thinking by which we identify problematic aspects in our surroundings and intentionally strive to transform them – lies at the centre of pragmatist thinking. This resonates with design, which is inherently an interventionist discipline in which we bring our action and reflection to bear on identifying potentials for positive change and devise new methods, services, products, and environments to that end. By extension, the notion of *ongoing experimentation* is central to both design and pragmatism. The Deweyan perspective stresses how inquiry is an ongoing process of experimentation in which reflection and action are intertwined as conceptualizations are informed by, directed at, and tried out in practice. These experiments have the potential to transform all components in the situation: the designer may be transformed by gaining new insights that alter his view of the problem at hand; existing technologies and products may be re-aligned; new products and services may be developed and introduced into the situation; existing routines and practices may be changed; people's perception of the situation and their potential for acting in it may be altered; or, as is often the case, several or all of these aspects may change reciprocally as a result of designerly inquiry.

A series of past contributions have explicitly employed pragmatist perspectives to inform the field of design, among these McCarthy & Wright's *felt life* perspective on interaction (2007), the work on *aesthetic interaction design* by Petersen et al. (2004), Dalsgaard's work on *designing for inquisitive use* (2008), and the aforementioned work by Schön on *reflective design practice* (1983). The most widely recognized pragmatist contribution to design is arguably Schön's exploration of designers as competent practitioners in *The Reflective Practitioner* (1983) and *Educating the Reflective Practitioner* (1987). Notions such as "reflection-in-action", "reflection-on-action", "problem setting", "framing", "reframing", "repertoire," and "seeing as" have been influential in understanding the design process and the competencies of skillful designers.

We will devote the remainder of the paper to a more thorough discussion of how pragmatism may inform and inspire the understanding of creativity and constraints in design. Given the scope of the paper, we will focus on three main implications of adopting a pragmatist perspective, namely that it prompts an understanding of design creativity as an *emergent, situated*, and *reciprocal process*; that design is an *inherently technological mode of inquiry*; and that creativity is a *distributed phenomenon*.

4.1. Design creativity as an emergent, situated, and reciprocal process

Pragmatism conceptualizes inquiry as a fundamentally creative endeavor as it marks out as a departure from habitual thinking toward re-alignment of one-self and the environment in which alternatives to the present state are imagined and brought about. Creativity, in a pragmatist perspective, is not solely a cerebral activity. It is instigated by and – to varying degrees – directed toward environmental conditions, and it is embodied and externalized through the act of creating. The Deweyan perspective thus offers an understanding of design creativity as an *emergent* and *situated phenomenon* that comprises both *action* and *reflection*, and arises *reciprocally* as an interplay between the subject and the environment. Creativity is a common trait; it is not the exclusive domain of gifted creative individuals. This does not mean that everyone exhibits and explores creativity to the same extent, for the capacity for creativity may be honed, and we may be placed in, or actively seek out, situations that place demands on creative practice. Indeed, honing the capacity for creativity is often accomplished by being in challenging situations, to the extent that for instance artists will set up such challenges for themselves as well as for those who encounter their works, as explored in (Dewey, 1934). We will argue that this pragmatist conceptualization resonates clearly with the notions of *self-imposed constraints* in contemporary design creativity research. These conceptualizations may also help us develop our understanding of such constraints by considering how they fit into the assemblage of the situation, most prominently with regard to how they can be employed in the process of transforming the situation into a determinate state. During the crucial first stage of inquiry, such constraints become a technology for directing the design process by helping the designer name and frame the problem, and at later stages they can serve as means to stabilize the situation by the way in which they simultaneously enable certain ways of understanding and acting while ruling out others.

4.2. Design as an inherently technological mode of inquiry

A further consequence of the pragmatist perspective is that it prompts us to consider a more inclusive notion of self-imposed constraints. In a Deweyan understanding, technology is a broad and expansive concept, referring to the use of an artifact or a construct to carry out a task or to achieve an objective. Since designers draw upon numerous resources and instruments – be they semantic, social, or physico-spatial – in the inquiries at the centre of design, design can be considered an inherently technological activity. Technology, in this perspective, is not limited to being a means to an end, something that we employ to facilitate our actions in the world once we have a pre-formulated plan for how to transform the situation we are in. Technology is always already present, in our repertoires and habits formed by past experience, and in numerous forms in our surroundings. This pervasive nature of technology means that it also frames, directs, and scaffolds our experience of the world: *"… technological arts, in their sum total, do something more than provide a number of separate conveniences and facilities. They shape collective occupations and thus determine direction of interest and attention, and hence affect desire and purpose"* (Dewey, 1934, p. 345). Even technologies that are widely construed to be functional tools frame and shape the experience of inquiry in which they are employed; for instance, Johnson (1997) has explored how different text technologies such as pen and paper, typewriters, and word processors affect the ways in which we think about and engage in the writing process (ibid, p. 145). If we bring this perspective to bear on the notion of constraints, it prompts us to consider how the tools and resources we employ in design in themselves serve a dual role as *constrainers* and *enablers* of our inquiry. In some situations we may well be aware of this dual nature, but this is not necessarily so. Indeed, it is often the case that the more proficient we become at employing specific technologies, the more they shift into the background and the less we consider what they are, precisely because they become taken-for-granted extensions of our faculties and means for acting. Consequentially, a part of becoming a skilled designer can be understood as *internalizing technologies* that not only enable, but also constrain how we perceive, interpret, and act.

4.3. Design creativity as a distributed phenomenon

The reciprocal traits of enabling and constraining also present themselves in the relations between the designer and the design situation. The environment is not a passive recipient to the actions of the subject; it responds to the subject as he tries to transform the situation in creative action. Schön (1983), building directly on Deweyan thinking, has explored this phenomenon through a dialogical metaphor under the label of *"situational back-talk"*, stressing that designers need to (1) accept that back-talk is intrinsic to design, and (2) to embrace it as a resource for moving toward design solutions that are well-aligned with the specific situation and all of its tensions and challenges. Design creativity can thus be described as a *distributed phenomenon* between *inquirer(s)* and *technological resource(s)*. On a semantic level, creative inquiry can for instance be distributed between inquirer and language, which Dewey considered to be: *"the tool of tools"* (Dewey, 1925/1981, p. 134). Poets, for example, often introduce linguistic constraints such as particular poem structures to establish simultaneous tensions and affordances in the writing process. Physical instruments for creative inquiry are often easier to observe and lend themselves well to study. A palpable example of this is how designers use sketches, models, mock-ups, and prototypes when exploring potential future forms of an artifact. In a pragmatist perspective, these provisional forms are more than just ways of communicating ideas; they are a crucial part of the creative work: they serve as an extension or distribution of imagination and allow for the designer to bring the world into the process and enter into multiple reflective conversations to explore potential futures. This understanding of distributed creativity in design is akin to the theory of *distributed cognition*, developed by Hutchins (1995), which holds that cognitive processes occur beyond the individual and can be distributed across people and technologies. A further development is found in Gedenryd (1998), who builds upon both Dewey and Hutchins to develop the term *interactive cognition* to denote the distributed process of creative inquiry, and the term *situating strategies* to denote the particular method of employing resources in the situation to augment imagination: *"Quite simply, these techniques re-create the various parts of this situation that do not yet exist. To make interactive cognition work well, the designer has to create her own working materials; before the world can become a part of cognition, the designer has to create it"* (Gedenryd, 1998, p. 157).

5. Concluding remarks and future paths for conceptualizing design creativity

It seems appropriate to begin by acknowledging that ideally, we would have liked to also relate the theoretical findings of this paper to some of the design projects our lab has been involved in. Such a two-fold strategy, however, lies beyond the scope of this paper. Instead, our aim has been to focus on the fecundity of introducing *a constraint-oriented, pragmatist conceptual framework* to contribute to inspire and inform ongoing research into design creativity. In our view, one of the main reasons the notion of design creativity suffers from the current, terminological cloudiness is the fact that not even 'creativity' is consensually understood; a terminological diffusion that becomes even more significant within design research (Askland, Ostwald & Williams, 2010). Given the fact that some scholars argue that the notion of creativity may be traced back to pre-Socratic philosophers, even ancient mythologies (Mason, 1988), it is quite remarkable that no philosophy of creativity, including a cohesive, conceptual framework, has yet been introduced, although it seems to be slowly emerging, see (Stokes, 2006; 2008; Gaut, 2010).

One of the main arguments presented above is the contention that the importance of constraints in creative activities is gradually being transformed. What current studies of designers suggest is that even inviolable constraints are often being challenged, at least for a while, to allow for a more situated or dialogical, approach to constraint management or better: constraint manipulation. This changing conceptualization of constraints and their relation to creativity, including design, has recently been echoed by leading creativity researchers, notably in an authoritative anthology of creativity research (Kaufman & Sternberg, 2010). As a very young discipline, design obviously relies on much work within related areas of research, which forces it to look both back toward previous contributions to theory that might help qualify its ongoing theoretical advancements, as well as toward vanguard currents in creativity research. In this paper we have done both. Deweyan pragmatism offers a well-developed framework for addressing how *creative inquiry in design* plays out as an interplay between the creative agent (i.e. the designer), and the resources given in the actual situation. This complex dialectic interplay resembles the duality of constraints as adhering to both opening/expanding and constraining/delimiting the problem and solution space for the designer. Until a more unifying theory or even philosophy of creativity, encompassing both design and other forms of creative practice, should arise, we hope to have offered a contribution to the advancement of insights into the complex and intriguing concept of *design creativity* by building on both past and present theorizations.

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CREATIVITY, SURPRISE & DESIGN: AN INTRODUCTION AND INVESTIGATION

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Abstract: This paper weaves together some of the basic ideas about surprise, and creativity, in the context of design. Situations in which design surprise might occur are identified, and a few are discussed in more detail. The goal is to identify areas where additional theoretical, experimental and computational research might be beneficial, leading to the ultimate goal of computational design systems which produce artifacts that are judged to be creative.

Keywords: *creativity, design, surprise*

1. Introduction

There is no such thing as a creative computational system, only ones that produce artifacts that are evaluated as creative. Hence, to build computational design systems that produce artifacts that will be judged to be creative, we need to understand more about how artifacts get evaluated.

Evaluations have strengths; therefore artifacts may be seen as more, or less, creative. In addition, the evaluation of creativity is multidimensional. Any evaluation in a single dimension results from the evaluator's biases about how to combine dimensions, where the biases of the evaluator affect which dimensions get weighted more highly. Those biases get changed over time, and change according to the situation. The evaluator may be the designer, someone else (e.g., a user), or a computer program.

Evaluation is based on:

- the knowledge, experiences, context, feelings and preferences of the evaluator;
- the type and degree of exposure to the thing being evaluated (e.g., see, touch, manipulate, or use) (Ludden et al., 2008);
- the "norms" for the relevant population to which the evaluator belongs (e.g., novices, experts).

If computational design systems are going to be reliably judged as creative they will need to be able *aim towards* creative solutions: hence they should be able to evaluate their own work, both during designing and at completion. Hence evaluation is a key research area.

Many writers have mentioned **novelty** as one of the dimensions used to evaluate whether an artifact is creative, and some mention **value** or **utility** (Boden 1994) (Maher & Fisher 2011) (Sarkar & Chakrabarti 2011). Fewer discuss the role of **surprise** in evaluation: creative products often seem surprising at first. For example, Besemer (2006) includes it in a set of nine dimensions that she has discovered are used by people to evaluated product creativity (Brown 2008).

As surprise is part of creativity evaluation, computers may need to be able to be surprised by their own work, and be able to judge the likely surprise of others. Note that we are concerned here with cognitive surprise, and not any physical or emotional aspects.

In this paper we describe Boden's model of some types of creativity, then the eight types of surprise described by Ortony & Partridge. Next we discuss the criterion of radical originality, followed by an exposition of 24 contexts for surprise, finishing with an examination of some of these contexts.

2. Boden's model

Boden (1994) writes about a **conceptual space**: i.e., all the concepts that can result from a synthesis system (human or machine) using its knowledge. The "space" is just the collection of artifact descriptions (e.g., about designs, poetry, or music) that is possible given that knowledge and those synthesis mechanisms.

For convenience, from here on we'll refer to an "artifact", with "description" implied, even though for design an artifact is a realization of a description. We will use the term "artifact" instead of "design" in order to try to allow for some generality.

Boden refers to **first-time newness** (FTN) as a property of those artifacts that have not been generated before (i.e., they're new), but which fall *inside* the conceptual space. She considers that these FTN artifacts cannot be judged to be truly creative, as the synthesis system is just "exploring" the conceptual space (i.e., finding new examples from the space, such as a beige milk jug, not a white one). As a consequence, this has been termed **exploratory creativity** (EC).

Boden (1995) in response to criticism admits that exploratory creativity "can offer surprises comparable to the surprises provided by transformational creativity" (more on the latter below) — note that this does raise the question of why those surprises might be comparable. However, she writes of "mere" exploration to emphasize the difference. Several researchers do not denigrate this kind of creativity quite a much (Ram et al. 1995) (Schank & Foster 1995) (Beghetto & Kaufman 2007) (Brown 2011).

It seems that the perceived weakness associated with exploratory creativity hinges on the fact that FTN artifacts, in principle, either were, or could have been, 'expected'. The implication is that exploring leads to less surprising results, and, as surprise factors into our evaluation of creativity, those results are less creative.

An **expectation** is some sort of description of, or proposition about, an artifact (e.g., milk jugs have a handle). An expectation can be **satisfied** or **violated** when matched with a description of a newly generated artifact. An **expectation violation** resulting from such a *mismatch* produces one of the most common types of surprise. "Mary had a little lamb, wasn't the doctor surprised" surprises both the doctor, and you, with expectation violations.

So, for FTN artifacts within a conceptual space, we make the assumption (for now) that expectations about those artifacts are similarly limited to that space. Those expectations are **deducible** in that they could be produced from the knowledge base being used for synthesis. However, Ortony & Partridge

(1987) refer to **practically deducible** expectations, adding a touch of realism, because they are trying to describe a plausible cognitive model.

They do not provide a detailed explanation of what constitutes "practical", just stating that it should "not require many and complex inferences". It's likely that what is practical or not depends on the situation. For example, given a design and plenty of time to examine it visually, and perhaps physically, it is certainly possible to be surprised by inferred expectations about the artifact as more data about it is gathered. As such, "practically" is very much like the term "real time", in that it depends on the current situation and its temporal constraints. Note that using the term "deducible" is not intended to make any claims about the kinds of reasoning involved.

Clearly, not all expectations about artifacts are necessarily "practically" deducible. Some may be deducible but not practically. As a consequence we can consider two kinds of FTN expectations: practically deducible (PD) expectations and those that *are* deducible, but ***not*** **practically deducible** (NPD). The amount of effort involved for each is different, as the reasoning chains will be longer, and/or more complex in the NPD case: i.e., you will get an expectation *eventually*. The collection of deducible expectations (D) consists of the union of PD and NPD: i.e., **D = PD ∪ NPD**

The PD expectations can be further subdivided. Imagine working on a design problem, having framed the problem in a certain way. Some of one's knowledge would be in focus, or active, as it is relevant to the task at hand, while other portions would not currently be in use.

Active knowledge might include recently made decisions, for example. As a consequence of that and other active knowledge, there would be **active expectations** (A). For example, having decided that a width was 1 mm, there might be an immediate active expectation produced that the length would be less than some amount due to strength requirements. Active expectations are available for matching as soon as an artifact is presented. This is clearly in the PD class, as when matching is done (e.g., with the actual length), no inference is needed: the expectation is already present.

Even if the active knowledge did not produced active expectations, the fact that it is being focused on allows expectation inference to be fast. These **active knowledge expectations** (AK) are also be in the PD class, as when matching is done and expectations need to be tested, a relatively small amount of reasoning is required to produce them.

One can imagine a class of PD expectations formed from knowledge outside the active knowledge: i.e., ***not*** **active knowledge expectations** (NAK). Deducing those expectations will take a little longer. So, **PD = A ∪ AK ∪ NAK**, and each type has the potential for producing useful expectations.

For completeness, it is possible to conjecture knowledge that does not combine with other knowledge and the existing reasoning mechanisms to allow expectations: i.e., expectations are ***not*** **deducible** (ND). That knowledge would not to be useful for synthesizing any FTN artifacts either.

Ram et al. (1995) consider creativity to be in the context of a task and a specific situation. This "pragmatic context" influences and restricts the kinds of the knowledge and the reasoning that are used: i.e., it affects what is deducible. This allows a designer to use strategic (i.e., "meta") reasoning to change the context, changing what is in D, and hence in PD too.

3. Surprise

There is little detailed discussion about the role of surprise in creativity, the mechanisms that underlie surprise, and surprise in creative design specifically. An important recent review paper about computational surprise is "Artificial Surprise" (Macedo et al. 2009). The seminal paper from AI is by

Ortony & Partridge (O&P) (1987), describing the role of expectations in *cognitive* surprise (N.B., this does not address emotional or physical responses).

O&P introduce eight types of surprise, divided into two categories, one where expectations are practically deducible (PD), and one where this is *not* possible (NPD): i.e., given the current knowledge something could not easily have been expected. They propose two cases of surprise with PD expectations. An **active expectation** case (A) where the expectations have been already been produced (i.e., "I expect this"). A **passive expectation** case allows for situations where expectations *can be made active on demand* (i.e., "could I have expected that?"). This passive case corresponds to the AK ∪ NAK expectations described above.

O&P suggest that violations of active expectations should produce more surprise than violations of passive expectations, presumably because the knowledge involved in producing active expectations is more relevant to the situation. If active knowledge is the source for active expectations, perhaps that represents the more typical, more frequent propositions.

O&P suggest another distinction that affects the amount of surprise: the typicality of the content of the expectation. For example, an expectation that a desk has a flat top is about something you'd expect of *all* desks, while an expectation that a desk has drawers is about something typical. So a new artifact can contradict an expectation where the knowledge involved is considered to be **immutable** (i.e., always true), or an expectation representing something **typical**. Note that this is a continuous dimension; however, O&P take two values for convenience.

One would expect violations of immutable expectations to be the strongest, and stronger than violations of typical expectations. It is probably also affected by the *degree* of typicality, the *belief* in (or evidence for) that degree value, and whether the expectation was active.

There is on-going discussion about how the **amount of surprise** is produced (Macedo et al. 2009; Maguire et al. 2011). One view favors some form of probability-based surprise, and another considers surprise to be relative to the degree to which "representation updating" is required to make sense of the new event: i.e., if an event is very different from an expectation, but can easily be explained, its surprise will be lowered. In this paper we try to remain as neutral as possible about these views.

In addition to PD expectations, there are also situations where expectations are not practically deducible (NPD). O&P suggest that even the fact that nothing was deduced is in itself surprising.

In the NPD case there can be no 'active' expectations. They refer to a kind of passive expectation that can result in "a conflict between the input proposition [i.e., the artifact] and what, after the fact, may be judged to be normal or usual": i.e., the conflict is "on the basis of deviations from the norms".

O&P give the NPD example of a finding a person levitating as contradicting "immutable" passive expectations. Having a rock come through one's window is given as an example of contradicting "typical" passive expectations: but it too (under normal circumstances) is not practically deducible.

Notice that the conflict they describe is between the input (e.g., a person) and a proposition about what is "normal or usual". However, that judgment requires some kind of inference (e.g., induction from examples). But if it is inferred then this makes it practically deducible! That proposition about what is normal is a passive expectation, and must be in the PD class. This contradicts O&P's claim that this kind of surprise occurs in the NPD situation. Hence we must conclude that contradicting norms is a special case of PD, and that given O&P's model there are *no* NPD examples of surprise. This seems wrong initially, but clearly what is practical can be situation dependent: i.e., there *are* examples, but not in this situation.

Interestingly, despite previously following O&P very closely, Macedo has pared down his model of surprise (Macedo et al. 2009) to remove NPD cases, without stating it as explicitly as we have above.

4. Expectations about surprise

In Macedo & Cardoso's (2001) multi-agent system, agents produce descriptions of new items for other agents to inspect. Each agent considers a variety of possible new items, evaluating each for the amount of surprise it is *expected to cause in other agents*. As there is potential benefit from causing surprise, the most surprising design is chosen.

Normally, this evaluation would require a model of the other agents' knowledge: i.e., you have to know the other agents' norms in order to violate them. In that system it can be done because there is a single, shared, frequency-based scheme (i.e., the norm) for calculating the amount of surprise, and therefore no need for models of what other agents know.

Designer agents form expectations for each possible new item about how much other agents will be surprised. We will refer to these expectations as **surprise expectations** (S). We conjecture that a human or computational system making design decisions can be motivated by the goal of producing creative artifacts, hence they might intend to surprise, and could have S expectations.

The S expectations appear to be 'active'. They are not deducible at the design knowledge level, but should be at the **design process meta-level**. S expectations will not be included with type A expectations, as despite being active they are not directly about the design.

In Macedo & Cardoso's system, because of the shared model of surprise, the S expectations will be confirmed. However, in general, if the evaluator is *not* surprised by the design, then the designer's S expectation fails, causing the designer to be surprised ("Wow! I thought they'd be surprised!").

5. Radical originality

Boden's view of the newness needed for what she considers to be true creativity, and not "mere" exploration (EC), is the kind of "radical originality" that results from changing the conceptual space. As the space needs to be transformed, this is referred to as **transformational creativity** (TC).

The resulting new, creative artifacts are in the transformed space, but not in the original space. They could not have been expected using the original knowledge (for the old conceptual space), because those expectations do not apply to the new conceptual space by definition: i.e., expectations about complete new artifacts are not deducible for the new space using the original knowledge.

Boden suggests that these new artifacts, resulting from the transformation, would be "surprising". She does not say what this means, nor for whom this will be a surprise. We assume that she means that expectations are violated, and that this is *at least* surprising for the external evaluator.

The transformation might be produced by relaxing constraints, abduction, induction, analogy, or by some other method. Other possibilities include mental simulation, reinterpretation, emergence, explanation, and merging/combining knowledge from other less pragmatically related areas. For more discussion of transformations see Ritchie (2005; 2006) and Wiggins (2006).

Boden also writes about **combinatorial creativity**. While EC and TC cases are defined in terms of the space of possible concepts, combinatorial creativity is a way of generating new concepts by combining existing ones. Note that this can transform the conceptual space. As this type of creativity is more about 'process' it is categorically different from EC and TC, and appears to be an example of how to produce a new artifact in a transformed space.

Consider the transformational creativity of a designer who has transformed the conceptual space: she now has new, recently formed knowledge. As before, we assume that the designer can now form an expectation about any new design that they might generate using this new knowledge.

Ritchie (2005) is unusual in that he uses "the perspective of the individual assessing the artifact", thus putting the onus for transformation on the evaluator: i.e., the *evaluator* needs to transform his or her own conceptual space so that the designer's artifact 'fits' into the transformed space. This resonates with Schank's theories of "creative explanation", as well as the theory (Maguire et al. 2011) that surprise is concerned with revising knowledge to explain the difference between the expectation and the artifact.

Table 1. When and How Surprise Occurs

		EXPLORATORY		TRANSFORMATIONAL	
		DESIGNER	EVALUATOR	DESIGNER	EVALUATOR
PARTIAL DESIGN	A	1	4	7	10
	AK	2	5	8	11
	NAK	3	6	9	12
COMPLETE DESIGN	A	13	16	19	22
	AK	14	17	29	23
	NAK	15	18	21	24

6. Contexts for surprise

At this point we can ask in what situations surprise might occur, and whether the classes of expectations, A, AK, and NAK, can affect the type of surprise that might be produced if each were violated. A key issue is how surprise can occur for EC, in addition to TC. The other variables that affect the context for surprise are whether the expectation is used with a complete, finished design or with a partial design during the design process. As the designer may or may not be the evaluator, both cases need to be considered: i.e., who gets surprised. This produces 24 contexts for surprise (Table 1).

For example, the surprise in cases 1, 4, 7, and 10 represent situations where active expectations about a partial design are violated, while 2, 3, 5, 6, 8, 9, 11, and 12 are passive expectation violations. It is most likely that only the designer will see partial designs, while both the designer and the evaluator see complete designs. The most significant outstanding question is "how can a designer be surprised by their own design?".

7. Discussion

Ritchie (2005) discusses what Boden might mean by a conceptual space, distinguishing between an **artifact-set**, and a **space-definition**. The former is the actual set of artifacts that constitute the space, while the latter is “a more compact definition of possible artifacts”. The space-definition is knowledge that can be used to generate new artifacts, while known artifacts in the artifact-set can be used for case-based reasoning as well as expectation formation.

Imagine that space-definition knowledge can be modeled in rule form. Clearly, a designer can know the rules, but not necessarily know in advance all the results of successive applications of these rules. It is highly unlikely that much of the space is already known: probably occurring only in very routine situations (Brown 1996). As Boden (1995) points out, exploration can take us to “regions that were previously unsuspected” and show us boundaries “in surprising places”: i.e., the designer is surprised.

Using natural language as an example, the phrase “half a pair of purple trousers isn’t really better than none” might be in the space of sentences (i.e., artifacts), but it would fall into a “previously unsuspected” region: before now, that is. This corresponds to exploratory creativity.

Another possible argument for why a designer might surprise themselves, in both EC and TC cases, can be made if we consider a conceptual space to be formed from concepts. Rosch (1999) describes the “Graded Structure/Prototype” view of concepts as: not having clear cut boundaries; not having *necessary* attributes to determine membership; having gradations of membership; containing a rich amount of information about some situations; and being very flexible. She considers concepts to be “situation based and participatory rather than identification functions”, strongly tied to contexts and situations. This makes the conceptual space much fuzzier and unpredictable than, for example, something generated by a formal system. Given this view it is much easier to envision that a designer might be surprised by some intermediate or resulting design.

One possible situation where a designer might be surprised by their own partial designs is if they are sketching. Sketching allows the possibility of recognizing unexpected associations with other design concepts, or finding emergent properties (Suwa et al. 1999). In this way their expectations (probably “active”) will be violated resulting in surprise about a partial design. It is even possible that such associations might be ‘fuel’ for a transformation of the conceptual space.

A general issue for the TC case is whether expectations can be formed as easily for the transformed space as for the original conceptual space: after all, *the original space is more familiar* and more explored already. It seems likely that until the transformed space becomes familiar, TC artifacts will cause surprise for the designer as she will tend to produce expectations from the original conceptual space. This is clearly just a hypothesis, but a plausible and interesting one.

Referring back to the natural language example, the phrase “lovely chubby babies sleep quietly” could be recognized as the result of known rules (EC), and even expected, but in the TC case, “awkward blue concepts feel furiously” is surprising, even though we can infer that **relaxation of semantic constraints** must have been involved in the transformation of the space.

Let us assume that an external evaluator shares the same original knowledge, and the same original conceptual space, as the designer. They will both be able to produce active or passive expectations about any design in the original conceptual space: although not necessarily the same at the same time. However, using that original knowledge, they will *not* be able to produce expectations about *complete* designs in the transformed conceptual space. However, despite that, it is possible that *some* expectations about *properties* of designs in the transformed space are shared with those in the old space, as not everything about the new designs will be radically new. As Boden (1995) points out, “some aspects of the previous space need to be retained”.

Consequently, the designer, using their original untransformed knowledge, should be able to try to evaluate their own new TC designs for creativity. Some of their expectations *will* be satisfied, but some will be violated due to the changes brought about by the transformation. Their surprise will result in the same way as an external evaluator’s might if they share the same original knowledge.

Alternatively, the evaluator might have enough design ability and experience to have an expanded or different conceptual space, able to produce active or passive practically deducible expectations about some TC design solutions. So, depending on the overlap between the designer’s transformed space and the evaluator’s expanded space, in some situations the evaluator would not be surprised by TC solutions, and sometimes they would have surprise from expectation failure.

In general, however, the designer’s knowledge may be quite different from the evaluators (e.g., customer, professor, CEO, etc.). For example, in case 22 (Table 1) a complete TC design is evaluated by an evaluator with an active expectation and she is surprised. Active expectations can be caused by prior knowledge of that product type, with knowledge of examples, probably plus extensive knowledge of typical similar products. The correctness of an expectation depends on the closeness of the design to existing products. Note that if the evaluator has access to intermediate versions of the design (i.e., partial) then this might allow them to produce additional expectations.

The evaluator could even know requirements and have mentally produced a rough design themselves, producing expectations about many of the design decisions: much as was done by the Active Design Documents system (Garcia et al. 1993).

In situations where *redesign* is being done — perhaps due to the evaluator having done an evaluation of which aspects of a rough/conceptual design might be seen as creative, as Besemer (2006) suggests — they might have quite strong, active expectations about the outcome.

When the *evaluator has the same* original knowledge as the designer then their expectations will be mostly limited to the untransformed design space. To be surprised the evaluator must be faced with properties of the TC design that do not arise from old knowledge. In situations where the *designer has more* knowledge than the evaluator, even exploratory creativity might be quite surprising to the evaluator, and TC designing is sure to be. In a situation where the *evaluator has more* knowledge than the designer, it is more likely that the evaluator’s expectations will be satisfied (i.e., they’ve seen it before). So while it might be **P-creative** (Boden 1994) for the designer, it will still not be surprising for the evaluator (similarly for cases 23 & 24, and passive expectations).

Maguire et al. (2011) emphasize the difference that this kind of *sophistication* can make; pointing out that a “flying rabbit” would be very surprising for an adult, with strong (immutable) expectations, but “more easily accepted” by a child. However, they propose that adults tend towards generalized representations that allow easy integration of surprising events. Children however find most things surprising, as what representations they have are still quite specific and hard to integrate with. An interesting issue is whether the expectations themselves can vary from general to specific, thus changing the matching process with the artifact, perhaps changing the way expectations are “violated”.

Horn & Salvendy (2006) confirm that expectations influence product creativity evaluation. If a product falls short of expectations it can lead to “disappointment” and “dissatisfaction”: but **pleasure** and **emotional arousal** affect judgments of creativity. These effects are claimed to apply across each dimension of the evaluation (e.g., novelty).

8. Conclusion

This paper has attempted to present and weave together some of the basic ideas about surprise, and creativity, in the context of design. Situations in which design surprise might occur have been identified, and a few were discussed in more detail. This provides a *framework* in which to consider situations where designers or evaluators might be surprised.

The background goal of this work is to identify areas where additional theoretical, experimental and computational research might be beneficial, leading to the ultimate goal of computational design systems that produce creative artifacts.

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Practice

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PLAY, AUTONOMY AND THE CREATIVE PROCESS

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Abstract: Play has started to be recognised as having an affect upon the creative design process, but mainly in terms of playing with prototypes. In this study we explore play a little further to understand more about the type of play and its affect upon the creative process. We look at physical, imaginary, social and non-related play, in relation to solving a creative problem. Surprisingly, the condition with the highest scoring and fastest completion times was the non-related play condition. This would suggest that there is more going on than just iterative feedback when a person is playing in the creative design process. Relatively new research has started to show that play may also be important because of the intrinsic motivation that is inherently part of the nature of play. This intrinsic motivation and elements of autonomy have also been shown to have an affect upon people's feelings of well-being. This study supports the idea that play may be even more important to the creative process because of the affect it has upon a person's 'state of being'.

Keywords: *play, autonomy, creativity*

1. Introduction

Brown and Vaughan (2010), Kelley and Littman (2002) and Schrage (1999) contend that play is an important aspect of the creative process. Sutton-Smith (1966, 1992) stresses the role of play in the development of flexibility in problem solving. We are interested in why play is an important aspect of the creative process. In a previous study (Loudon and Deininger, 2011) we explored the role of play and prototyping in creativity. The results of that study raised the following questions:

- Does play support creative problem solving?
- Does play need to be related to the task at hand?
- Does the form of play affect the creative problem solving performance?

The aim of this study is to try and answer these questions. In looking at the question of whether play needs to be related to the task at hand we are actually asking the question of whether the role of play is directly connected to prototyping or whether there is something deeper going on.

1.1. Play as an altered state

Play has often been defined as being a spontaneous activity that is joyful, having the absence of consequences and the removal of constraint (Lieberman, 1977; Gordon, 2008). Brown and Vaughan (2010) describe play as being an altered state, exploring the possible in which joyful emergence occurs. Csikszentmihalyi (1996) describes the concept of ‘flow’ during the creative process where people have the feeling of things as “almost automatic, effortless, yet highly focused stated of consciousness”. Csikszentmihalyi highlights nine elements of flow:

> *There are clear goals every step of the way*; *There is immediate feedback to one’s actions*; *There is a balance between challenges and skills*; *Action and awareness are merged*; *Distractions are excluded from consciousness*; *There is no worry of failure*; *Self-consciousness disappears*; *The sense of time becomes distorted*; *The activity becomes autotelic*.

These ideas of play as putting a person into an altered state or as being an aspect of the ‘flow’ experience suggest that there may be a deeper element to play. In previous studies we have been looking at the affect of ‘state of being’ upon creativity (Deininger and Loudon, 2011). This study may shed more light on the link between play and creativity in terms of ‘state of being’.

2. Methodology

To explore whether play supports creative problem solving and if the form of play is a factor in creative problem solving we chose to use Duncker’s candle problem (1945) as the creative problem solving challenge. Duncker’s candle problem has been used in a wide variety of psychological studies and is accepted as a good creative problem-solving task. In this task the participants sit at a table next to a corkboard. On that table are a candle, a box of drawing pins and book of matches. The task is to attach the candle to the wall, without wax dripping onto the table when the candle is lit. We modified the task because books of matches are not so easily available and boxes of drawing pins rarely come in cardboard boxes as described by Duncker. Therefore we provided a standard (cardboard) box of matches, a candle and a handful of loose drawing pins. See figure 1 below.

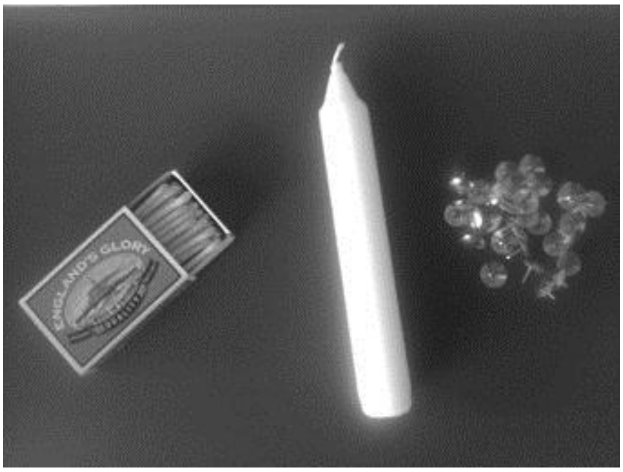

Figure 1. The candle, box of matches and drawing pins used in the task

The task was then presented in written form and participants were allowed to write or draw the solution. Fifty participants were selected from a larger group of undergraduates of the product design and architecture departments. Participants in the study had no previous knowledge of Duncker's candle problem. Participants were randomly assigned to five different conditions to see what effect different forms of play had on solving the problem. Ten participants were in each condition.

These conditions were:

- Social Play: In this condition participants were allowed to communicate with each other via a Facebook application on their mobile phones. They were instructed not to talk to each other during the task.
- Imaginary Play: In this condition the participants were given the task in the form of an imaginary story. The imaginary story was:

  Once upon a time you went into an enchanted forest. You went there because you had heard that there was a magic castle on the other side of this forest. You had decided that today was the day you would go to that castle. As you entered the enchanted forest you saw bushes filled with lovely berries to eat. You felt hungry but decided not to stop and pick the berries. You came across lovely patches of soft green grass but you did not lie down on them, as you were determined to get to the castle. You even saw playful pixies trying to tease you into chasing them. But you kept going through the forest.

  Eventually you came out the other side of the forest and before you stood a rather grand but rather strange looking castle. It was not round but not square either. It was quite tricky to find the entrance but being rather clever, you ended up finding how to enter the castle. After you entered you found yourself standing in front of a magnificent spiral staircase. You decided to climb the staircase. At the top of the staircase was a cosy little room. Feeling rather tired by now you went into the room to see if there was somewhere to sit.

  Standing in the room was a wise old wizard, and he said, "Ah, I have been waiting for you." He continued, "You have shown that you are perhaps worthy to be my apprentice. You have passed through the enchanted forest without being distracted or tempted to stay. You have found the entrance to the castle and you were brave enough to climb the spiral staircase and enter this room. Now you have just one more task to complete which will show me that you are meant to be one of my apprentices. And of course you answered "What must I do, oh great and wise master?" The wizard points to a table. On this table you have a candle, a box of matches and some drawing pins. You need to attach the candle to a wall (cork board) so that it does not drip onto the table below.

- Non-Related Play: In this condition, before being told of the task, participants were asked to take part in a game that was not related to the challenge. The game used was the 'Human Knot'. In the 'Human Knot' game all of the ten participants were asked to stand in a circle. Then, each person was asked to place their hand in the middle of the circle and to grasp another person's hand – then they do the same with their other hand, ensuring that they take the hand of a different person. The group then tries to unravel the 'Human Knot' by unthreading their bodies without letting go of each other's hands.

- Physical Play: In this condition the participants were given the actual materials (the candle, the box of matches and the drawing pins) to manipulate in order to help them solve the problem.
- No Play: In this control condition, participants were just given the written instructions and asked to solve the problem.

All participants were given a maximum of five minutes to complete the task. All participants attempted the task and recorded their solution independently. The time taken for each person to complete the task was recorded. If the solution was not completed within the assigned time, it was recorded as a time of 5 minutes.

3. Results

Figure 2 below shows an example of one participant's correct solution. Figure 3 shows an example of another participant's incorrect solution.

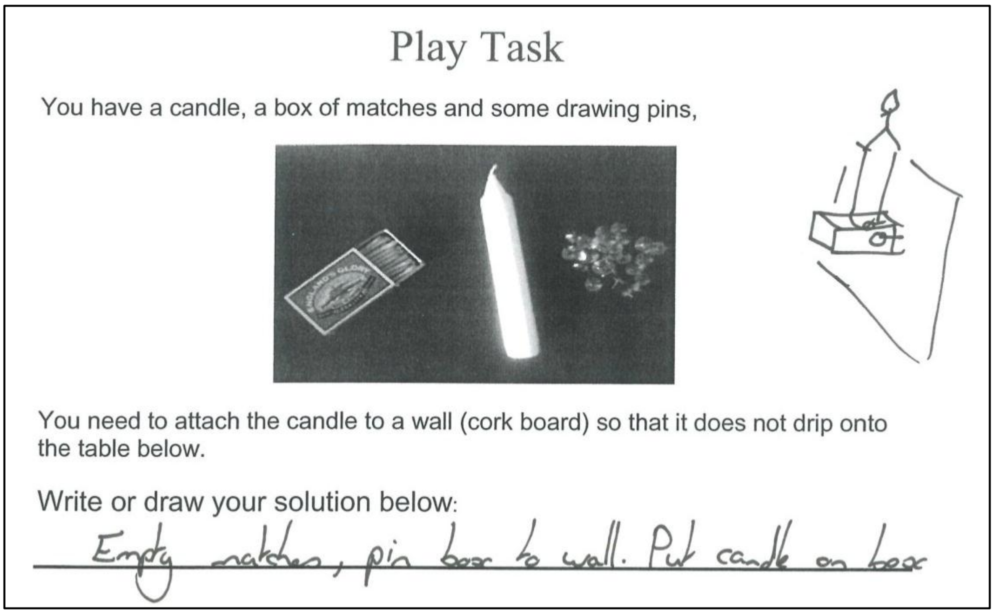

Figure 2. An example of a correct solution to the problem

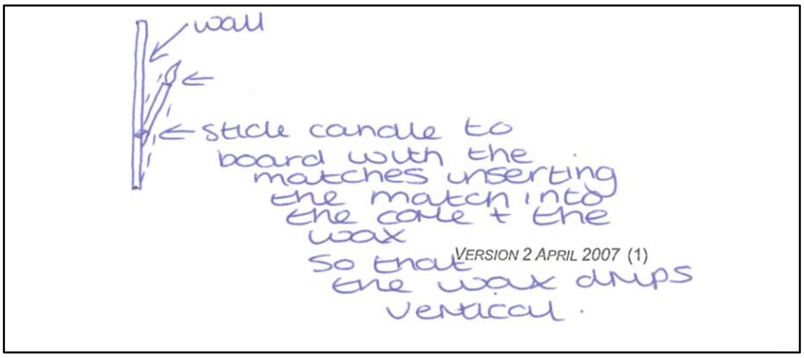

Figure 3. An example of an incorrect solution to the problem

In terms of the 'Social Play' condition only a limited amount of conversation took place on the Facebook application. See Figure 4 below. Some ideas were shared on how to solve the problem. It was observed that participants were also using the Facebook application for their own personal use. It was reported by some participants that there was not enough time to use the Facebook application effectively.

Figure 4. The Facebook conversation amongst participants in the 'Social Play' condition

Figure 5 below shows the overall number of correct solutions for each condition. The ‘Non-Related Play’ condition and the ‘Social Play’ condition had the highest number of correct solutions (6 out of 10). The ‘Physical Play’ condition had the next highest number of successful solutions (4 out of 10), followed by the ‘No Play’ control condition (3 out of 10) and then finally the ‘Imaginary Play’ condition (1 out of 10).

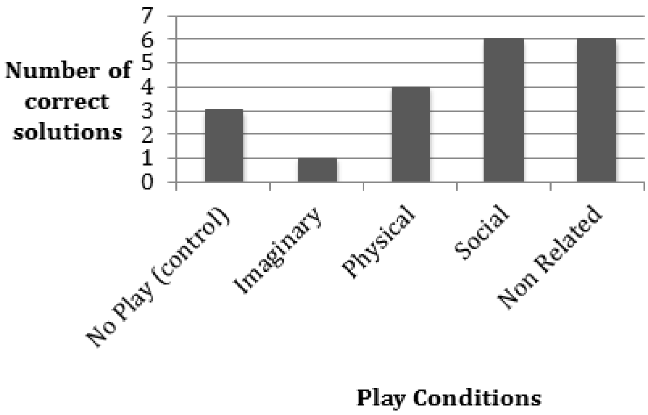

Figure 5. The number of correct solutions for each condition

Figure 6 below shows the average completion times, in seconds, (including 95% confidence intervals) for each condition. The results show that on average, participants in the ‘Non-Related Play’ condition had shorter completion times (*M* = 141, *SD* = 31) than participants in the ‘No Play’ condition (*M* = 233, *SD* = 74), the ‘Imaginary Play’ condition (*M* = 270, *SD* = 51), the ‘Physical Play’ condition (*M* = 252, *SD* = 101), and the ‘Social Play’ condition (*M* = 252, *SD* = 79).

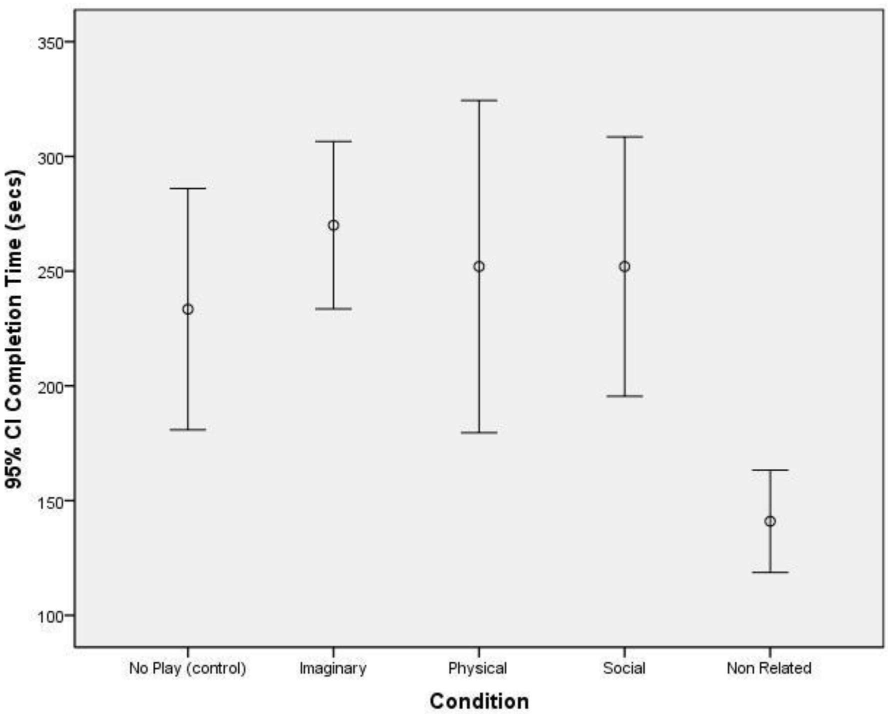

Figure 6. The average completion times for each condition, including 95% confidence intervals

The completion times were analysed using a univariate analysis of variance. There was a significant effect of condition, $F(4,45)=5.17$, $p=0.002$. The completion times were analysed between two conditions at a time. Note that we used an alpha level of 0.05 for all statistical tests. Table 1 shows that there were significant differences between the 'Non-Related Play' condition and all other conditions.

Table 1. Significance of differences between completion times of 'Non-Related' Play condition with other conditions

Conditions	**F-test Statistic (F values)**	**Statistical Significance (p values)**
No Play	14.00	0.002
Imaginary Play	46.60	0.000
Physical Play	10.99	0.004
Social Play	17.09	0.001

4. Discussion

After analysing the results it is clear that the 'Imaginary Play' condition had the lowest performance both in correct solutions and completion time in relation to the 'No Play' condition. There is no clear indication as to why this may be the case. One possibility could be that the story did not clearly communicate the task. Another reason could be that there was a large amount of text to read, which may have been strenuous for some students.

The 'Physical Play' condition had a higher number of correct solutions and a longer average completion time in relation to the 'No Play' condition. Even though the number of correct solutions was higher than the 'No Play' condition it was only marginal. This condition is closest to a prototyping process therefore it was somewhat surprising that there was only a marginal difference in performance, in relation to the 'No Play' condition. Prototyping is largely regarded as one of the fundamental elements of the design innovation process therefore we would have expected a much higher number of correct solutions (Kelley and Littman, 2002).

The 'Social Play' condition had a higher number of correct solutions and a longer average completion time in relation to the 'No Play' condition. This was not expected, as there was only a limited amount of interaction through the Facebook page. It had also been observed that the participants were distracted by going onto their personal Facebook pages. Perhaps this distraction was also a factor in the creative problem solving performance. Wallas (1926) and more recently Dijksterhuis and Meurs (2006) have established that the element of distraction can have a positive effect upon creativity. It could also then be said that this form of distraction may be another type of non-related play.

A surprising result was that the 'Non-Related Play' condition had a higher number of correct solutions and a much shorter average completion time, in relation to the 'No Play' condition. The question is why? Brown and Vaughan (2010) and Csikszentmihalyi (1996) have touched on the idea that play may be linked to an altered state. From the definition of 'flow' there seem to be three particular aspects that are present in the 'Non-Related Play' condition. These are: there is no worry of failure; self-consciousness disappears; and the activity is enjoyable. What may be emerging is that the non-related play activity was not only enjoyable but was free of performance expectations. Deci and Ryan (1985) suggest "that the concept of flow represents a descriptive dimension that may signify some of the purer instances of intrinsic motivation." To be truly intrinsically motivated a person must also feel free from pressures, such as rewards or contingencies. "The concept of intrinsic motivation is simply another way of saying that people are interested and enjoy what they are doing" (Cameron, 2006). The controlling nature of extrinsic motivation has been found to be detrimental to creativity (Amabile, 1996). It has also been suggested that intrinsic motivation occurs when action is experienced as autonomous or self-determining (Deci & Ryan, 1985). It would seem that non-related play displayed the characteristics that define an intrinsically motivated activity.

If we look at both the 'Non-Related Play' and the 'Social Play' conditions, both exhibited an element of autonomy because they were not related to the task at hand. This autonomous element has often been related to prototyping exploration (Schrage, 1999). However, researchers have also found a link between autonomy and overall well-being (Pink, 2009). This would suggest that autonomy could also be related to the 'state of being' of the person carrying out the creative task. In previous studies we have found that 'state of being' does play a role in the creative process (Deininger and Loudon, 2011). 'State of being' seems to be more of a factor in the current study than prototyping itself. The findings of this study seem to suggest that a non-causal relationship is having a greater affect upon the creative process than a causal one.

5. Limitations of the study

As only fifty participants were involved in the study, covering five conditions, it is difficult to draw too many strong conclusions from the results. This is especially true with regards to the limitations imposed in the 'Social Play' condition where participants stated that they did not have enough time to use the Facebook application effectively, and therefore the amount of social play involved was limited and the comments became more goal orientated. In the 'Imaginary Play' condition information on the imaginary story was presented in a written form and again could have been presented in a more playful and immersive form. It could be argued that the 'Non-Related Play' condition also had an element of social and physical play. Finally it might have been useful to understand how engaged each participant felt in their play condition after completing the activity.

6. Future Research

This study has highlighted a very interesting, possible link between play, autonomy, state of being and creativity. We plan to explore these possible relationships more deeply at a quantifiable and qualifiable level in future studies.

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THE DESIGN OF NARRATIVE JEWELRY AS A PERCEPTION IN ACTION PROCESS

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Abstract: The creation of jewelry involves processes, which are often very experimental and intuitive, encompassing both the creative process and production techniques. In this paper, which is based on a recently realized research project in narrative jewelry, we will reveal and reflect on the process of creating and producing a series of jewelry pieces, based on a narrative musical work - The Carnival of the Animals. Due to the nonlinear process of the project and the co-evolution of drawings, narrative illustrations and jewelry pieces, the project is part of the emergent paradigm of design methodology. Taking into account the dominant role of perception in the creative design process, we will explain and reflect on the jewelry project through the application of the Perception-in-Action Model, which is based on the emergence of design solutions in a co-evolutionary process guided by perception.

Keywords: *design cognition, design methodology, narrative jewelry, creative process, perception*

1. Introduction

Over the last thirty years, scientific interest in the creative thinking and working process of designers has grown rapidly. Research in design cognition started with the increasing criticism of the rational design methodology in the 1980s. Numerous researchers who studied the cognitive processes of designers have demonstrated, that the creative design process is too complex to be reducible to mere linear ‘problem-solving’ or ‘information-processing’ (Lawson 1986, Schön 1983, Cross, Dorst & Roozenburg 1992, Goldschmidt 2003, Oxman 2002). Designers decide what to do and when, on the basis of the personally perceived and reconstructed design problem or task. This perspective is confirmed by the theory of Radical Constructivism, which points out that perception and recognition is exclusively a reorganization of previous experiences (Schmidt 1992, 2000). Constructivist authors challenge the existence of an objective ontological reality and recognize the plurality of perception. According to authors such as Schmidt, Von Glasersfeld or Roth, our brain is a functionally closed system that operates on the basis of generic evolution, cultural patterns and earlier internal experiences (in Schmidt 2000). Therefore, these authors describe the brain as a ‘self-referential’ and ‘self-explaining' system, which doesn't have direct access to the world but which constructs and presents 'reality' only for itself and within itself. Consequently, perception operates as a 'self-organizing-information-system', based on our own personal history, which explains the fact that designers interpret the same given design problem in quite different and subjective ways. According to constructivist theory, perception is always 'interest guided', based on our own personal history, and thus, perception is our interpretation and assignment of meaning (Roth 2000). All new design solutions emerge, grow and mature during the creative process in an interaction with the situational system of the project.

In this paper, we will reveal the creative design process of a series of jewelry pieces and reflect on the importance perception had in the evolution of the project and the emergence of the semantic and material solutions. In the field of jewelry, often the content of the creative process is as, or more interesting than the finished object. While some product and communication designers and design agencies publically expose their creative design processes and the tools they applied (see the example of IDEO in Kelley & Littmann 2001), in jewelry it is extremely difficult to find documented examples of the complete process of a project, either to protect the work from the danger of copies, or simply because many jewelers do not feel the need to explain or justify their work. The master project-thesis which the first author (Áurea Pereira) developed in 2011, oriented by the second author (Katja Tschimmel), is one of the first works in which the creative thinking process of a jewelry project is made public.

2. Narrative jewelry and the importance of perception

From the many approaches to jewelry, the narrative is the one that asks for a more profound understanding of its meanings and content, that leads observation to a process of interpretation (Besten, 2006). And, though we can find many examples sharing the same principles and intentions in the Middle Age and Victorian Era, according to Cunningham (2007) the term "narrative" has been associated to jewelry only since the XX century, since the jewelry maker manipulates meanings and contents in a conscious manner. In his PhD Thesis on European Narrative Jewelry, Cunningham defines the narrative jewel as a wearable object constructed by an author with a clear intention of communicating a message, through a wearer, to a viewer. Telling a story and transferring its narrative essence through different means implies the study of several elements related to the communication process. The same narrative source, when adapted to a different language, receives the perceptive and interpretative contribution, not only from the author or narrator, but also from the semantic language used in its representation.

What the designer perceives with all his senses while reflecting on a design task, has a profound impact on how a situation is interpreted and how design solutions are developed. To be innovative in design, to be able to think about new narrative and material possibilities, the designer needs to liberate himself from routines of perception. Only a non-stereotypical perception and the subsequent connection of two remote perceptions or mental patterns can lead to new, original solutions (Koestler 1964, De Bono 1996). An automatic, unconscious and uncontrolled perception generally blocks the creation of new ideas and products, since people tend to organize the stimuli of their environment to facilitate easy, fast and well-known solutions. For this reason, creative thought processes can only emerge in three kinds of perceptual phenomena: 1. by a confusion in sense perception (as in the case of the deafness of Beethoven), 2. by malfunctioning parts of the brain (in the case of schizophrenia or drug-induced hallucination) or 3. through a conscious, goal-driven and attentive perception (Tschimmel 2009). An intentional perceptual process, oriented toward the on-going project, can above all prevent a stereotypical perception and thus be part of a creative thought process. Some cognitive researchers, who deal with the phenomenon of conscious perception and its disturbance, hold the opinion that "conscious awareness is a sort of focusing of the brain on its own internal processes, most important at a given moment" (Roth 2000: 252). Thus at the moment a jewelry designer is looking for new semantic and narrative possibilities, he has to recall relevant information from his memory to respond to the contextual conditions of the project. A creative perception of the situation depends mainly on the designers' previous experience and from his ability to handle his wealth of experience in a flexible and imaginative way, applying creative thinking operations, such as associative thinking, thinking in analogies, visual reasoning and perception with all of the senses.

3. The methodological approach: The perception-in-action model

Each time we, design researchers, observe, describe and visualize a creative design process, we have to choose in which design paradigm we are moving, because the understanding of design creativity is influenced by the dominant methodological paradigm of the moment. To expose the creative process of the first author's master jewelry project, we chose the Perception-in-Action Model, which was developed by the second author (Tschimmel 2005, 2009, 2011), considering the importance a deliberately oriented perception had in the development of the semantic and material solutions and expression of the jewelry pieces. The name of our model is homophonicaly based on the methodological design paradigm proposed by Schön (1983), the 'Reflective Practice' with it's Reflection-in-Action Process. Doing this, we are not denying the importance of reflection, but shifting the focus from the reflection mode to the perception mode. With the concept of Perception-in-Action, we observe and describe the design process as a process of consciously challenging stereotypical thinking, searching for new perspectives and semantic solutions inside the tasks domain. The objective is the posterior establishment of connections between perceived impulses and elements of the project. Obviously none of this is possible without reflection. It is perceptual reflection that we consider the essence in the creation of new realities. The Perception-in-Action Model suggests the deliberate use of perception as a tool in the creative process, in order to promote originality by disengaging perceptive routines towards finding new perspectives. It is not only visual or verbal stimuli that intervene in the creative process. The designer can find new ideas by being alert to his perceptive capabilities. Texture, smell or sound can trigger creative mechanisms that will enrich solutions if brought as a strategy to the surface of consciousness. In fact, the designer's subjective perspective of reality and personal experiences play an important role in this process. This perceptive awareness extends to the appropriation of chance as another factor to promote new solutions. Even some mistakes, properly analysed, are potential paths towards originality, as we will show in our case study (4.4).

The procedures involved in the Perception-in-Action Model are defined in 5 stages: 1. the perception of the task, 2. the perception of new perspectives, 3. the perception of new semantic combinations, 4. the perception of new solutions in model constructing and 5. prototyping and the perception of the users' reaction (Tschimmel 2009, 2011). Each one of these procedures implies an advance in the design process, although each resulting solution space (Sx) interacts with the rest of them in a non-linear way, establishing new relationships between the different aspects of the design and helping to better define the problem/task (p/t). Design problems can't be defined, reformulated, developed and solved without thinking at the same time about possible solutions.

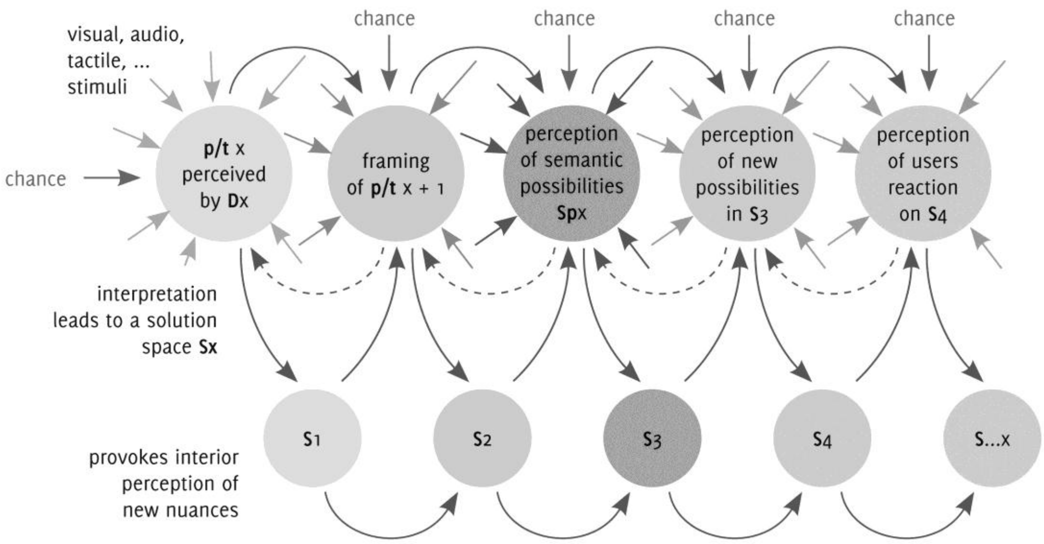

Figure 1. The 5 stages of the Perception-in-Action process where at any moment, chance can influence the perception of the problem/task and of the actual design situation.

4. The jewelry project

The design task of the jewelry project examined here, was the creation of a series of jewelry pieces with a narrative approach, using drawing and illustrations both as a tool and as a part of the final result.

4.1. The perception of the task

The first phase of the Perception-in-Action process is the perception of the problem/task (p/t). The designer (Dx) analyses and interprets the design task, on the base of his previous personal and professional experiences, his world vision and a recalling of relevant memorized information for the project (Tschimmel 2011). The first step to better define the task of our jewelry project was to choose a narrative source to interpret visually. As narrative texts, according to Bal (1997), can use different languages such as written words, visual means or sound to tell a story, as long as they're constructed by an agent who interconnects several elements with a clear intent to communicate a message, the source chosen as a starting point to this project was a musical suite - The Carnival of the Animals (original: Le carnaval des animaux). This musical suite, by the French Romantic composer Camille Saint-Saëns, is divided into fourteen movements and its narrative structure includes an introduction, a presentation of a variety of characters and a final theme. The choice of a musical narrative instead of a written text was for two main reasons: the difficulties in finding a written story interesting enough to illustrate, that had not already been over-explored, and the perceptive possibilities offered by a language with a higher level of abstraction.

After choosing the narrative source, we have structured the project in two main stages. First, we visualized the music and represented it through a series of illustrations. Second, based on visual and symbolic aspects explored in the illustrations, we created a series of jewelry pieces.

To help visualize the music, and after initiating research on this musical suite, we listened to each theme analyzing its content, in order to identify useful characteristics to interpret visually. The elements selected consisted of: characters involved, actions that took place and the general atmosphere of the theme. From this analysis Áurea Pereira, chose a couple of key words that summarized our first subjective perception and interpretation.

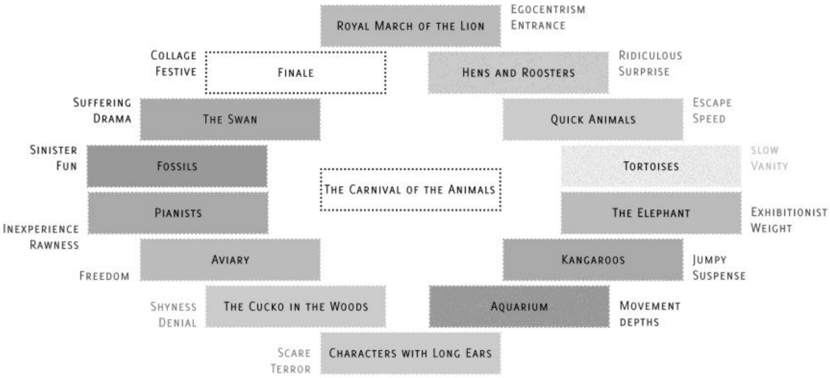

Figure 2. Diagram of key words that summarized the subjective perception of the musical expression of the 14 movements

4.2. The perception of new perspectives

In the second stage of the Perception-in-Action process the designer is consciously working on new perspectives of the design task, selecting various stimuli which will be integrated into the design process and which can help to produce original ideas. In our project, the reinterpretation of earlier aspects of the project is the result of the exploration of the music's narrative through drawings and illustrations. The insertion of illustration, as an intermediate stage between the original narrative text and the creation of jewelry pieces, allowed a broader approach to the story, for it not only enables a different perspective, but also enriches the interpretation by exploring a different language in a first approach. Drawings and illustrations need a slow, intense and thorough perception, permitting the designer to appreciate the different relations between the music, the visual expression, the future artifact and the individuals and their characteristics. Graphic representations are both, a result of a mental process and a spur to further mental activity from the designer. While drawing, through the interaction of line, form, symbols and ideas, new characteristics, unconnected to the design task, appear which hadn't been planned by the designer (Tschimmel 2011). In the jewelry field, drawing is mostly used to register and communicate ideas, an initial step, subordinated to the final object. And there are even jewelers that dispense with its use, starting the creative process along with the production in the final materials. But as drawing allows us to transcend the limits of reality, it can be used to stimulate imagination and not only to solve technical problems. In our project, the illustrations had a double function: Firstly as a part of the final result, they place the jewelry pieces in a context and secondly they are an impulse for ideas in the next stage of the process – the jewelry making. Other kinds of drawings were also used throughout this project to register ideas, visualize the solutions or present them to others. In order to frame the application of this tool in our project, we used Lawson's taxonomy that divides drawing types by its function on the design process: Presentation Drawings, Instruction Drawings, Consult Drawings, Experiential Drawings, Diagrams, Fabulous Drawings, Proposal Drawings and Calculation Drawings (Lawson 2004). Most of the drawings included in our project relate to at least one of these drawing types, though we found no corresponding category for the illustrations as generators of ideas, which we called "Ideation Drawings".

As the illustrations are meant to work as Ideation Drawings, the illustrated elements were chosen to create situations, narrative moments suggested by music, explore line and texture details, without previously intending to find solutions for the jewelry pieces. Through them, we searched for a visual translation for our interpretation of the situations described by the music and for a "tone" that could correspond to the broad musical suite atmosphere. For instance, we associated the Aviary to the idea of freedom (key-word), for this theme song's melody suggests movement and birds singing. As the title, Aviary, describes a place where birds are kept, we decided to present open cages on the illustration, suggesting the idea of freedom through the emptiness left in the place they were trapped before.

Figure 3. Illustration/Ideation Drawing for the “Aviary”

As this project involves a series of 14 moments to be illustrated, there was the need to alternate constantly between a visualization of each individual illustration, with its specific problems, and the global narrative formed by the whole set of drawings. To make it possible, we used a storyboard, where we placed copies of the illustrations that were being updated and where we could easily connect them to improve the results by establishing relations between them.

4.3. The perception of new semantic combinations

The second phase of the project consisted on the creation of a series of jewelry pieces based on the previous series of illustrations, whose main function, at this point, was to generate ideas for semantic and symbolic solutions. In the previous stage, the solutions found through the illustrations added a subjective perspective to the narrative which was continued onto the creation of the series of jewelry pieces. Searching for new semantic expressions, the perception of elements founded by chance led us to surprising solutions by analogical thinking. As we included references from childhood in the drawings, we decided to maintain a playful atmosphere for the jewels, using toys as inspiration and asking for an active participation in some of the pieces. Taking, as an example, the same musical moment presented previously, the Aviary, we started from the shape of the cages that are suspended in the drawing and seem to move with the wind. We noticed that the cage in the front is unfinished, like it appears from the bottom of the frame. So, the first idea was to explore the shape of a sectioned three-dimensional cage.

Through Proposition Drawings, we analyzed this shape and decided to turn it into a ring, using the hoop from which the cage is suspended to adapt this object to the human hand. Also through these drawings, we developed a few solutions to make this an interactive object. The final object consists of a ring and a holder, where the ring fits. By taking the ring from its holder/cage, the wearer reveals a birds' beak, suggesting the song of a bird that has been set free. We called this ring "Somewhere Not Here".

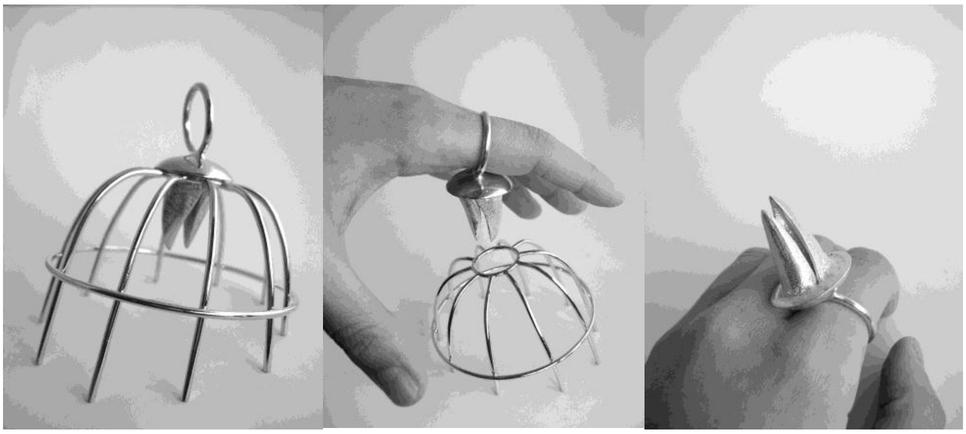

Figure 4. Ring and support piece "Somewhere Not Here"

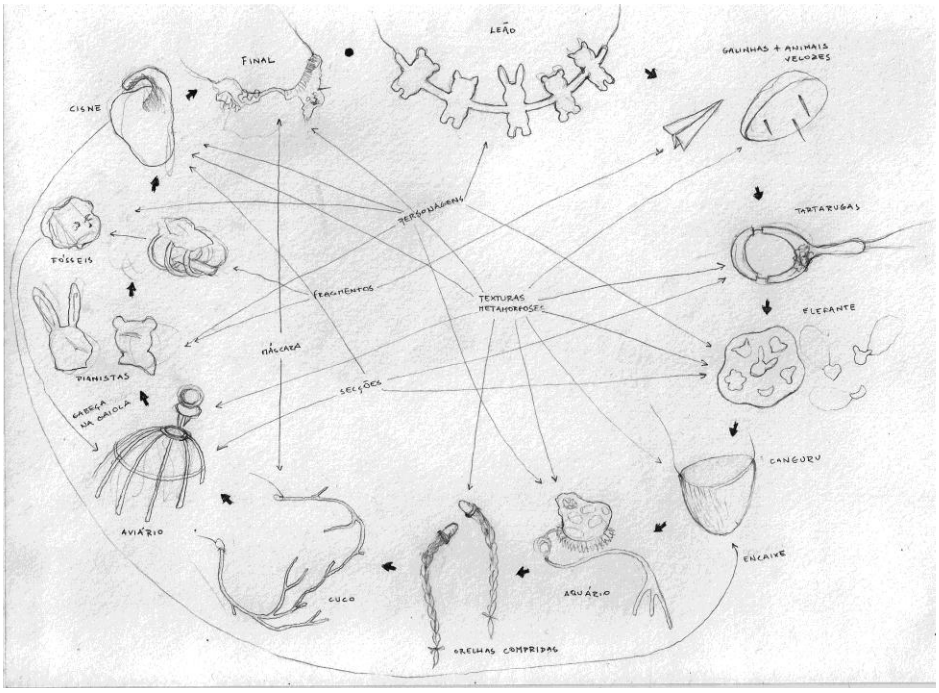

Figure 5. Storyboard of the series of jewelry

In this stage, there was also the need to use a storyboard with the jewelry pieces in progress, to create a similar visualization of the narrative as we did with the illustrations. Through drawings of the jewels, we analyzed their shape, meaning and relation with the complete series in an easier, practical way.

4.4. The perception of new solutions in model constructing and prototyping

The fourth stage of the Perception-in-Action model is characterized by the material development of the project. Although many of the materials were already chosen when we began the process of making the jewelry pieces, it is at this stage that the object is tested and may still undergo some improvements and major changes. In a narrative jewelry project, the focus is on the communication of messages, therefore even the materials should contribute to the story telling. Silver, the main material used for the pieces in this project, places them in the jewelry field, distinguishing them from the universe of real toys. Even links and other elements needed to fix the jewels to the body were carefully chosen to avoid polluting the message. So, we chose cotton cords to substitute chains and, since they are colored, we selected their color according to the palette used in each corresponding illustration. Besides the color, the cotton cord was used to add meaning to the jewels by using its length to place the piece in a particular area of the body. For instance, the pendant for the Kangaroos is attached to a brown cord whose length indicates it belongs over the belly region, relating it to the marsupial pouch. The experimental character of this stage led us to make some technical mistakes that we bore in mind and used later to create certain effects. In particular using lost wax, whose behavior when melted has a certain level of unpredictability, we analyzed rejected experiments and learned to use its “wrong” effects in other more appropriate solutions.

4.5. The perception of the users’ reaction

During any of the previous four phases or in the final phase of the Perception-in-Action process, the new product can be tested by target users. In our jewelry project which is still not completely finished, an exhibition is planned where the series of jewelry and illustrations will be presented simultaneously, along with photos of each jewel placed on the body. This exhibition will allow viewers to see the full story and to interpret it using their own subjective references and participating in the narrative process. We also plan to register some of the visitors reactions by asking them to choose one piece and, as Cunningham did with one of his brooches, to describe what they see and what the piece makes them think of. Apart from the interaction with the narrative artifacts, the appropriation of its meanings to a self-referenced story is as valuable as the translation of the maker’s intended message, for it enriches and continues the narrative itself. Still, the perception and reaction of the visitors to this exhibition will probably contribute to a rethink of parts of the jewelry pieces which may lead to some formal or material modification, since the main concerns in the creation of this jewelry were more related to meaning and content than to usability. The viewers’ perspective can be especially useful to change these jewels into more wearable pieces, to be reproduced in small handmade series, in the future.

5. Conclusions

Describing and reflecting on the creative process of our jewelry project, it has become clear that in the intuitive, reflective and emotional process of the project, perception played a very central role. In a perceptive dialogue between her imagination and her graphic representations, Pereira identified, altered, reinterpreted and improved situations and elements of the design task. Applying the Perception-in-Action model to our analysis, we want to emphasize that all original and innovative design is the result of an intentional liberation from the routine of perception - the routine of the designer’s perception, and also the routine of the users’ perception. The important role of drawings and illustrations in the evolution of the project showed that drawing is an extension of mental imagery in jewelry. By drawing, the designer expands the problem space of the project task, to the extent of including and even discovering, new aspects, which he/she considers relevant, as much as through a subsequent interpretation of the graphic representations. The activity of drawing in this jewelry project, clearly served as a kind of modulation of the narrative problem space. Due to the amount of illustrations and jewelry pieces involved in this project, their progress and revaluation required a constant perception of the narrative as a whole. The use of storyboards allowed Pereira to relate each artifact to its series, transferring characteristics from one to others and adjusting its individual features to the coherence of the group.

Our jewelry project proved also, that in the Perception-in Action process, the designers' models of reality and personal experience of all sorts, which he/she relates to the situational factors of the project, underlie every decision.

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THE INVESTIGATION ON THE EFFECTS OF PRIOR EXPERIENCE ON THE PRODUCT DESIGNERS' CREATIVITY

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Abstract: As a creative problem solving process, product design involves designers' prior experience. This study investigates the effects of prior experience on the product designers' creativity as well as notes the differences in their design process. The sketches from a design task performed by senior and graduate students in product design department are examined via Zaltman Metaphor Elicitation Technique. The mental map revealed the difference of their design process according to the different degree of prior experience. Furthermore, the sketches are rated by four expert designers by Creative Assessment Technique. We found that product designers with higher prior experience can produce more creative outcomes. Theoretical and practical implications of these finding are discussed.

Keywords: *prior experience, sketch, creativity, Zaltman Metaphor Elicitation Technique (ZMET), Consensual Assessment Technique (CAT),*

1. Introduction

Creativity has been defined as the ability to restructure old ideas to produce singular inventions (Heap, 1989) and to apply original thinking (Coyne, 1997). The creativity process involves combining existing ideas and resources into something new and useful (Baughman & Mumford, 1995; Mobley, Doares, & Mumford, 1992; Hofstadter, 1985). In product design domain, mostly, to be creative is not about creating an entity out of thin air (Campbell, 1960; Simonton, 1999), designers use prior experience to explore new ideas and design alternatives. This paper investigates the effect that the prior experience performs in the product design, including the product design process and the creativity of the design concepts.

During the early conceptual stage, it is typical for designers to express their ideas as simple free hand sketch done rapidly and without much detail (Purcell and Gero, 1998). Many researchers have been done to reveal the creativity involves in the sketch. However, the investigation of prior experience factor in the conceptual stage of design – sketch- is relatively rare. On the other hand, the relation of prior experience and creative performance has been studied widely (Amabile 1983; Martinsen, 1993; Chua & Iyengar, 2008). But the theoretical finding has not been evaluated in a specified domain, such as product design.

Based on the previous work, we argue that the prior experience can affect the product designers' design creativity as well as their design process. Through the analysis the results of a design task, we evaluated the conceptual works of product designers with different prior experience.

2. Related works

2.1. Prior experience in product design

Research in creativity has suggested prior experience in a given task domain to be an important predictor of creative performance (Martinsen, 1993; Chua & Iyengar, 2008). Amabile (1983) argued that possession of domain relevant skills is an important component of individual creativity. Furthermore, the degree of domain relevant skills one possesses depends on formal and informal education, and on the individual's experience in the given domain (Amabile, 2001).

Chua and Iyengar(2008) investigates the effects of prior experience, task instruction, and choice on creative performance. And they found that only individuals with high prior experience in the task domain and given explicit instruction to be creative produced more creative outcomes when given more choice.

2.2. Assessing the creativity in product design

Since 1950 researchers have developed an array of formal methods for measuring creativity. The widely used assessing methods are: through determination of personality traits using the Torrance Tests of Creative Thinking or the Myers-Briggs Type Indicator; through outside rating of a product or through thinking tests (Amabile, 1982; Hocevar 1981).

Moreover, creativity has also been assessed in a number of ways in art and design domain: uncover the sketch process by which an individual creates through various types of observations (Goldschmidt, 1991); analyze the imagery created, and quantified the sketches with coding schemes in an attempt to uncover the cognitive processes performed during the sketching as thinking process (Goel, 1995; Kavalki & Gero 2001); "think-aloud" protocol analysis combined with content analysis of the product (Menezes & Lawson, 2006; Goldschmidt & Weil, 1998, Suwa & Tversky, 1996) to document the thinking process as the individual sketches.

2.2.1. Sketch

Sketch allows quick exploration of ideas at a high level of abstraction, avoids early commitment to a particular solution, allowing many alternatives to be explored (Fish and Scrivener 1990; Ullman, Wood et al. 1990). Drawing remains the focus of design activity in domains such as product design and architectural design where the product is a physical object; the drawing is typically the single representation that the designer uses throughout the design process, from initial rough sketch to final fabrication drawing (Gero, 2004). Hence, sketch has been studied for understanding the designers' creativity.

Ayiran (2008) explicated the role of sketches in terms of creativity in design. Reviewing the generated concepts and the physical evidence of cognitive processes may illuminate a link between sketching and a final creative product (Ryan, 2008). And we believe that designers' sketches are suitable materials for examining whether or not the designers' prior experience affected their design creativity.

2.2.2 Zaltman Metaphor Elicitation Technique

Zaltman Metaphor Elicitation Technique (ZMET), developed by Zaltman in 1994, is a qualitative technique that elicits both conscious and especially unconscious thoughts by exploring people's non-literal or metaphoric expressions. Originally, ZMET is a developed to understanding costumers'' need as a market research tool. As Zaltman described "A lot goes on in our minds that we're not aware of. Most of what influences what we say and do occurs below the level of awareness. That's why we need new techniques: to get at hidden knowledge-to get at what people don't know they know." (Pink, 1998). The technique has been used by academic researchers and for marketing purposes to study a variety of topics related to both marketing and the social sciences. Zaltman argued that humans think in images – often in the form of visual images – rather than in words (Shocker and Zaltman, 1977; Zaltman, 1991). The goal of the ZMET interviews and analysis is to uncover the relevant fundamental structures that guide people's thinking about a topic.Therefore, we believe that ZMET is a reasonable method which can be used to reveal the design thinking and design process through the only explicit presentation in the conceptual stage of design –sketches.

2.2.3 Consensual Assessment Technique

The Consensual Assessment Technique (CAT), developed by Hennessy and Amabile in 1999, was selected for this study to assess the evidence of creativity in free-hand sketch because of its reliable use in previous examinations of creative assessment of a product (Carson, Peterson & Higgins, 2005; Chen et al, 2000; Dollinger, Clancy Dollinger, & Centeno. 2005).

3. Methodology

We chose an experimental approach to find out the influence of designers' prior experience on product design. Experts were invited to assess the creativity of the students work via the modified Consensual Assessment Technique. The design experiment aimed to investigate the following research questions:

- Does the designers' prior experience affect their design creativity?
- Are there different patterns among the designers' design process and idea generation with and without prior experience?
- Can any relationship be identified between the prior experience of designers and their design creativity?

It was hypothesised that the higher the prior experience one possesses, the higher creative design concept he/she can generate in the product design task. To answer these research questions, forth year undergraduate product design students and second year master students with different educational background (bachelor of biology, product design and space design) in the product design department in a national university in Taiwan were recruited for the study. This ensured that the participants have the necessary experience to be able to take part in the study meaningfully as well as enough mature design education to fulfil the design task.

3.1. Experiment

3.1.1. Participants

In order to compare the different effect of prior experience, the experiments were conducted in three different groups. Group A contains seven students, and all of them have the experience of keeping pets for at least one year, we define this group as informal education prior experience group. Group B is formal education prior experience group, contains two students who have a bachelor degree of biology. The number of participant is relatively few because the students with the interdisciplinary background are limited. Group C includes seven members who have neither keeping pet experiences nor biological educational background. The demographic characteristics of the participants are summarized in Table 1.

Table 1. Participant attributes

Participant		Gender	Age	Education background	Major
Group A (Informal education group)	P1	Female	21	senior	Product design
	P2	Male	25	Master student	Product design
	P3	male	23	senior	Product design
	P4	female	28	Master student	Product design
	P5	Female	25	Master student	Space design
	P6	Female	26	Master student	Space design
	P7	male	21	senior	Product design
Group B (Formal education group)	P8	Male	30	Master student	Product design + biology
	P9	Female	28	Master student	Product design + biology
Group C (Non-prior experience group)	P10	male	22	senior	Product design
	P11	Male	27	Master student	Product design
	P12	Male	28	Master student	Product design
	P13	Female	20	senior	Product design
	P14	Female	28	Master student	Space design
	P15	Female	19	senior	Product design
	P16	Female	24	Master student	Space design

3.1.2. Environment setting

Group A participate the experiment in a standard classroom. Free-hand sketching tools are provided.

The experiment of Group B and Group C is conducted in the observation lab in the product design department. The room is divided into two parts. The experimental subjects stay in the inner room, where needed facilities to fulfil the design task, such as desktop computer, drawing and writing tools, are provided. A video is set up at the front of the table to shoot the drawing process in a close distance, and the whole process of the experiment is recorded by the video equipments at the four corners of the ceiling. The observers stay at the outer room, where they can observe all of the participants' movement through a one-way version glass.

3.1.3. Task and procedures

Three groups with different prior experience are asked to perform the similar design task- design a product based on your own experience about biology. The biology-related experiment was selected because the biology knowledge is shared universally. Hence, we can achieve the general conclusion according to the study.

However, we narrowed down the scope of biology. Group A performed the design exercise based on their own experience of keeping pets within 1 hour. Group B and C did that after 12 minutes video documentation about 7 kinds of crabs was shown to them. And then they sketched and generated design ideas within 1 hour. During the 1 hour, they can review the segment video or pictures of each kind of crab by the computer provided.

On one hand, the same stimulation ensured that the experiment result revealed the pure relationship between the designers' prior experience and their design idea generation; on the other hand, we can build an assessment standard to analyze the design outcome efficiently and systematically.

The experiments of all the three groups comprised two consecutive tasks: the first is a session for generate design concepts via free-hand sketches, and the second is to complete an in-depth interview exclusively related to the concepts. The in-depth interview is aimed to further the outcome of the students' design process, specifically, inquiring into their design inspiration and the referring prior experience.

After the design task, the idea sketches are analyzed by four expert designers, two are product designers with 9 and 11 years design experience in company, and the others two are associate professors in product design department with 8 and 11 years education experience. The four expert designers graded the design concept based on the modified Consensual Assessment Technique and also their own experience.

3.2 Analyzing the design process via ZMET

Once we got the sketches from the participants, we can investigate the stages of design process and the main elements in each stage with the ZMET. Zaltman defined 10 ZEMT interview steps: storytelling, missing issues and images, sorting task, metaphor elicitation, representative image, opposite image, sensory images, mental map, the summary image, the vignette; and these steps can be adjusted slightly for different topics (Zaltman and Coulter, 1995; Zaltman, 1996). Considering about the research focus, we executed the first to eighth steps, the detail are described below.

1. Storytelling：The participants recalled and described the main process and content of their design thinking in the in-depth interview. This is named Metaphor Elaboration by Zaltman, According to the external result of the design thinking- sketch and text; the participants explained the effect of their prior experience on their design thinking, via the semi-structure interview. This retrospective protocol will be the main content for the analysis.

2. Missed Images: the participants can reveal any information what they did not concern but is meaningful. For example, P9 said when he saw the climbing crab, the building cleaners' movements appeared in his mind, so he decided to design an electric vacuum cleaner in crab's shape. In this example, the missed image is the building cleaner, which is revealed in the interview. Without the missed images, the design process will not be interpreted completely.

3. Sorting: the interviewee categorized the participants' design thinking and activity in order to extract the construct of design thinking in the next step.

4. Construct Elicitation: Based on Kelly Grid and Ladder, three layers of design thinking are defined: originator construct; connector construct and destination construct. In this study, the originator construct means the stimulation: animal's metabolism, animal's body colour, animal's shape, animal's organs, animal's movements, and animal's living environment. The connector construct means the design thinking: association, attraction, curiosity, analogy. The destination construct means the design outcome- product design.

5. Most Representative Picture: the interviewer point out the most representative pictures among which inspired his/her design thinking.

6. Opposite Images: the interviewer finds the most contrast images with their design concept, which is helpful to understand their design thinking.

7. Sensory Images: The participants can describe the other perception, including touching, tasting, smelling, listening and emotion, which inspired them in the design process.

8. The Mental Map: The interviewee confirmed each participant' design process and represent it via the mental map.

3.3. Assessing the design creativity via CAT

The measure of creativity was implemented through use of the Consensual Assessment Technique (CAT). We modified the CAT related more directly to a product to address the specific of our research. The CAT method assesses separately between the areas of creativity, aesthetics and technical quality. The creativity score was derived from the raters' personal definition of creativity; includes the degree to which the idea was novel or unusual, and the consistency of the concept throughout the design process. The aesthetic score consists of overall aesthetic appeal, the pleasing product composition. Technical quality was assessed by the degree to which the concept considers the technical requirements, how well is the problem solved.

Four expert designers as raters were given verbal instructions, definitions, and standardized review forms. Raters were instructed to look at all the sketches prior to starting the review, and to grade the sketches in a random order. Eight items were assessed on a seven-point Likert scale, indicating agreement descriptions such as "low" or "high", "not at all" or "is apparent" depending on each item. Assessment entailed using a Likert scale survey rating for creativity, technical quality and aesthetics. Raters worked independently, and ranked the sketches based on their personal interpretation of creativity. The final score of each participant is the mean of the grade given by the four raters.

4. Discussion

The sketches of the participants are shown below.

Most of the members in Group A fulfilled the design task in a very detailed way (Figure 1). The characteristics of pets are introduced, and the problems they met are solved by new design. Each sketch contains abundant textual information and design process cue like arrows or text.

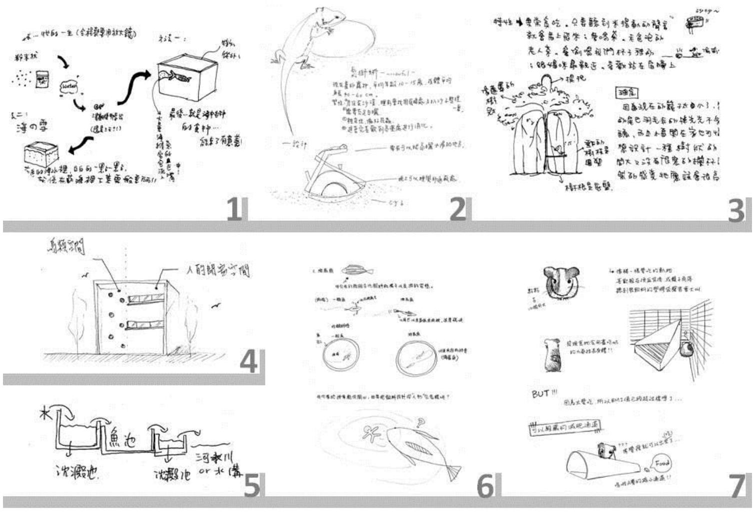

Figure 1. Sketches generated by Group A

Comparatively, the sketches generated by Group C are mainly roughly pictures without textual information and design process cues. Three examples are shown in Figure 2.Their sketches look like isolated segments of the videos, we cannot find the significant continuity of design thinking.

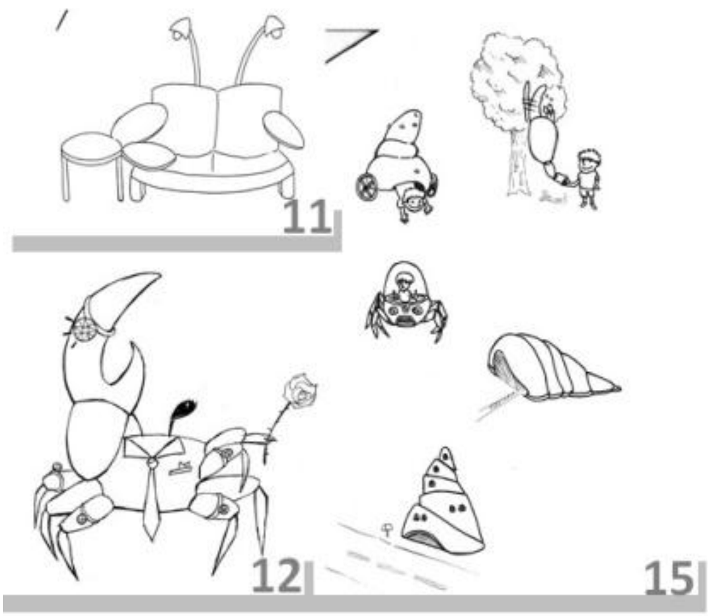

Figure 2. Examples of sketches of Group C

4.1 Mental maps of design process

In this study, we generated the mental maps of all 16 participants. And we summarized them into three styles: administrative levels style (Figure 3), explosive style (Figure 4), and rigorous style (Figure 5).

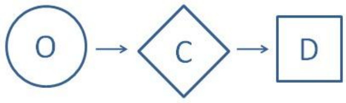

Figure 3. Administrative levels style mental map (O: originator construct; C: connector construct; D: destination construct)

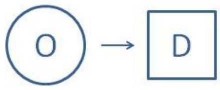

Figure 4. Explosive style mental map

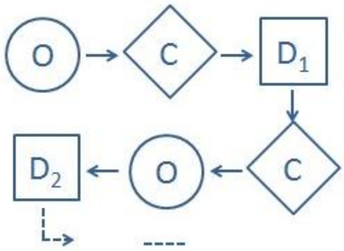

Figure 5. Rigorous style mental map

We found that most designers with higher prior experience (P1, P2, P3, P4, P5, P7 in Group A and P8, P9 in Group B) fulfilled the design process in administrative levels style, which means they performed the design in a standard and complete way according the three construct of ZMET: originator construct, connector construct, destination construct.

However, the mental maps of the designers without prior experience (P11, P12, P13, P15, and P16 in Group C) presented an explosive style. Their design concepts were inspired by the video, hence their design concepts generated in a short time and design thinking lacked continuity. Furthermore, three participants (P6, P10 and P14) were thoughtful, and their mental maps were iterative and strict. We believe that this is partly caused by individual personality.

4.2. CAT score of design concept

On a scale of 0-7, the Group C got the lowest mean score4.7 even there are some individual high score, such as P11's aesthetic score (5.2) and P16's creative score (5.4). The score of CAT is tabulated in Table 2. No significant difference between the Group A and Group B. The influence of formal educational prior experience and informal educational prior experience on the product design needs more precise investigation in the future work.

Table 2. CAT score in all categories

Participant		CAT creative score	CAT aesthetic score	CAT technical score	CAT overall score
Group A (Informal education group)	P1	5.2	5.0	5.2	5.2
	P2	5.0	4.9	5.3	5.0
	P3	4.9	5.1	4.8	5.0
	P4	5.2	5.2	5.0	5.3
	P5	5.4	5.5	5.1	5.2
	P6	5.2	5.2	5.1	5.4
	P7	5.4	5.2	4.9	5.0
	Mean	5.2	5.2	5.0	5.2
Group B (Formal education group)	P8	5.3	5.5	5.4	5.1
	P9	5.1	5.2	5.0	5.2
	Mean	5.2	5.3	5.2	5.1
Group C (Non-prior experience group)	P10	4.2	4.6	4.2	4.3
	P11	4.7	5.2	4.6	4.8
	P12	4.8	5.0	5.0	5.0
	P13	4.9	4.8	4.5	4.6
	P14	4.5	4.2	4.8	4.4
	P15	4.4	4.7	4.5	4.5
	P16	5.4	4.6	4.8	5.0
	Mean	4.7	4.7	4.6	4.6

In addition, another interesting result is also revealed in the experiment. Designers were believed to be attracted and affected by the appearance/form of the creature. However, among the nine participants inspired by the video of crab, there are eight times that designers said they were inspired by the movement of crabs. Comparatively, it is surprised that the appearances of crabs illuminate them five times.

4. Conclusion

Prior experience plays influential roles over almost every aspect of human aspects and product designers are not exempt from the effects. In this paper we analyzed the differences in the way design concepts are generated, which we found to be caused by the difference degree of prior experience. The experimental study involving participants with different prior experience revealed significant contrast in the way design concepts were created. Furthermore, the CAT score rated by expert designers demonstrated that the higher prior experience can enhance the product designers' creativity, which supported our hypothesis.

It is important to recognize the prior experience contains not only the domain knowledge, what kind of structure of prior experience can benefit the product designers best will be studied in the future work.

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ENHANCING THE UNDERSTANDING OF STATISTICAL DATA THROUGH THE CREATION OF PHYSICAL OBJECTS

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Abstract: For many people outside of the scientific community statistical information and graphics remain abstract and unintelligible. This research begins to investigate how we might interrogate statistical information from the engineering sector through the creation of material/physical objects, with the intention of bringing better understanding and increased accessibility to scientific data.
This inquiry will be achieved through a strategy of media transformations that move information sources between digital and material environments, for example; by translating digital statistics into 3D computer models, which can then be output into real-world objects using 3D printing techniques. Undertaken by a multidisciplinary team of designers, engineers, technologists and end-user communities the project aims to investigate how these translation strategies can be used to communicate and transfer knowledge between different stakeholders. User centered activities will be conducted to explore what visual metaphors might be appropriate for different contexts.

Keywords: *information visualisation, tangible data, creative practice*

1. Introduction

In the last few years we have seen a marked increase in interest into how we can build stronger relationships between digital and physical environments. The recent exhibition at the V&A, the "Power of Making" (Power of Making, 2011) exemplifies this interest in exploring ways in which we can creatively combine the tangible qualities of material culture with the dynamic attributes of the digital. This proposal is based on theoretical writings and research by the author around the concept of the 'data-object' (Gwilt 2011), and other emergent work in the area (Klanten 2010). The intention of the proposed research is to apply the concept of the data-object to a set of practice-based design activities, which explore how our understanding of statistical/scientific data is mediated when it is represented as a physical object.

The data driven object as a communication device needs to be considered in light of the existing conversations taking place in the area of information visualisation. This includes issues around complexity of information, the veracity of the visualisations, user engagement, knowledge transfer and so on (Tufte 1993; Ware 2004). However, the creation of a physical object based on a digital data set is in a sense a new 'complex' media form which has the potential to speak to the inherit traits found in both digital and material cultures. Part of this research will include an investigation into how, or indeed if, these data-objects can successfully combine properties from both digital and material paradigms in the communicate their message. Properties that on the one hand include digital notions such as morphology, data density and networkability, which potentially give widespread and democratic access to information and experience (something that is often difficult to achieve with a physical object). And on the other hand physical objects, which often hold strong and inherent cultural notions of authenticity and value, ascribed through the empiric experience and interaction with a singular physical object (Riggins 1994). In the best case scenario the manifestation of digital information into a material form should utilise the strengths of both of these two paradigms. Moreover, these synthesized constructs offer up a new way of looking at the digital/material relationship. The data-object might be considered a syncretic agent, capable of appealing to a cross-section of communities.

Two examples of work in this emergent field are the data driven sculptures of Abigail Reynolds and Mitchell Whitelaw. In Abigail Reynolds work *Mount Fear* (2002) sheets of laser-cut corrugated cardboard are cut out and stuck together to create a room sized three-dimensional bar chart of crime statistics in London. In this work audience members can walk around the data-based sculpture where, thorough the use of scale and materials, the roughly constructed object creates an intimidating representation of the data content. In another example the work entitled *Measuring Cup (Sydney 1859-2009)* (2010) by Mitchell Whitelaw, uses temperature statistics from Sydney, Australia to inform the shape and form of a plastic tumbler. The tumbler is constructed in a series of rings, with each ring representing one year of statistics. The rings of data build up the sides of the container, and like the growth rings of a tree, the rings of annual temperature data create a tangible realisation of growth and flux. In this physical representation of data the recent upward trend in overall temperatures combines to give the tumbler a flare upper lip that echoes the ergonomic convention typically used in the design of drinks containers.

Currently there is little formal research that examines the communicative potential of these types of creative works and this project hopes to add new knowledge to the field of creative information visualisation and design. For the purposes of this particular piece of research, data gathered on the 'openability' of consumer packaging was used to test the general concept of the data-object. This issue of packaging openability has been identified as an area of major concern for an aging community, which needs to be addressed by packaging design engineers. Specifically the project utilises data collected by the Engineered Packaging Research Group and Departments of Mechanical Engineering, and Engineering Materials at the University of Sheffield. In research led by Dr Alaster Yoxall, a Principal Research Fellow in Human Centered Engineering at Sheffield Hallam University (SHU), the findings of a simple scientific grip test suggested that the problem of difficult-to-open packaging is especially apparent when looking at elderly people or people with a disability (Yoxall 2006). As this research highlighted, ageing brings with it many issues, not least a loss of strength and dexterity, and in order to design effective packaging an understanding of the ability of aged consumers to effectively use established forms of packaging such as glass jars and bottles is becoming increasing important.

After meetings with Dr Yoxall and other engineers/researchers responsible for gathering the initial data, it was identified that a significant problem existed in sharing this information with specific parties outside of the engineering field. In particular the question of how to communicate these findings effectively to designers, who in the experience of the engineers involved in collecting the data did not typically respond well to statistical information presented in the form of a graph was noted. Developing strategies for communicating the relationship between age and dexterity/strength and the importance of understanding this relationship, for different sectors of the community (including designers) was therefore acknowledged as being an important research question worthy of investigation. Further meetings with Professor Pat Langdon, a senior researcher in the Engineering Design Centre at Cambridge University affirmed the importance of this issue. Through these meetings the need to develop design tools and creative approaches in addressing the problem was also recognised (Langdon et al. 2007). In addition it was acknowledged that different sectors of the community including designers, carers, the general public might have a specific requirement of the data or need a particular level of insight into the problem, and that this range of requirements might be addressed through the development/use of a variety of information forms. The skill sets and resources of the Art and Design Research Centre, in the Faculty of Arts, Computing, Engineering and Sciences at Sheffield Hallam University were identified as being of a relevant mix of disciplines to address this problem. In particular a strong relationship and history of interdisciplinary research projects occurring between creative practices, design and engineering within the research institution, and a close link to the resources, staff and students in the Sheffield Institute of Arts was identified as being a healthy environment from which to undertake the research.

2. Aims and objectives

The intention of this research was to run a practice-based scoping project that would explore the cross-sector communicative potentials of creating data-informed objects. Seed funding to run the initial stage of the research was successfully gained from the Arts and Humanities Research Council (AHRC), Digital Transformations initiative (Digital Transformations initiative, 2011). Initially we intended to conduct user-centred focus groups/interviews with designers and other stakeholders that would A; introduce the scientific data and findings outlined above and B; introduce the notion of the data-object as a device for communicating this information. The findings of these focus groups were then to be used to inform the creation of a second round of data-object prototypes. An initial selection of data-objects was introduced to the focus groups to examine whether the attendant qualities of the media form could reveal different insights and comprehension of the data beyond the conventional engineering paradigm. By the end of the project, it is hoped that we will be able to comment on how different stakeholders might read these data-objects in comparison to the usual data presentation strategies, and to draw some conclusions as to the potential benefits of representing data in these new forms. The process and outcomes of the scoping exercise will also be documented in a website and through a public exhibition (Data Objects, 2011). The findings will also form the basis for additional research into the use of data-objects (based on larger more complex data sets) to enhance knowledge and understanding across a variety of communities.

2.1. Pilot study

Three data-object design concepts have been developed which were used to test the concept with a section of user communities. The activity of making these objects has been carefully documented and will in itself form part of the research evaluation methodology. Initial examples of data-objects were presented to a selection of adult participants from three stakeholder communities; engineers/scientists, designers and the general public (with a non-scientific/engineering or design background). Semi-structured interviews with individual representatives from each community were undertaken to explore the following research questions:

- Can the creation of physical artefacts based on data extracted from statistical digital information systems change the way we read, interpret and respond to digital information?
- By translating information from the digital environment into a physical environment what new understanding (if any) to the original information is engendered?
- What role do the material qualities of the objects play in comprehending data when moving from digital to material environments?

Details on how we carried out this user testing are described in section 3 below.

2.2. Creating the objects

As part of a practice-based methodology the statistical data was initially interpreted by Dr Koutaro Sano, a Japanese ceramicist, designer, and researcher. These interpretations were undertaken after briefings from Dr Alaster Yoxall, on the meaning of the original scientific data, and briefings from Professor Ian Gwilt on the background concept of the data-object. Dr Sano was then encouraged to explore a number of creative interpretations of the data. During the concept development stage a discussion was had about what different types of visual metaphors and ways of representing the statistical data in the form of a physical object might be used. Whether or not it was necessary to relate concepts to the context of the origin dataset was also discussed. It was proposed that three separate concepts be developed to the test the hypothesis of the data-object. One concept used the metaphor of landscape, another was based on a series of jar lids, which had a close symbolic relationship to the original data, and a third concept based on an abstract form were chosen. Working with the other project members, Dr Sano began by developing some initial ideas. First, these ideas were progressed through conversation, and recorded in the form of note taking and sketches (Fig 1.). Second, initial sketches were then developed to inform the construction of three-dimensional 'test' models (Fig 2.). Third, more robust and developed models were made that could be used in the focus group activities. For this stage a number of fabrication techniques were trialled (Figs 3. and 4.). The design workshop facilities and technical staff at Sheffield Hallam University were engaged to help make models using traditional materials including, clay, wax, and plaster. At the same time digital fabrication techniques in the shape of Fuse Deposition Rapid Prototyping were used to make robust objects. A selection of differently fabricated objects were then chosen to present to the user communities.

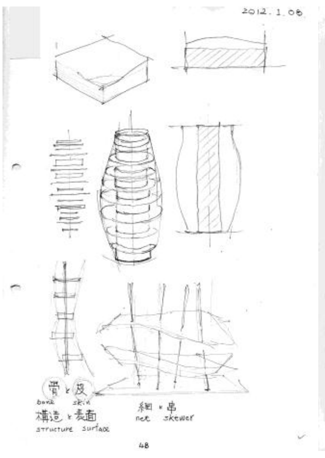
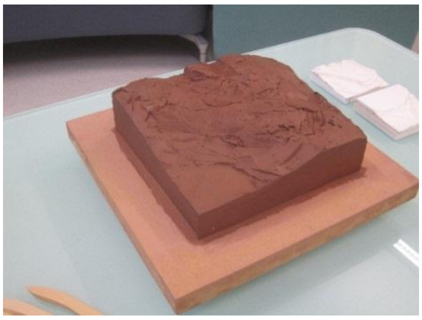


Figure 1. Initial drawing ideas.

Figure 2. Test models showing 3 initial concepts.



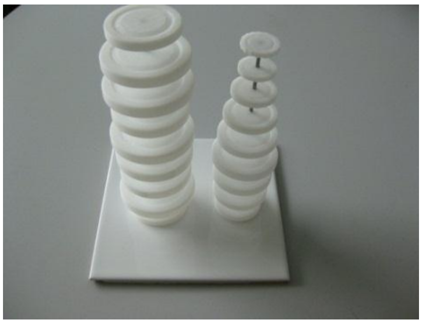


Figure 3 and 4. Developed models – Landscape concept in clay and Jar lid concept, Rapid Prototype model.

3. Testing the premise

Using the three data-object concepts developed by the research team through the design process outlined above, the research set out to investigate if the translation of statistical information into physical artefacts could aid cognition and understanding of complex digital data. Using semi-structured questions, interviews were undertaken with representatives from three user communities; designers, scientists/engineers and the general public. The interviews were used as a vehicle to explore, from a users perspective, whether or not, data-objects could be used to aid cognition of statistical/graph-based data and to question what insights/conversations into the meaning of the data represented in the data-object might be engendered. Interview questions were also used to examine what the effect/impact of the physical materials/affordances of the various data-objects, such as scale, material usage and finish might have on comprehension and engagement.

Interviews of 10 representatives for each user community were undertaken (30 in total). These were conducted in the Art and Design Research Centre (ADRC) at Sheffield Hallam University in individual sessions that lasted for a duration of between 15 - 20 minutes each. All sessions were conducted by the same two investigators and notes and photographs were taken during the sessions. Each session followed the same format, which is outlined as follows; after initial conversations around research ethics, process and compliance etc. the data-objects, which were arranged on a table in front of the participants were brought to their attention. The objects consisted of, small and large landscape representations of the data (made of plaster and Rapid Prototype plastic), two related objects which represented the data using the metaphor of a Jar lid, and another Rapid Prototype object which consisted of a number of circular discs mounted on concentric spokes radiating from the same hub (Fig 5.). Participants were invited to interacted with the data-objects which were described as containing/representing information, (the details of the specific information were not revealed at this point). The data-objects were examined in turn (in a random order) and questions as to the meaning/nature of the object and what information/data it might represent were asked. After two or three objects had been discussed, a graph of the original data was shown and explained, after which the remaining objects were examined and the initial objects were returned to.

Figure 5. Data-objects on table ready for user testing.

4. Initial findings

Following the interviews some general trends in respect to the meaning/potential use of the data-object as a means of communicating statistical information began to appear. Similar patterns of response and observation emerged from each user community. From the scientific/engineering community the initial response to the data-objects was frequently one of bemusement, and comments along the lines of why not stick with the original graphical representation were recorded, for example one participant suggested "why not just use a pretty graph". However, on interacting with the objects – which usually entailed picking up the objects, turning them around, feeling the differences in weight, surface texture form etc. there were a number of comments made which referred to how the different objects gave different impressions of data density – this was most commonly related to the surface textures of the landscape based models. Indeed the tactile nature of the objects was generally seen across all three communities as something that might be useful in communicating data in this form. This idea of data density being analogous to the granularity of the objects surface was frequently commented on – both as a positive and a negative, in terms of comprehension.

In many cases after the original graph-based data was explained there was a positive shift towards the concept of the data-object, in particular the physical objects where often thought to be more likely to stimulate a discussion around the data and the implications of the data for individuals. After the revealing of the graphical data the potential value of the data-objects as a discursive form was frequently commented on, comments such as "graphs work for papers they don't work for people" and "objects are much more powerful as a communication tool" reflected this train of thought.

Patterns in the data-object preferences (landscape, jar lid, abstract shape) also began to emerge within the user communities. In general the scientist/engineers favoured the jar lid shaped objects that were perceived as having a close correlation to the graphical data in terms of how the data was presented, but few people made the connection between the data content and the metaphor of the jar lid. The smooth plastic Rapid Prototype was also preferred by this community as it was seen to be more comprehensible than the 'noisy' surfaces of the plaster landscape models. From the design community a number of comments were made about how they do not generally use graphs or statistical information, and did not readily respond to information in theses forms. However the plaster-based models were often seen to be engaging as "they invite you to explore possibilities that are more tangible and more satisfying", and "they are better than prescriptive forms as they make you want to decode the object". Another participant "really liked the interpretative nature of the large plaster object" and found it more engaging "not black and white" (Fig 6.).

Figure 6. User testing the data-objects

If the general preferences for the scientific/engineering community were towards the analytical representation of data as shown in the graph and the jar lid data-object, and the preferences from the design-based participants were centered around the more open-ended, experiential data representations, predictably the participants drawn from the non-scientific, non-design community sat between these two camps. Some of these participants were used to looking at statistical/graph-based data as part of their work-based activity and preferred this approach while others – although not familiar with data presented in the form of an object, found the physical models to be "much more memorable". Interestingly when asked about how they might visualize the data a number of participants thought that colour would be a useful addition.

Across all the user communities the data-object based on the circular discs was seen to have a particular resonance with the original statistical information. Within this object each disc has a different resistance (when pushed), which correlates to strength/ability at different ages. This tangible feedback was seen to offer an analogues relationship to the data displayed in the graph and as such was easy to interpret and memorable due to the experience. However, there was some disagreement as to whether an easy to push disc represented an aged/weak person or a person who was young and strong. This point of contention highlighted a broader concern, relevant to all the data-objects tested, wherein it was commonly agreed that for the objects to have any use beyond the visual aesthetics and tactile experience of the form, some contextualization, in the shape of instructional information on how to read the object was required.

5. Future directions

The pilot study described in the paper indicates that the premise of the data-object as a communication tool that can add insight and aid comprehension of technical/scientific data for a non-technical audience has some merit. However, it is apparent that the success of the visual language used within the data-object is dependent on context of use, particularly in terms of the users expectation/requirements from the data contained within the form. Whether or not the data-object needs to somehow embody the nature of the content within its form needs further investigation, but according to this preliminary study there is a relationship between comprehension and decisions made around fabrication techniques, finishes and physical form. More work on the use of metaphor, shape, and material usage, use of textures, colours, contextual graphics and so forth is required. It is also apparent that there is no single solution for creating successful data-objects, and it was never the suggestion of this research that one visual representational form should 'replace' another. What is becoming clearer is that the extended visual language of the data-object can not only work in tandem with more traditional data visualisation forms like statistical graphs, but can also offer a rich, dialogical bridge or media-bridge that can complement more analytical forms, and by doing so potentially broaden the community of understanding.

In terms of future directions additional research on the features outlined above is intended, and applying the concept of the data-object to other more complex data sources is seen as an avenue which will offer further potential for investigation. It is our intention to publish findings in appropriate professional and technical journals and to present this and future research on the area to a variety of audiences in the creative and cultural sectors, academic and engineering communities and to promote knowledge transfer opportunities by expanding the methodology to other information sources and contexts.

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Design Process

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INFLUENCES OF DESIGN TOOLS ON CONCEPTS GENERATION

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Abstract: Concept generation plays a vital role in establishing a broader foundation in the design process to create novel products. In globalized, collaborative, designing scenario, unambiguous representation of captured ideas to explicate designer's thoughts is important in sharing and reuse of concepts. Various design studies noted the impact of design tools on concept generation. However, the results did not detail the influences of variety of tools in representation and reinterpretation of concepts through captured design documents. This paper aims to understand the influences of conceptual design tools: Mobile e-Notes Taker™, Wacom™ Tablet, and Computer with Rhinoceros™ CAD on concept representation and reinterpretation, during original and redesign phases. Analyses of six individual designers' using video protocol studies conducted in original and redesign phases reveal that the design tools had significant impact on concept generation, in terms of the number of concepts generated and the textual and graphical representation of the design elements.

Keywords: *Concept generation, design tools, representation, reinterpretation*

1. Introduction

Innovation is a key factor to sustain in this competitive globalized industrial market. Designers are increasingly being stressed to create quality innovative products in faster cycles. Typically, designers are trained and motivated to be creative, where creativity is often expressed through fluency, flexibility and originality (Renzulli et al., 1974). A common definition of creativity proposes that "Creativity occurs through a process by which an agent uses its ability to generate ideas, solutions or products that are novel and valuable" (Sarkar and Chakrabarti, 2011). It has been shown that there is a positive correlation between the number of ideas produced during the design process and the novelty of the design concepts (Srinivasan and Chakrabarti, 2010). People, product, process, tools, organization and environment in which designing takes place (Blessing et al., 1995) have significant impact on the idea generation process. In these facets, design tools play a vital role in capturing designers' thought processes and in facilitating sharing and reuse of design outcomes. Design tools assist 'reflective conversation' (Schön, 1983) between designers and design outcomes (e.g. external representations of requirements and solutions) which help generate a mental image that, in turn, may produce more sketches (ideas) which may, again, generate another mental image, and so on and so forth (Fish and Scrivener, 1990).

It is a designer's responsibility to choose appropriate design tools in the design process, based on understanding of the ability of each tool alternative available. However, studies have shown that although the frequency of use of CAD is less for immature designs (i.e. conceptual stage), it is still the most frequently used mode of working (Robertson and Radcliffe, 2009). They argue that a possible reason is the importance of digitalization of design outcomes, which is important for future analysis and process integration. Ibrahim and Paulson (2008) pointed that the transitional and iterative conceptual phase is a potential knowledge-loss period that is identified in the product development lifecycle process. But this raises the question as to whether designers really understand the influences design tools have on their creativity and outcomes generated. While Cham and Yang (2005) cited a number of good examples of successful integration of CAD and design education, this situation is hardly universal.

Various design studies have been conducted to understand the differences between pencil-and-paper-aided-designing and CAD designing, especially for their impact related to creativity in design. Most of the studies conclude that CAD is not suitable during the conceptual stage, as it exerts a negative influence on creative design and provides inadequate I/O systems to support intuitive idea creation (Whitefield, 1996; Kwon et al. 2003; Lawson, 2002; Stones & Cassidy, 2007). Geol (1995) found that levels of ambiguity were much higher in freehand sketching than in digital working. He concluded that sketching supported creativity in design more effectively than constrained computer usage did, particularly in terms of supporting reinterpretation. Alternatively, Won (2001) argues that the frequency of reinterpretation could be accounted for by the speed of digital working – the ability to 'move-see-move-see' that computers support so effectively. But he concluded that more alternatives could be generated using conventional drawing than using the computer.

Robertson et al. (2007) found that CAD enables enhanced visualization and communication, but with the negative effects of premature fixation, circumscribed thinking, and bounded ideation. They argued that enhanced visualization and circumscribed thinking cause students to develop a false sense of reality of CAD models. Lawson (1997) pointed out that certainty in the finished appearance of a digital mark proves destructive and restrictive in the early stages of design. Stones & Cassidy (2007) highlighted that CAD systems usually oblige designers to generate an early, precise, external representation of the object to be designed, and to use highly structured rules, which orients their reflections and does not correspond to their spontaneous process of creation.

Kwon et al. (2005) argue that the limitation of intuitive sketching capabilities in CAD tools is a reason for their inapplicability during the conceptual phase. Ibrahim and Rahimian (2010) illustrate that neither manual sketching tools nor CAD software are the better media for current conceptual design communications. They found that design semantic gets lost when manual design fails in articulating an explicit design idea, while design creativity diminishes when using arduous CAD software. Stones & Cassidy (2010) studied the impact of design tools (conventional paper-based sketches and digital tools) on reinterpretation during graphic design ideation activity. From their experimental results with student-designers, they have shown that paper-based sketches can support the vital process of reinterpretation that generates new ideas. Rosenman & Gero (1996) argue that a single-model approach to representing a design object is insufficient for modelling the different views of the different disciplines.

It is clear from these literature results that for the conceptual stage, current CAD software is not yet a better alternative to replace conventional sketching tools, even though CAD provides enhanced visualization and speedy manipulation of objects. However, the importance of capture and reuse of digitalized design outcomes forces us to develop enhanced novel design tools that retain the merits of both the medium. For developing such tools, it is vital to understand current behaviour of designers in using various conceptual tools in terms of the textual and graphical representations of captured design documents. Also, behavioural changes of designers in reinterpretation of the captured design documents need to be studied across various conceptual tools. Literature does not report in any detail the behavioural changes of designers in representation of concepts in captured design documents. The focus of this paper is to understand the influences of conceptual design tools – Mobile e-Notes Taker^{TM}, Wacom^{TM} Tablet, and Computer with Rhinoceros^{TM} CAD – on concept representation and reinterpretation during original and redesign phases. In literature, reinterpretation is studied during original designing rather than in the redesigning phase. We intend to study the influences of original captured documents in redesign phase.

2. Research objectives and methodology

The aim of this paper is to study the impact of conceptual design tools on the behavioural changes of designers in (1) representation of design concepts in design documents captured during both original and redesign phases, and (2) reinterpretation of captured concepts during the redesign phase. A concept is defined as an entity that satisfies an overall function (Srinivasan & Chakrabarti, 2010). We have chosen Mobile e-Notes Taker^{TM}, Wacom^{TM} Tablet, and Computer with Rhinoceros^{TM} CAD (Figure 1) as an initial set of conceptual tools for this study. Mobile e-Notes Taker^{TM} and Wacom^{TM} Tablet were selected for their potential to replace pencil and paper tool which are currently the most commonly used aid for the conceptual design, and also on their ability to support capture and reuse in digitalized formats of design concepts. For comparison with CAD, Rhinoceros^{TM} CAD was chosen because it has been widely used in our design centre (CPDM, IISc, Bangalore) as a conceptual CAD tool. Mobile e-Notes Taker^{TM} is a portable handwriting capture device based on natural handwriting as input. A plain paper of any kind can be attached to the tool and the Hi-Tech's electronic pen can be used to capture, store and share handwritten drawings, sketches and notes. In this study we used Wacom^{TM} DTU-710 tablet. The Wacom DTU-710 Interactive Pen display combines an LCD monitor with a Wacom tablet. This gives a direct point-and-draw-on-screen interface that can be used with a PC. Rhinoceros^{TM} CAD that is widely used during conceptual designing. Rhino offers uninhibited free-form 3-D modelling, extreme precision, unrestricted editing, 2-D drafting, annotation, illustration, compatibility, and a short learning curve.

Figure 1. Mobile e-Notes Taker^{TM}, Wacom^{TM} DTU-710 Tablet, Computer with Rhinoceros^{TM} CAD

A map of the hypotheses explored in this work is shown in Figure 2. Representation of captured concepts, reinterpretation of captured concepts in the redesign phase, designer adaptability to design tool, time taken to capture each concept are the four parameters studied in detail. Representation of captured concepts is studied through textual and graphical formats. Textual contents are analysed by counting the number of words used to express function, behaviour and structure elements of the concepts; whereas graphical contents are analysed using the number of distinguishable components represented through sketches and diagrams. For distinguishing function, behaviour and structure elements, the definitions used by Chakrabarti et al., (2005) are used.

- *Function: Descriptions of what a system does: it is intentional and generally at a higher level of abstraction than behaviour.*
- *Behaviour: Descriptions of how a system does its function. This is generally at a lower level of abstraction than function.*
- *Structure: Structure is described by the elements and interfaces with which the system and its immediate interacting environment are constructed.*

Reinterpretation of captured concepts are analysed by the ambiguity and incompleteness of design elements and assumptions made by the designer working on redesign phase. Ambiguity can be defined as ‘interpretable in two or more distinct ways’ or as ‘vague or imprecise’ (Stacey and Eckert, 2003). Video protocols have been analysed to segment ambiguous portions expressed by each designer. Adaptability with the design tools has been studied through comfort of the designer. Video protocols and audio transcripts have been used to understand and segment portions of uncomfortable behaviours. Time taken to capture each concept is noted by using timestamps in the video protocols. We have formulated the following hypotheses to be verified in this study:

2. Conceptual design tools have a significant impact on the number of concepts generated.
3. Conceptual design tools have a significant impact on the amount of time spent by the designer in capturing each concept.
4. Conceptual design tools have a significant impact on the representation (graphical and textual format) of captured concepts in terms of functional, behavioural and structural elements.
5. The amount of time taken to capture each concept has a significant impact on the representation of captured concepts.
6. Formats of representation of captured concepts have a significant impact on the reinterpretation in the redesign phase.
7. Designer adaptability to a design tool has a significant impact on the representation and reinterpretation of captured concepts.

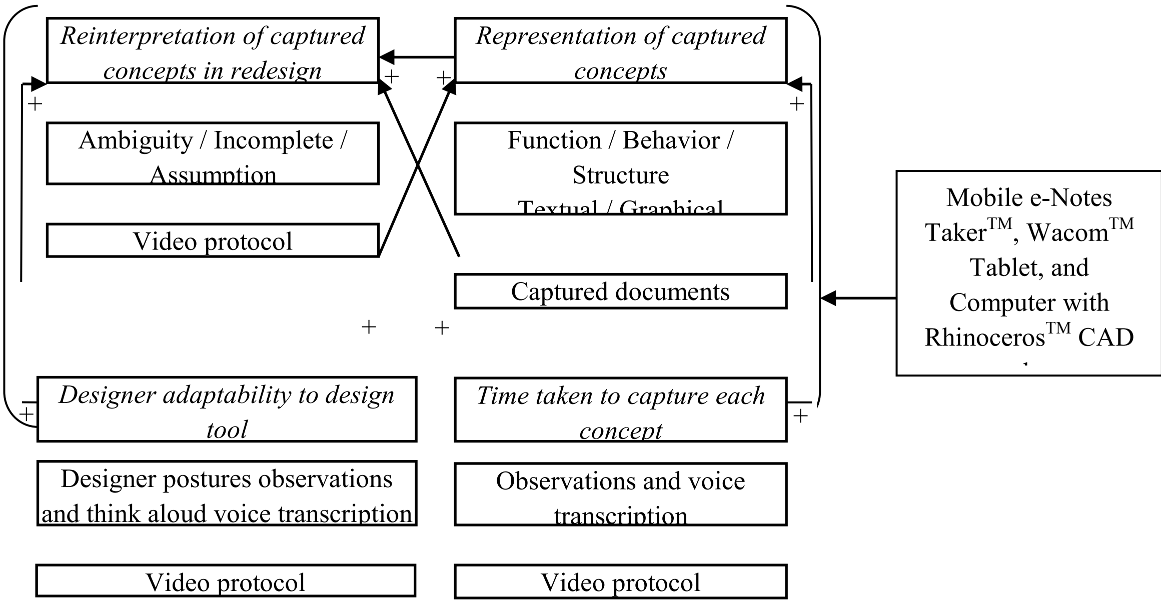

Figure 2. Research hypotheses map

To verify these hypotheses, in-house design experiments are conducted in a laboratory setting. Table 1 elaborates the structure of the design experiments conducted with the three design tools. To study the capture and reuse aspects, original and redesign experiments are conducted. Three original and three redesign experiments are conducted with four Master-of-Design students and two design researchers (Master-of-Design and Engineering). Industrial experience of the six designers varies from none to three years. A single design problem is used in all six experiments. For the redesign experiments, documents captured during the original experiments are provided as input. Only task clarification and conceptual design phases are covered in these experiments. Designers are given adequate training to use the tools before conducting the experiments. During the design experiments, each subject is asked to 'think aloud' such that the researcher can obtain a rich externalisation of their thoughts and activities from the experiments.

Table 1. Structure of design experiments and time taken for each experiment

Tools	**Original** (Design problem 1)	**Redesign** (Design problem 1)
Mobile e-Notes Taker™	Designer 1 – 1Hr 5Min	Designer 4 – 44Min
Wacom™ Tablet	Designer 2 – 34Min	Designer 5 – 25Min
Computer with Rhinoceros™ CAD	Designer 3 – 1Hr 33Min	Designer 6 – 1Hr 33Min

3. Results

8. Conceptual design tools have a significant impact on the number of concepts generated.

Table 2 details the number of concepts generated in the original and redesign experiments across the three design tools. Captured documents are analysed to note the number of captured concepts. A preliminary concept is defined as an idea to solve the given design problem; whereas a detailed concept is taken to one elaborated with more details. Designers using computer with Rhinoceros™ CAD have chosen MS PowerPoint to explore preliminary concepts, and used Rhinoceros™ CAD in detailing the design. In the original design experiments, the number of concepts generated in Mobile e-Notes Taker™ and Wacom™ Tablet are higher compared to those using the CAD software. Reduction in the number of ideas, when Computer (MS PowerPoint) with Rhinoceros™ is used, could be due to premature fixation, as pointed out by Robertson et al. (2007). The level of precision necessary in articulating the concepts could be another reason for a resistance to change and develop newer concepts with Rhinoceros™ CAD. In the redesign experiments, the number of concepts generated does not seem to be impacted much by the tools. This could be due to fixation with the original concepts provided during the redesign phase. Overall, the results indicate that conceptual design tools have significant impact on the number of original design concepts generated.

Table 2. Number of concepts generated in the original and redesign experiments

Tools	**Original**		**Redesign**	
	Number of preliminary concepts	Number of detailed concepts	Number of preliminary concepts	Number of detailed concepts
Mobile e-Notes Taker™	7	5	2	1
Wacom™ Tablet	-	6	-	1
Computer (MS PowerPoint) with Rhinoceros™ CAD	2	1	1	1

9. Conceptual design tools have a significant impact on the amount of time spent by the designer in capturing each concept.

Table 3 elaborates the amount of time spent on capturing each preliminary and detailed concept, in three point estimates. Video protocols have been used to segment and record the time spent on capturing each concept. In Mobile e-Notes Taker™, the amount of time spent in capturing concepts vary more uniformly (standard deviation for capturing detailed concepts: 227 seconds) than in other tools. The fixation highlighted in the previous hypothesis in using Rhinoceros™ CAD is indicated by the amount of time spent on detailing concepts. Even though many concepts are generated in Wacom™ Tablet, the non-uniform time distribution in capturing concepts leads to stronger indication of occurrence of fixation. These indicate that conceptual design tools have a significant impact on the amount of time spent by the designer in capturing concepts.

Table 3. Amount of time spent on capturing concepts in original and redesign experiments

Tools	**Original**						**Redesign**					
'-' represents for one, two or no concepts generation	Time in capturing each preliminary concept (seconds)			Time in capturing each detailed concept (seconds)			Time in capturing each preliminary concept (seconds)			Time in capturing each detailed concept (seconds)		
	Min	Av	Max	Min	Av	Max	Min	Av	Max	Min	Av	Max
Mobile e-Notes Taker™	8	27	55	280	403	720	103	-	267	-	-	117
Wacom™ Tablet	-	-	-	67	260	1064	-	-	-	-	-	630
Computer (MS PowerPoint) with Rhinoceros™ CAD	43	-	132	-	-	3200	-	-	182	-	-	2325

10. Conceptual design tools have a significant impact on the representation (graphical and textual format) of captured concepts in terms of functional, behavioural and structural elements.
11. The amount of time taken to capture each concept has a significant impact on the representation of captured concepts.

Table 4 shows the number of textual and graphical contents in terms of functional, behavioural and structural elements of captured concepts in the original and redesign experiments. Captured documents were analysed to segregate the number of words and distinguishable components used to represent the concepts. Observations from Table 4 are the following:

- Textual descriptions of concepts both in the original and the redesign phase are substantially higher in Mobile e-Notes Taker™ then other tools.
- Graphical elements are used to represent mostly the structural elements of concepts in all the tools. Except Wacom™ Tablet where functional elements are also graphical represented.
- Most behaviour elements are represented textually; that is higher in Mobile e-Notes Taker™.
- Since only few distinguishable structural components with precision are captured in Rhinoceros™ CAD, factors mentioned by Robertson et al. (2007) such as large amount of detail and interconnectedness and the complexity of the model influencing premature fixation might be questionable.
- Comparing Tables 3 and 4 reveals that only with Mobile e-Notes Taker™, the amount of time taken to capture each concept has impact on the wider representation (function, behaviour and structure elements) of captured concepts. In other tools, only precision in representation (especially structure elements) is increased with the amount of time spent.

The observations indicate that conceptual design tools have a significant impact on the representation of captured concepts. The amount of time taken to capture each concept does impact on the representation of captured concepts but in varying levels of precision and expression elements.

Table 4. Representation formats of captured preliminary and detailed concepts in original and redesign experiments

Tools	**Original**						**Redesign**					
	Textual			Graphical			Textual			Graphical		
	Fun.	Beh.	Str.	Fun.	Beh.	Str.	Fun.	Beh.	Str.	Fun.	Beh.	Str.
Mobile e-Notes Taker™	14	24	33	-	-	-	12	60	27	0	9	7
	33	150	92	0	8	36	0	28	8	0	0	0
Wacom™ Tablet	-	-	-	-	-	-	-	-	-	-	-	-
	-	3	-	25	1	23	21	1	9	4	-	12
Computer with Rhinoceros™	4	7	27	-	-	-	-	13	42	-	-	-
	-	-	-	-	-	4	-	-	-	-	-	9

12. Formats of representation of captured concepts have a significant impact on the reinterpretation in the redesign phase.

Table 5 shows that the amount of time spent by the designer in reinterpretation of original concepts is very minimal in the redesign experiments. Textual or graphical format does not significantly change the reinterpretation time. Video protocols show that the designers were interested to understand only the overall working principle of the concepts, rather than looking into the details of the concepts. Also, only the concept chosen by the original designer was focused on during the redesign phase. This could be one reason for the small number of redesign concepts generated. Goldsschmidt (1994) statement 'one read off the sketch more information than was invested in its making' could be valid for original designer rather than designer using original captured documents in redesign. Some observations relevant for the reinterpretation hypothesis are:

- In Rhinoceros™ CAD and Wacom™ Tablet, deleted and erased contents were not captured and subsequently not provided in the redesign experiment.
- The designers involved in the redesign phases assumed the original designer's thoughts and progressed accordingly.
- The designers found difficulty in Rhinoceros™ CAD to link the design problems and the requirements generated by the original designers.

Table 5. Time spent on reinterpretation of captured concepts in the redesign experiments

Tools	Amount of time spent on reinterpretation of all the original concepts (seconds)
Mobile e-Notes Taker™	310
Wacom™ Tablet with viewing facility	128
Computer (MS PowerPoint) with Rhinoceros™ CAD	309

H6. Designer adaptability to a design tool has a significant impact on the representation and reinterpretation of captured concepts.

Video protocols are analysed to understand a designer's discomfort during interaction with the design tools. Before and during the experiments, none of the designers questioned the ability and usability of the given design tools. Except for few adjustments, all designers were well adapted to the conceptual design tools. The few minor adjustments carried out by the designers were: observing the right mode of capture function, body movements to orient themselves for using the tool, paper adjustments, mouse requirement, tool orientation, transferring between paper sheets and continuation of capturing, and modification being restricted by the original designer. Bonnardel and Zenasni (2010) argue that technology developments should be adapted to designers' cognitive processes instead of requiring them to adapt to new technologies. However, considering the highly adaptable nature of the designers, it is difficult to find real cognitive, technological needs of the designers. Adaptability is not found to be an issue with the assessed tools. All the results obtained for hypotheses H1-H5 are not influenced by adaptability.

4. Discussion and conclusions

Figure 3 summarizes the findings in the influence diagram from the experiments analyses. The foremost implication from these results is to help designers understand and learn the facilities provided by design tools and their influences on the design process. From the industrial perspective, efficacy of design tools in capturing and reusing concepts in appropriate representation for better reinterpretation during the redesign process needs to be established

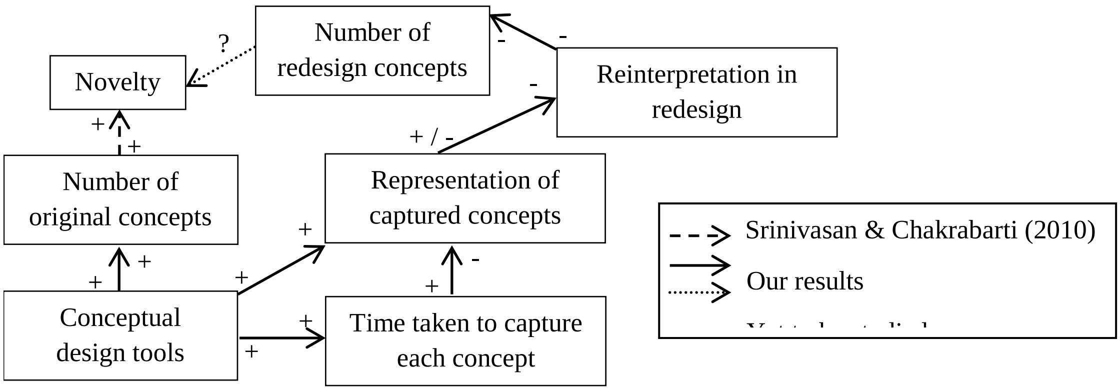

Figure 3. Influence diagram from the research findings

Since less time spent in reinterpretation process could have strongly influenced the number of redesign concepts generated, designers have to be trained in the reinterpretation design process to extract necessary knowledge from the concepts originally captured, rather than assuming about the original designer's thoughts process. Also, design tools need to aid the reinterpretation process because none of the tools currently support capture of all necessary information and knowledge required for the redesign process. Notable proposals such as representation of the functional properties of design objects to accommodate multiple views of design objects in a collaborative CAD environment (Roseman and Gero, 1996) and agent models (Maher et al. 2007) to monitor and augment designer in capturing and reusing required information and knowledge need to explored for supporting conceptual paper-based and CAD tools. But to build effective agent models to support reinterpretation, the core descriptive research question to be answered is 'what information and knowledge are not captured but should be otherwise during the design process'. We are presently analysing more experiments conducted to validate results using elaborated statistical technique.

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CONSIDERATION OF MATERIAL BEHAVIOUR IN THE CREATIVE DESIGN PROCESS: A PERSPECTIVE FROM STRUCTURAL ENGINEERING

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Abstract: The purpose of this paper is to examine how material choices are made in practice by structural engineers and by implication how material behaviour is understood. The research uses documents from recently completed design projects. By extracting specific design ideas and decisions from project documentation and categorizing them based on the type of material knowledge, (either theoretical or technological), and the process by which the decision was made, (either intuitively or using a specific design tool to verify), the authors wish to illustrate the role of material in the creative design process undertaken by structural engineers. The results reveal a complex interconnection between material represented as matter (as defined in the theories of structures and strength of materials), and the particular nature of individual materials as understood through technological knowledge.

Keywords: *material behaviour, creative design process, technology*

1. Introduction

In the profession of structural engineering, designers are confronted with a wide range of materials, ranging in behaviour from highly variable natural materials such as soil and rock to refined metal alloys. As a result, an understanding of the breadth of possible material behaviour is fundamental to the profession's knowledge base and the designer's creative process.

1. 1 Knowledge framework: theory v technological knowledge

The theoretical basis of contemporary structural engineering was largely established with the formulation of elastic theory in the nineteenth century, (Heyman, 1998). A key concept developed in elastic theory, was the intrinsic material property which is independent of the form or geometric extent of the material. (Examples include among others Young's Modulus E and the Poisson's ratio υ). This conceptual leap was the key to the development of methods to quantify structural behaviour, but equally, from the standpoint of material science, can be seen as a convenient approximation used to allow the development of mechanics, which contradicts the observed reality that form and material behaviour are difficult to separate. (Gordon, 1988).

In parallel to the extensive theory available to the structural engineer, (calibrated against a mass of laboratory tests on material), empirical rules of thumb and direct experience regarding material behaviour continue to form a significant portion of the structural engineer's knowledge base. Particularly with regard to materials with highly non-linear properties, such as reinforced concrete and timber, a wealth of observations of built work, provide data about movements, tears, cracks and instabilities. This information comes from a limited number of full-scale laboratory experiments, and mostly from both, the practicing engineer's active involvement in construction, and from fields such as the renovation and conservation of buildings. Critically, it can be argued that the study of full scale precedent, remains a key tool in structural engineering design education (HarvardGSD, 2010). In this paper, the authors will refer to this type of knowledge as technology based knowledge in contrast to theoretical knowledge. For a wider discussion of knowledge and its classification the reader is referred to (Ahmed et al., 2005) and (Christiaans, 1992). Such classifications of knowledge are seen by the authors as compatible with the theoretical v technological knowledge model referred to here.

1. 2 Process: intuition and analysis tools

The design process can be broadly divided into two activities, idea inception and testing. The former follows a process of 'intuition' and the latter is largely encompassed by methods of analysis in the context of structural engineering.

Although there have been recent developments to introduce some of the physically 'intuitive' aspects of computer games to structural software, including project Vasari (developed by Autodesk) and Kangaroo (developed by Rhino), software remains substantively a modeling tool for testing predesigned structural concepts rather than to generate ideas. As a result, structural engineers continue to use a range of intuitive ideas about structural behaviour in formulating design ideas. The range of intuitive approaches is open ended and can be intensely personal. Approaches include variations of bio-mimicry, for example, in which the designer imagines the structural form as a plant and visualizes where the stems would be and their relative thicknesses. (M. Cook, personal communication, September 21, 2011). Equally, intuition can be based directly on precedent, with the designer visualizing the project as a structure similar to existing built work. Some intuitions can be related directly to structural theory, such as the visualization of load paths to create an equilibrium force state in a structure or the distribution of movements and hence forces in a structure, as a result of the relative stiffness of different elements. (Brohn, 1984). Mainstone provides a most illuminating description of intuitive processes, categorizing approaches as based on observation, visualization or the feeling of force within the body (Mainstone, 1963).

Critically, the different modes of intuition incorporate a variety of ideas and assumptions about material behaviour, which in turn create a complex picture of how structural engineers understand material.

MATERIAL PRESENCE

INTUITION	• In intuition, material can be critical to concept or entirely absent
ANALYSIS TOOLS	• Analysis tools use generic material properties

PROCESS

KNOWLEDGE

TECHNOLOGY	• Material behavior fundamental to technology
THEORY	• Theory based on a generic understanding of material

Figure 1. Framework for considering material in terms of design process and knowledge

2. Research approach

Using the framework of design knowledge and process as described in figure 1, three projects were examined for the presence and nature of material understanding . By extracting specific design ideas and decisions from the documentation and categorizing them based on the type of material knowledge, (either theoretical or technological), and the process by which the decision was made, (either intuitively or using a specific design tool to verify), the authors examined the role of material in the three projects, from the perspective of the structural design.

2. 1 Project Choice and Characterization

3 projects were chosen for examination, namely:

- The Massar Children's Discovery Centre, Damascus, Syria.
- The 'Skywalks' pedestrian footbridge network, Riyadh, Saudi Arabia.
- The Institute of Diplomatic Studies, Riyadh, Saudi Arabia.

The projects were chosen on the following basis. Firstly they all had an extended design process, (minimum 1 year), with a considerable quantity of documented design information that it was possible to refer to. This was important as the objective was to study a design environment rich in decision making. In each case a large selection of design reports, email correspondence, meeting minutes, drawings and specifications were available to the authors. Also, the projects had certain similarities which encouraged a detailed discussion of structural behaviour. They all had a geometry which could be described as complex and which required sophisticated software to describe the form but more importantly, in each case the structural solution was not immediately obvious at the outset of the design process. In fact, in each case the suitability of the building envelope or 'skin' as structure was discussed at length. All the projects were a collaboration between Buro Happold Consulting Engineers and Henning Larsen Architects between 2006 and 2010. The primary author had first hand experience of all the projects.

In addition each project had unique characteristics. The Massar Discovery Centre design process was concerned with the feasibility of achieving a specific architectural form within the building culture and technological constraints of Syria. By contrast, in the Institute of Diplomatic Studies project the structural ideas were drivers of form generation. The main architectural design concept was the creation of a central communal space or 'oasis' and the architects were keen for the structural and environmental technological possibilities and constraints to influence the form. In this instance, the design was developed using form-finding software and physical modeling techniques to create an optimized structural form, based on idealized load conditions. The Skywalks bridge network project had different design drivers again. In this case the architectural spatial constraints were less significant and the design process was focused on delivering a generic design which, while on the one hand was materially efficient and adaptable to the different physical constraints of the various sites, could be constructed by a number of construction techniques (to create an open and competitive procurement route) and also had a unique and striking form.

Figure 2. Institute of Diplomatic Studies

Figures 3 and 4. The Massar Discovery Centre and the Skywalk Bridge Network

2.2. Method of data analysis

The method of analysis was as follows. A total of 281 separate references to ideas or decisions regarding structural behaviour were identified in the documentation of the three projects. Henceforce, these will be referred to as structural 'design statements'. The majority of design statements were from the structural engineering documentation but those from other design professionals including architects, building service engineers and contractors were included when they weren't covered within the structural engineering documentation but had a structural basis. (50 of the original data set were in fact discarded due to their lack of structural basis or repetition of ideas).The design statements were collected from a range of pre-construction phases.

Each design statement was coded in relation to the type of knowledge on which the statement was based (theoretical or technological), and its role in the design process, either as an expression of structural intuition or the documentation of the use of an analysis tool to verify an idea regarding structural behaviour. (See figure 1).The method of articulating intuition, for example by sketching or talking, was also coded. Before commencing the coding process, an extended list of sub-codes had been established based on a literature search and previous interviews, to further divide the various categories. This was used as a starting point, and during the coding process, this was modified in response to the data being analyzed. Unused categories were removed. It should be stressed that the sub-coding process was used in this context to allow the observation of patterns of design thinking, rather than a process of classification and as such was continually under review. In fact, the original pass at coding and sub-coding was reviewed in full after 6 months and some small changes made. A total of 27 sub codes were recognized in the 3 projects and are outlined in table 1.

Following completion of the coding and sub-coding process, the data was presented in terms of the relative frequency of the different categories of knowledge, process and method of articulation. This was undertaken for the full data set (figures 5, 9 and 10) but also split up by project phase, individual project and the profession of the designer. Correlations in the data set were also examined. The frequency of cases in which specific sub-codes of knowledge, process and method of articulation were present in the same design statement, was analyzed.

It should be noted that the analysis does not take into account the relative importance of each design statement in developing the overall project or the time it took, or indeed the quality of the design decisions made as a result. Also, the number of design statements varied based on the richness of the data set. The Masser Children's Centre had the largest data set of 107 design statements, while the Institute of Diplomatic Studies and Skywalks project had respectively 55 and 79 design statements.

PROCESS		**KNOWLEDGE**	
Intuition Categories – Design Inception (IC)		**Technological Knowledge (TEC)**	
IC1A	Load Path/Equilibrium Concept	TEC1	Material Based Technology
IC1B	Relative Stiffness Concept	TEC2	Empirical Testing as Design
IC2	Observation of Precedent	TEC3	Design by Components
IC3	Biological Analogy	TEC4	Ideas from Cultural and Historical Context
ICA	Abstract Concept- (*Idea generating form*)	**Theory of Structures and Strength of Materials (T)**	
Mathematical Tools- Verification (TM)		TS1	Geometrical Load Path (Tension and Compression)

TMH1	Hand Calculations based on Force Distribution	TS2	Beam and Frame Load Distribution
TMH3	Hand Calculations based on Elasticity	TE	Theory of Elasticity (and extensions to the Theory of Elasticity)
TMN1	Software Calculations based on Force Distribution		
TMN3	Software calculations based on Elasticity	**Method of Intuition Articulation (IM)**	
TMN4	Software Calculations based on Inelastic Behaviour	IM1	Hand Sketching
TMT3	Tabulated Solutions based on Elasticity	IM2	Noting
TMT4	Tabulated Solutions based on Inelastic Behaviour	IM3	Talking
Physical Models –Verification (PM)		IM5	Images
PM1	Form Finding Models	IM6	Computer Sketching

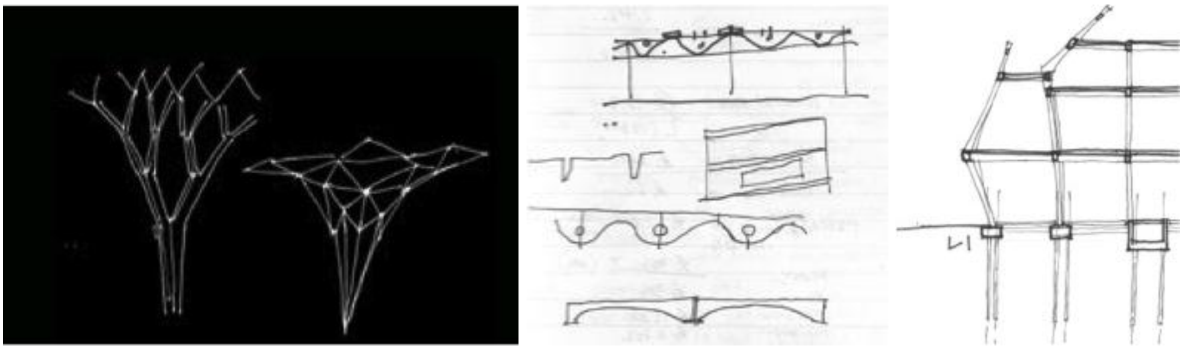
Table 1. Process, Knowledge and Method of Articulation Sub Codes

3. Findings

3.1 'Method of articulation' data set

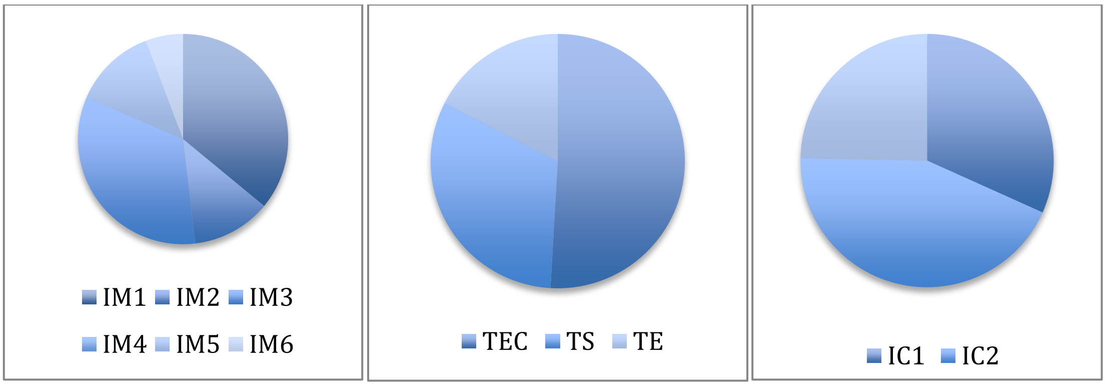
The data set indicates that the majority of design statements are articulated either by sketching by hand (IM1) or through discussion (IM3) in the design team, primarily at meetings, although there are a number of other methods used (Figure 8). Sketching using a computer is not very prevalent (IM6), although its incidence is higher in the Skywalks bridge project due to the specific personalities in that design team. The frequency with which design statements are articulated using words (written or verbally) is relatively constant through the various project stages, an indicator of a continuing dialogue within the design team and with the client in each project. By contrast the use of images, reduces dramatically after the first stage in all the projects as the design becomes more concrete. The use of sketches peaks at concept and detailed design stages, corresponding to the stages of most rapid design development.

A significant majority of the design statements described by images and through discussion, articulate intuitions based on precedent and refer exclusively to technological knowledge. In the case of images 70% and in the case of discussion 81%. By contrast, the ideas articulated by sketching can be based on the theory of structures or technological knowledge or indeed both which highlights the adaptability of hand sketching as a design tool, and the often complex interaction between the theory of structures and technological knowledge . More specifically, of the 'sketch' data set, 28% of the design statements are based on technological knowledge only and exclusively articulate a process of intuition based on precedent while 38% of design statements refer to knowledge founded on the theory of structures and articulate a process of intuition based on mathematical systems including equilibrium, relative stiffness or a mechanism. The remaining 25% of design statements are based on both technological and theoretical knowledge and articulate a mixture of intuitions. Examples of these three types of sketch are shown in figures 5, 6 and 7.



Figures 5, 6 and 7. Sketches indicating various knowledge sources: Theory of Structures only, Technology only and Combined Theory of Structures and Technology.

Examples of each of these sketch categories can be seen in all stages of each project's design process with the exception of certain early stages of the Institute of Diplomatic Studies, where the mixture of technological and theoretical knowledge is absent. This would appear to be due to the 'abstract' design process chosen as discussed previously.



Figures 8, 9 and 10. Complete Data Sets: Method or articulation, Knowledge and Process.

3.2 Knowledge data set

Figure 8 reveals that 52% of the design statements depend on technological knowledge (TEC) rather than theoretical knowledge (TE and TS). The authors would argue that this large presence of technological knowledge indicates a frequent consideration of material behaviour in the projects. This proportion decreases from approximately ¾ of design statements at the feasibility stage to a 1/3 as the projects progress to completion. Material and component based technological understanding is consistently present through all stages of each project but technological knowledge which is more loosely based on the cultural or historical context, appears to reduce significantly as the projects progress. In the complete data set, technological knowledge appears to closely relate to intuition based on precedent. 90% of design statements with intuition from precedent are based on technological knowledge rather than the theory of structures.

Technological knowledge is strongly present through all the projects but it was particularly noted that material knowledge remained very dominant throughout the Skywalks bridge design project due to the need to develop a design which promotes an 'open' technological procurement route compatible with the full range of steel connection and erection technologies available. Similarly, in the Massar Children's Discovery Centre material technology is very prominent due to the detailed discussion regarding the specific construction context of Syria. It should be noted that the designers involved in all the projects, who were not structural engineers, used almost exclusively knowledge based on technology highlighting the particular disciplinary nature of the theory of structures. However, it should be pointed out that designers other than structural engineers only account for the generation of 9% of the data set.

Of the design statements founded on theoretical knowledge, 58% specifically relate to theory in which constituent material parameters plays no part. The remaining minority of statements are based exclusively on elastic theory or extensions to it, in which the Young's Modulus, as a measure of material stiffness, is used. The statements which are based on elastic theory are primarily analyses of movement or buckling behaviour and are more prevalent towards the end of the projects. The prevalence of elastic theory does vary between projects, based on the specific problems being tackled. For example, in the Skywalks bridge project, problems which required a value of Young's Modulus for analysis, are only present towards the latter stages, as the form of the structure was almost exclusively generated based on an understanding of force distribution. This highlights that elastic theory is useful to quantify specific problems but is not the only tool of choice of structural engineers.

3.3 Process data set

Figure 9 indicates that 25% of the design statements are based on a process of verification or testing ™, leaving the vast majority depending on intuition (IC). The dominant processes of intuition were as follows: 42% of the total of design statements were informed by an intuition based on precedent (IC2) and 32% on mathematical concepts of relative stiffness, equilibrium and mechanisms (IC1). The authors would argue that strong representation of precedent demonstrates a high presence of material consideration in these design projects.

Examples of intuition based on precedent reduce progressively from about ¾ to 1/3 as the projects progress while those based on mathematical concepts are relatively constant. By contrast, the number of design statements based on a process of verification or testing gradually increases as the projects progress, which would be consistent with an increased requirement for checking and verification as the design becomes more detailed. The Institute of Diplomatic Studies project has uniquely the presence of form finding techniques based on an efficient distribution of force, both using physical and mathematical modeling tools. Intuition based on biomimicry was also used on this project. Such processes, using an abstraction of material as 'matter', promote a generic rather than a particular understanding of material.

4. Conclusions

Looking at the data as a whole, it is clear that the variety of ideas and techniques available to structural engineers to understand materials is extensive. On the one hand, simple techniques based on the theory of structures allow quantitative testing of problems using basic material properties as ‘matter’. On the other, ready access to knowledge of the particularities of individual materials and technologies promotes their sophisticated use in design. With regard to the latter, it was noteworthy the dominance of material technology and precedent in the data set and hence the authors would argue a high consideration of the understanding of specific materials.

However, the data from these three projects indicates more complex patterns regarding how this knowledge is combined, than this simple opposition suggests. On the one hand images, appear to articulate the idea of technology in isolation, as does discussion. By contrast, the traditional technique of hand sketching is suited to the articulation of both technology and the theory of structures, often both at the same time demonstrating that in many situations the understanding of the theory of structures and technology and therefore the representation of material is interwoven in a complex manner in the mind of the engineer. This inevitably raises the question whether contemporary computer sketching techniques have the same level of sophistication as a tool for expressing ideas. The data set on these projects was not sufficient to conclude on this manner.

As a general comment on the design process of these projects, it is noteworthy the wide range of problems encountered and by necessity the requirement for expedient techniques and approaches to solve problems quickly. This can be seen in the prevalence of intuition, simple methods of analysis and the direct reference to specific materials, through technological knowledge and precedent. This conclusion reflects the observations of Vicenti (1990) that most design decisions are a process of satisfaction rather than optimization, given their sheer number and complexity.

To conclude the authors wish to point out that this is a study of specific design teams in unique companies with a strong design culture. As such, the conclusions do not necessarily have general applicability for industry. However, it is anticipated that the conclusions are being used to inform a series of semi-structured interviews with a wider range of practitioners to place the issues in a wider context as a second stage of research.

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VARIATION IN CREATIVE BEHAVIOUR DURING THE LATER STAGES OF THE DESIGN PROCESS

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Abstract: This paper presents results from an experiment studying the creative behaviour of 14 engineering designers during a later stage engineering design activity; with the aim of identifying important considerations that must be made when supporting designers in later stage design situations. Data gathered demonstrates the variation in designer behaviour that occurs even when completing identical activities; and differing creative approaches that designers may follow within the later stages of the design process. By understanding the individual behaviour of designers, it will be possible to better inform the use of methods for creative support within the later stage engineering design process.

Keywords: *creativity, designer behaviour, embodiment, detail*

1. Introduction

The importance of research into creativity is well recognised within design research, with extensive studies performed in a wide variety of disciplines. However, with few exceptions, research to date has focused on creativity in a general sense or on the earlier stages of the process, thereby excluding study into the appearance and effect of creativity and creative behaviour during later stages. Benefits within later stages have recently been identified in the field of computing (Brown 2010), and some case studies of late stage problem solving using creativity methodology exist in the engineering domain (Frobisher, Dekoninck et al. 2006).

The increase in constraint present towards the later stages of the design process (McGinnis and Ullman 1990; Howard, Nair et al. 2011), and the processes described by well-established design models (such as Pahl and Beitz (1984) or Pugh (1990)), show that the later stage design process presents a unique situation within which the designer must work. It may therefore not be sufficient to supply designers working within the later stages with the same methods of creative support as those working within the earlier stages.

To begin to address this concern, this paper presents a study focused on developing an understanding of individual designer behaviour within the later stage engineering design process, particularly the variation that exists between designers when solving identical problems. This is completed through the use of a specific creative behaviour coding framework, presented in greater detail within past work (Snider, Dekoninck et al. 2011). Through this framework the study aims to identify the importance and influence of the completed project brief on designer behaviour and preliminary evidence of differing creative approaches that designers exhibit. From this information it will then be possible to develop the understanding and direction needed for methods of creative support, which will work with the designers' inherent behaviour in an appropriate and beneficial manner.

1.1 The Coding Scheme

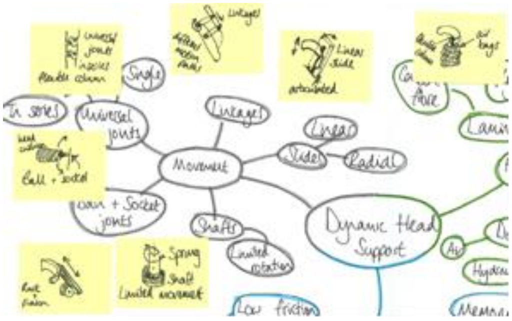
This work uses the coding scheme presented in detail in Snider *et al.* (2011), which is designed to identify creative design approaches followed by designers during the later stages of the design process.

This is achieved through study of the designers task activity throughout, specifically on the use of each task either to develop the information that they have about the design, the brief or the domain (called *information* tasks); or on the use of each task to develop the design itself as a physical product, e.g. the physical components, layouts and materials (called *application* tasks).

Each task is then defined according to its initial and final state based on information (I) and application (A), creating four possible options. Tasks in this work are defined as a transformation from either an information or application input state to a separate information or application output state, with the final classification referring to the final state of the task. For example, an information task is defined as any task that ends with an information state (see Figure 1). Designers may use the information they already have, and develop it into a broader or more developed version (I → I); they may apply the information that they have to create the design itself (I → A); they may take the current form of the design (application) and re-work it into a more developed version of itself (A → A); or they may take the current form of the design and analyse it to develop information (A → I).

In addition to these task categories, the coding scheme considers creative behaviour within each task according to whether it is completed in an *expansive* or *restrained* manner. Relating to the work of Guilford (1956), to be *expansive* refers to creativity in both divergence and convergence within the design process, through the pursuit of alternative products and technologies, or through the development and integration of new part combinations. To be restrained refers to a lack of creativity in either divergent or convergent processes. *Expansion* in a task then classifies it as *creative* within this work, while *restrained* tasks are classified as *routine*. The coding scheme identifies tasks as belonging to one of eight groups, as shown in Figure 1 according to their output entities. Throughout the work, the act of being creative in information tasks is referred to as being *astute*, and the act of being creative in application tasks is referred to as being *opportunistic*. A designer who is primarily creative in information tasks then follows an *astute approach*, while one who is primarily creative in application tasks follows an *opportunistic approach*. To provide option for further analysis, tasks are also classified according to whether their initial state is of the same type as their output state (called *single*), or of the opposite type (called *translational*).

	Information (I)		Application (A)	
	Single	Translational	Translational	Single
Routine	I → I	A → I	I → A	A → A
Creative	I → I	A → I	I → A	A → A



An *expansive* task performed by designer D, in which the *Function* (Dynamic Head Support) is transformed into a collection of sketches of several working principles (examples of suitable *Behaviour*). Hence the appropriate Entity Transformation and verb:

I → A: "*Expansive*"

Figure 1. The eight task types, and one example application task

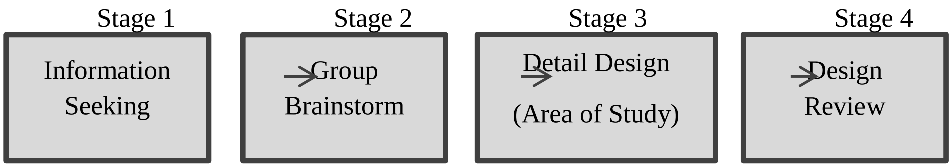
To provide illustrative example, Kevlar was originally designed as a replacement for steel within the wheels of racing cars, but has been applied to an array of applications due to its exceptional properties, ranging from body armor to loudspeaker cones. This is an example of an *astute* task, taking knowledge that already exists and applying it (with little modification) in a new context. In contrast, *opportunistic* tasks are creative through the way in which they use existing factors within the design context for new or alternative purposes, producing significant benefit. For example, through careful consideration of the configuration of components within a system it may be possible to arrange them in such a manner that some single parts are capable of completing multiple functions, or some parts are no longer needed what-so-ever. One such example could be the process of part-count reduction within design for assembly.

In addition to the coding scheme, it is necessary to categorise tasks as according to specific design stages, in order to ensure that only those typically occurring within the later design stages are included. Developing from the work of Howard (2009) and Gero (1990) this coding scheme defines design stages as according to their focus on design function, behaviour and structure. Design stages are identified according to the foci of the tasks themselves, rather than by chronology of the process (such as within Pahl and Beitz (1984)), in which later stage tasks refer to those occurring at a later point in time; or system hierarchy (Suh 1990; Ulrich and Eppinger 2012), in which later stage tasks refer to those on a lower system level. The coding scheme then includes all tasks with a focus on later stage activities regardless of when they occur, or the systems and components on which they are being completed. Within this work, later stage tasks are defined only as those concerned with producing the detailed behaviour and structure of the system, reflecting those tasks that would typically be considered as belonging to embodiment and detail stages of engineering design process models.

2. Methodology

The study was conducted on a total of 14 participants, of which two were professionals from industry with 4 and 10 years experience, two were final year undergraduate students with no direct industrial experience and 10 were final year undergraduate students with between 12 and 20 months of industrial engineering experience.

The study occurred according to Figure 2 over a period of four hours, not including supervised short breaks between stages (included to attempt to prevent fatigue and during which participants did not discuss the brief), designed to mimic a complete design process as described by Hales (1986). Breaks were not permitted between receiving the brief for a single stage and that stages completion. An extensive explanation of the methodology for this experiment is present in Cash *et al.* (2012). The brief throughout the process was to develop a remotely operated camera mount to be placed underneath a balloon for amateur aerial photography. In each stage of the experiment the designers were provided with identical sub-briefs designed to stimulate the appropriate design process activities. In each individual section, designers were working on identical sub-problems. The third stage of the study (on which analysis within this paper occurred) required the designers to "*Develop an appropriate, feasible, dimensioned, detailed solution*" from a single concept identified within the previous stage. In addition to this the designers were provided with goals that encouraged the completion of later stage tasks as opposed to early, such as "*include a description of the method of assembly*" and "*include methods of manufacture (for all components)*". Analysis only included tasks defined as occurring within embodiment and detail stages, any conceptual tasks that occurred were excluded. All analysis within the study considers only the designers as individual workers, as they were within the studied experimental stage. While the importance of the influence of working within teams in prior stages is recognised, such analysis is beyond the scope of this paper and will be considered in further work.



Duration	50 mins	50 mins	90 mins	50 mins
Teamwork	Individual	Group	Individual	Group

Figure 2. Structure of the Study

In addition to these stages each participant completed a detailed background questionnaire, a creative style test similar to the KAI test (Kirton Adaption-Innovation (Kirton 1976)), and the Torrance Tests of Creative Thinking (TTCT) Figural Form A (Torrance 2008) to determine personal creative level.

Within each individual stage designers were given identical specific instructions to stimulate tasks that match those that would occur in a realistic design setting. The third stage of the experiment, labelled "Detail Design" was specified such that it would require detailed design tasks typically found within the later stages of the engineering design process, defined according to Section 1.1 above. As only the third stage concerned later stage, individual design, it was the only stage included in the analysis presented in this paper. Further analysis regarding other stages of the experiment is ongoing.

Within each section of the study, data was collected through the use of webcams to capture the designer, Panopto software (www.panopto.com) to capture their use of computers, and LiveScribe (www.livescribe.com) notebooks and pens to capture their individual use of logbooks in detail, including an accurate measurement of time of occurrences. Through this comprehensive method of data collection it was possible to perform detailed analysis of designer behaviour over time.

Individual tasks were coded for each designer according to the scheme summarised in Section 1.1 by a single researcher, through careful analysis of markings within logbooks and computer use against time of occurrence. Coding of the work of each designer was completed in a single sitting to ensure continuity of coding standards. Only those tasks that were determined to be within the later stages were included in the analysis. Although no inter-coder reliability analysis was carried out in this case, the coding scheme has previously demonstrated a value for Krippendorff's alpha (Hayes and Krippendorff 2007) of $\alpha = 0.768$ on a similar data set (Snider, Dekoninck et al. 2011), a value that is suitable for exploratory work of this form (Blessing and Chakrabarti 2009).

3. Results and Discussion

In total, the 14 designers completed 130 tasks that were classified as later stage design tasks, with an average of 9 and range of 5 to 18 tasks per designer. All tasks within the third stage that were judged as conceptual were excluded from analysis; data within this work refers only to those tasks within the embodiment or detail stages, defined in this work as later stage.

3.1 The influence of the project brief on designer behaviour

Through comparison of the behaviour of the designers while completing the project it is possible to gain some understanding regarding the influence of the brief itself, and hence whether the larger influence on designer behaviour stems from the nature of the work that is being completed or from the individual approach of the designer themselves.

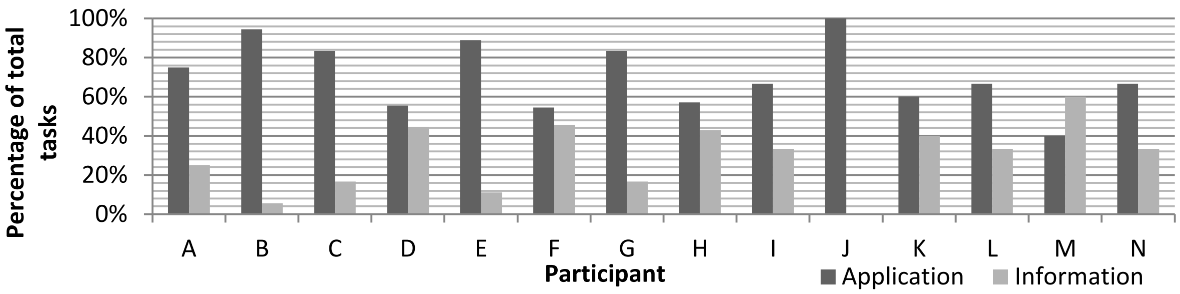


Figure 3. Proportions of information and application tasks

Despite being provided with identical briefs and instructions throughout the study, the behaviour of the designers within the third section varied greatly. While some (such as Designers D, F, H and M) completed a large proportion of information based tasks, others (particularly Designers B, C and J) almost entirely based their work in application. Therefore, while the former designers spent some time developing their knowledge of the task, other designs and alternatives within the domain; the latter designers developed ideas through manipulation of the design as it appeared following the group brainstorm session, with little additional input through information searching or development.

Particularly interesting is the variation in behaviour between designers. Previous work (Snider, Dekoninck et al. 2011) within a longitudinal study in which seven designers completed differing briefs highlighted a similar spread of difference in designer behaviour (Figure 4). That a difference in behaviour exists regardless of whether the designers complete different or similar briefs suggests that the primary influence is not the brief itself, but is rather the designer and their approach or style.

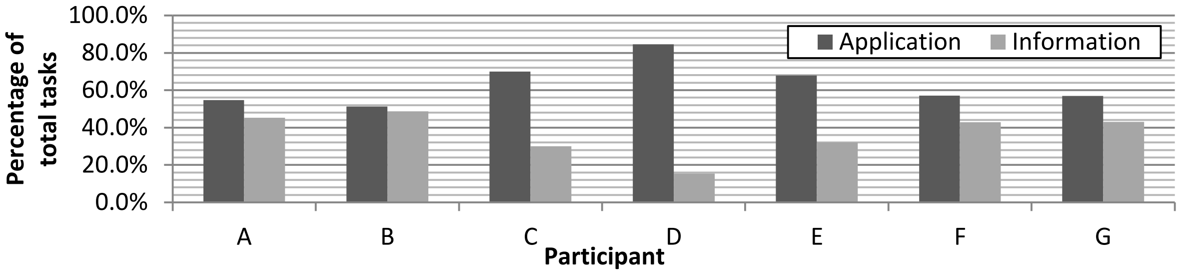


Figure 4. Information and application task proportions from past work by Snider *et al* (2011)

3.2 Variations in creative behaviour

There are some consistent trends present between designers relating to the type of tasks that they complete, and those in which they are creative, according to the data shown in Table 1. Statistical significance for findings was assessed using the Wilcoxon signed-rank test.

Designers tend to favour application output tasks ($p = 0.002$; designer average 75.4% application output tasks; Table 1, columns 1,2), and single tasks when working in later stages ($p = 0.0076$; designer average 63.8% of single output tasks; Table 1, columns 5,6). Then looking at the creative behaviour of designers within both single and translational tasks, there is a preference for a higher proportion of translational tasks to be performed creativily ($p = 0.0054$; average proportional translational expansion 34.3%; average proportional single expansion 15.1%; Table 1, columns 5,7).

Table 1. Percentage tasks within selected categories

	Information / Application split (proportional to total tasks)				**Single / Translational split (proportional to single/translational category)**			
Designer	**Application Output Tasks (%)**		**Information Output Tasks (%)**		**Single Output Tasks (%)**		**Translational Output Tasks (%)**	
	Single	Translational	Single	Translational	Expansive	Restrained	Expansive	Restrained
A	25.0	50.0	12.5	12.5	33.3	66.7	40.0	60.0
B	72.2	22.2	0.00	5.56	15.4	84.6	40.0	60.0
C	58.3	25.0	8.33	8.33	25.0	75.0	75.0	25.0
D	22.2	33.3	44.4	0.00	33.3	66.7	33.3	66.7
E	50.0	38.9	0.00	11.1	11.1	88.9	22.2	77.8
F	36.4	18.2	27.3	18.2	14.3	85.7	50.0	50.0
G	50.0	33.3	16.7	0.00	25.0	75.0	50.0	50.0
H	42.9	14.3	28.6	14.3	20.0	80.0	50.0	50.0
I	22.2	44.4	22.2	11.1	0.00	100	20.0	20.0
J	90.0	10.0	0.00	0.00	0.00	100	0.00	100
K	40.0	20.0	20.0	20.0	0.00	100	0.00	100
L	50.0	16.7	33.3	0.00	0.00	100	0.00	100
M	20.0	20.0	40.0	20.0	33.3	66.7	50.0	50.0
N	33.3	33.3	33.3	0.00	0.00	100	50.0	50.0
Mean	**43.8**	**27.1**	**20.5**	**8.60**	**15.1**	**84.9**	**34.3**	**65.7**
S.D.	**19.5**	**11.5**	**14.4**	**7.52**	**13.0**	**13.0**	**22.1**	**22.1**

That designers favour single tasks but are more creative within translational tasks suggests possible directions for creative support, and for the enhancement of creative behaviour within the later stages of the design process. Stimulating designers to perform tasks that switch between information and application rather than stay within one or the other may enable them to follow a more creative process due to the potential creative properties of translational tasks.

3.3 Differences in creative approach in later stage design tasks

While a strong similarity exists between designers in terms of the focus of their tasks and the appearance of creative behaviour in tasks that transfer from information to application or vice versa, differences appear when looking at creative behaviour against type of task output.

Although the majority of tasks within the later stages consistently focus on application output tasks across designers, the form of task in which they are expansive varies. While Designers A, B, D, E, I, M and N all performed a higher proportion of application output tasks expansively (proportional average 23.7% more application); Designers C, F, G and H all performed a higher proportion of information based tasks expansively (proportional average 30.4% more information; See Figure 5Figure).

This difference corroborates that found in past work (Snider, Dekoninck et al. 2011), and demonstrates both the varying ways in which designers may be creative, and that varying preferences for each exist. Furthermore, it agrees with the definitions for creative processes presented by other researchers (see Dym (1994)). The *astute* designer is one who is creative primarily through the information that they gather throughout the process, searching for alternative solutions, functions or features that could be incorporated into their design and then directly applying them to their work.

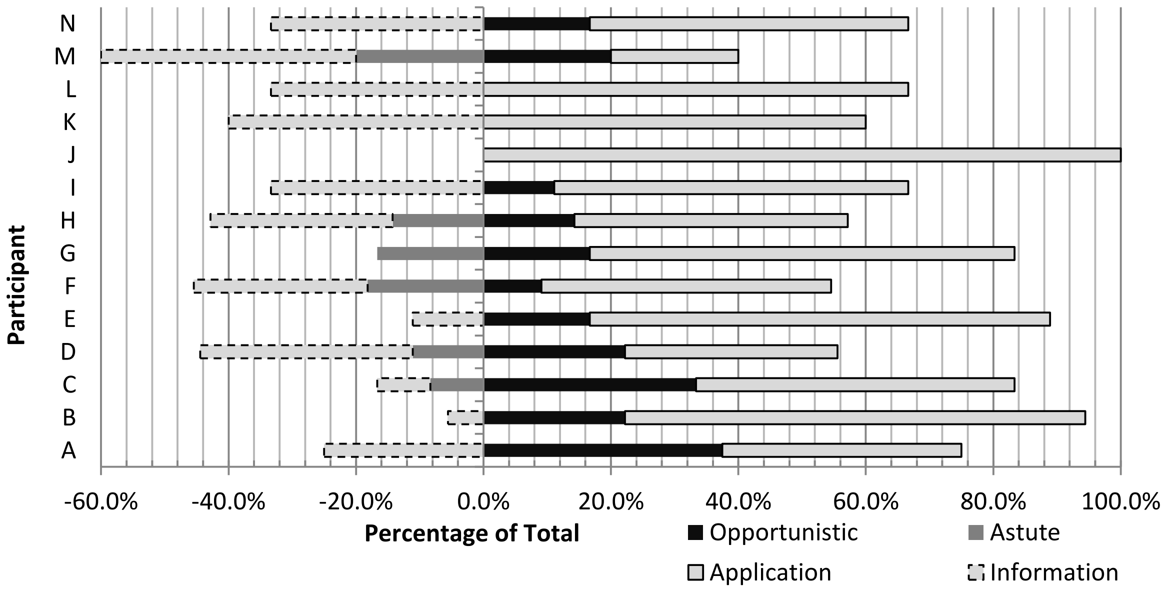


Figure 5. Proportions of information and application tasks, and expansion within each

3.4 Correlations between data and external creative tests

In addition to the main study, the designers also each completed a creative style test similar to the KAI test (Kirton 1976), and the TTCT test (Torrance 2008) to determine creative level. The results from each of these were then used to identify correlations between the collected data and these external, accepted measures of creativity, shown in Table 2.

Table 2. Correlations found within the data

1st Variable	2nd Variable	Correlation	Significance (p<…%)
Overall expansion	*Single* expansion	0.919	0.0166
Overall expansion	*Opportunistic* expansion	0.903	0.0486
Creative style test	Overall expansion	0.617	0.940
Creative style test	*Opportunistic* expansion	0.596	1.22
Translational expansion	TTCT Creative level test	0.427	6.39

That correlation exists between overall expansion within tasks and expansion within the *single* and *opportunistic* categories is not surprising; interest does however lie in the particular strength of these correlations. That designers who are expansive in single tasks (shown to be a less common trait; Table 1) are more expansive overall perhaps demonstrates an inherent creative ability; should you be more creative in tasks that are typically routine, you are more likely to be creative overall. Similarly, as *opportunistic* expansion is more common than *astute* (Figure 5) and therefore provides a larger contribution to overall expansion, this is perhaps an area of focus for the development of creative support. Should *opportunistic* expansion be more suitable within the later stages of the design process then tools should be tailored more towards its stimulation.

That significant correlation exists between the creative style test and overall expansion demonstrates a link between the results produced by the coding scheme and an external measure of creativity. Those that are more expansive are then similar to those identified as creative *innovators* within the test, a creativity style that is described as bearing a higher resemblance to typical views of higher creative level within the literature (Kirton 1976). The lack of significance between the data and the TTCT suggests that those who are more expansive are not necessarily those judged by the TTCT to have the highest creative level. Within this work the focus is not to capture those that produce the most creative results, but rather to identify creative behaviour within the later stages of the design process. The data does not then judge level of creativity, only those behaviours that increase the potential to achieve a creative result of some form. Correlation against creative level is not directly expected; that some designers may require a significant amount of creative behaviour to achieve a moderately creative result and some may require little creative behaviour for a highly creative result is a trait of the extent of their inherent creative ability, and not of their style within the process. Through future work this link can be studied in more detail; identifying the practices of those who have an inherently high creative level and whose work correlates with beneficial end results may highlight ways in which the creative design process can be made more efficient.

4. General Discussion

Of particular interest and implication for the support of designers within the later stage engineering design process is the knowledge that behaviour will vary independent of the brief; designers will follow their own creative approach, showing a preference for the types of task that they complete and for those in which they are expansive.

Considerations for creative support must then take this into account. While one tool may be particularly applicable for one designer in a specific situation, the frequently used assumption that a tool will be suitable for all designers in that situation or indeed for the same designer in any other situation cannot be made. While certain trends and preferences exist between designers, such as a predominance of application based tasks and translational expansion (Table 1), designer support must also take into account those aspects of designer behaviour that are not always shared. Tools or techniques could be proposed to enhance creative behaviour in a manner that is compatible with the designers' inherent style; thereby providing creative support which improves process efficiency or product value without the potentially stifling effect of encouraging designers to use tools that do not match the way in which they would naturally work.

One aspect that has not been studied in detail to date is the overall creative level or final value of the designs produced. As such, it is currently not possible to state the exact form that creative tools or techniques should take. For example, while more designers seem to follow an *opportunistic* approach (Figure 5Figure), it is not known whether this approach is preferable to an astute approach in terms of benefit. As such it is not logical to suggest the development of tools that encourage *opportunistic* behaviour; it is equally possible that those who are naturally *opportunistic* would benefit from enhancement of *astute* characteristics as it is that they would benefit from further support of their own natural style. Further work is then required on the benefits of these particular types of creative behaviour and of the effect on their manipulation.

5. Conclusions

The work presented in this paper has demonstrated the differences that exist between designers while working at the later stages of the engineering design process, particularly looking at behaviour that is deemed creative. While some designers primarily develop new ideas and alternatives through the use and discovery of new information concerning the design and brief; others primarily develop ideas through the way in which information is applied to the design itself, and how the form and arrangement of components can be manipulated. This behaviour exists irrespective of whether the designers are working on the same brief individually or on different briefs. Their behaviour is therefore likely a product of their own approach rather than of the design brief itself.

This study also reveals some directions for further research, which in turn will impact the development of creative support methods. It cannot be assumed that, given the present differences in behaviour, all forms of creative support will be appropriate and beneficial to all designers while they are working in the later stages. Similarly, it cannot be assumed that those tools which are commonly used and proven within early design stages are equally effective within the later stages. It is therefore important that both of these factors are taken into account when developing methods of creative support, which will lead to more beneficial end results.

6. Acknowledgements

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"CRITICAL MASS OF IDEAS": A MODEL OF INCUBATION IN BRAINSTORMING

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Abstract: This paper presents the results of experiments with a computational model of group brainstorming as an environment to study the role of incubation in creativity. In this model, exploration refers to the random search for solutions, exploitation refers to the guided search for new solutions based on existing solutions, and incubation is defined as the re-organization of the search processes used previously to find solutions but with no direct output of actual solutions. This work suggests that the beneficial effects of incubation in ideation could depend on the type of ideation processes carried out in previous stages of the creative process, and it provides insights for understanding the complex nature of incubation. We suggest the concept of "critical mass of ideas" as a plausible mechanism to explain incubation and argue for its inclusion in future studies of creativity.

Keywords: *incubation, brainstorming, multi-agent model*

1. Introduction

Generating and identifying novel ideas is hard. Facilitating ideation teams to generate and identify novel ideas is probably even harder. Key insights from research and practice provide some guiding principles to facilitate creative ideation in design. For instance, research on brainstorming has characterised the differences in ideational productivity of interactive (individuals collaborating in teams) and nominal groups (individuals working alone), suggesting that facilitation of creative teams has a large impact in the fluency of ideas (Isaksen & Gaulin 2005). Facilitation is acknowledged as a key strategy to overcome the well-known shortcomings of brainstorming interactive groups. Yet, there is a lack of systematic evidence and sound explanations of good facilitation practices. The creation of robust facilitation strategies for creative ideation in design is what motivates this work.

Laboratory studies of group brainstorming present considerable challenges such as the criteria to define the task or problem addressed by participants, the criteria to assess the quality of ideas, and subtle differences such as motivation and various societal dynamics that are difficult to account for.

This paper presents a computational model of group ideation that enables the examination of specific variables and their interaction over time in a multi-agent simulation that can be inspected in every detail and run iteratively under different initial conditions to understand the effects of incubation principles. The results of this computational social model cannot be generalised to situations of humans brainstorming, their value is instead as thinking tools to derive guiding principles for future research and practice. In this paper we focus on incubation principles in group brainstorming.

2. Incubation

The idea of 'incubation' in creativity research has been very influential. The term is usually credited to Poincare's anecdotal account of his mathematical discoveries as characterized by the 'four stage model' of Wallas (1926). This model suggests that the creative process iterates through a sequence that begins with an intense period of conscious work (preparation), followed by a period of leaving aside the task for a while (incubation), leading to a sudden flash of insight (illumination) complemented by intense and focused work on the resulting ideas (verification).

Incubation in the 'four stage model' suggests that the individual or team suspends the ideation process either by resting or engaging in other tasks, literally 'sitting on the ideas'. This has been hypothesized to protect the early ideas in the subconscious, possibly providing optimal conditions for understanding and connecting them with other ideas. Dreaming has been linked to creativity due to subconscious random associations between ideas. A recent study examined the role of REM sleep on the Remote Associates Test (RAT), a test where subjects build associations between words that are seemingly unrelated. That study compared conditions of REM sleep with quiet rest and non-REM sleep, concluding that REM sleep does enhance the integration of unassociated information (Caia et al., 2009).

Studying incubation during brainstorming is inherently difficult in laboratory studies. The main approach consists of introducing an unannounced break half-way in the session, during which participants are asked to engage in a different task like solving puzzles unrelated to the brainstorming problem, or to rest quietly (Smith, 1995; Sio & Ormerod, 2009). After this, participants resume brainstorming and their ideation productivity is compared to control groups of no-break condition. Participants in the break conditions have been found to generate more ideas than those in a no-break condition (Paulus et al., 2006). A recent literature review found a set of potential moderators reported, including the problem type, length of the preparation period (explicit and intense ideation), and the incubation task, leading to the possible existence of multiple types of incubation (Smith, 1995). Apparently, taking a break from work on a topic is differentially advantageous, and depends on the type of task undertaken during the break (Ellwood et al., 2009).

A study of expert and novice chess players found that incubation does not always facilitate creative problem solving, but only when the problem solvers' mind is fixated (Sio & Rudowicz, 2008). Similarly, manipulation of the inducement of fixation as well as the presence of breaks during the session confirms that incubation has the effect of increasing the number of ideas and the number of semantic categories of these ideas only when one has become initially fixated during a brainstorming session (Kohn & Smith, 2010). The observed positive effects of an incubation break include reducing the usual decline in quantity and variety in the latter stages of brainstorming (Kohn, 2009). In conclusion, incubation is a complex construct that may have a number of effects depending on given conditions. It has been generally defined as "a stage of creative problem solving in which a problem is temporarily put aside after a period of initial work on the problem" (Smith & Dodds 1999). Therefore one can expect incubation to have different effects depending on the preceding period in the ideation process.

Further research is necessary to understand why and how interruptions during a brainstorming session improve ideation. Interruptions may enable the reorganization of information or the relation between seemingly unassociated ideas, or they may serve to recover from cognitive fatigue, or they may allow people to assimilate more complex ideas and their implications, or de-emphasize and forget dominant or commonplace ideas. In teams they may additionally be helpful to redirect or balance group dynamics, or to regain focus and recover from idea drifting. Further research is also necessary to understand moderating factors such as the nature of the brainstorming problem, the timing of the interruption during an ideation session, the nature of the task performed during the break, and the state of convergence or fixation in the stage previous to the break. The facilitation of ideation groups would greatly benefit from a better characterization of incubation, its expected effects and its appropriate timing during a brainstorming session.

3. Hypotheses

In this paper we build a computational social model of group brainstorming to inspect the fundamental principles of incubation. A multi-agent system is constructed using a modelling framework of creativity and innovation where agents engage in three possible ideation strategies and interact over time producing or 'growing' outcomes of interest. Exploration refers here to the strategy of randomly searching for solutions, exploitation is the guided search for new solutions based on existing solutions, and incubation consists of agents re-organizing their search processes used previously to find solutions with no direct output of actual solutions. The exploration and exploitation mechanisms used here are inspired by the classic notions of divergent or 'horizontal' search to discover new knowledge and convergent or 'vertical' thinking to test the validity of the new knowledge (Nijstad & De Dreu, 2002; Lovell et al., 2012). During brainstorming sessions, one may assume that exploration enables the discovery of new categories or types of solutions, whilst exploitation allows for the generation of alternatives or new instances. The incubation mechanism used in this model is inspired by descriptions of the cognitive mechanisms described in the literature (Smith, 1995; Sio & Ormerod 2009; Paulus et al., 2006; Ellwood et al., 2009; Sio & Rudowicz, 2007). Beyond these modelling abstractions, we do not claim that the results from a computational social model can be generalised to human agents and teams working in real life conditions –a cautious disclaimer usually disregarded in laboratory studies.

The model can be considered open-ended since there is a range of valid solutions depending on the assessment criteria used. Creativity can be measured by the diversity of an agent or a team's solutions, or by applying other criteria that are relevant to the task. The term "ideational productivity" refers in the literature to the fluency of an ideation process usually by distinguishing the total number of ideas produced (gross fluency) from the set of unique and valid ideas (net fluency). Here ideational productivity refers to an aggregate measure of quantity and diversity of solutions without applying an explicit quality criterion. In this study we are working with shapes, so a solution generated by an agent is acknowledged if and only if the topological and geometrical features are not present in previous solutions. Details of the model are provided in the next section. Two hypotheses are explored here, the first hypothesis (H1) is that a combination of exploration and exploitation is likely to produce a significant increase in ideational productivity when compared to the output of exploration alone. The second hypothesis (H2) is that incorporating incubation will produce a significant increase in ideational productivity when compared to the output of exploration and exploitation combined.

4. Experiments

The model of group ideation presented here, called *shapeStorming*, is a model of brainstorming using shape emergence. It is defined using the channels of systemic interaction specified in the IAS framework of creativity: Ideas (I), Agent (A), Society (S) (Sosa et al., 2009). Agents (A) engage in a simple exploratory designing task of two-dimensional geometric composition with emergent shape properties that constitutes the agent-idea channel (Ai). The resulting geometric representations and their topological relations formulated as *design concepts* belong to the set of Ideas (I). Design concepts are shared by agents (Ia) and used as a basis to develop new design concepts (Aa) that are exploited or applied in the guided search of new designs (Ai') and social structures (S) determine the sharing of ideas between teammates (Si) (Sosa et al., 2009).

The random search of geometric compositions in *shapeStorming* is called the *exploration* mode, while the guided search of geometric compositions based on the transformation of available topological rules is called the *exploitation* mode. The construction of topological relations from geometric representations is called the *evaluation* mode. Evaluation is a sub-process of exploration and exploitation where new candidate ideas are inspected for emergent outcomes that support new topological rules. In *shapeStorming*, agents transition between modes in rates defined by the experimenter. The aim for agents in *shapeStorming* is to generate as many original solutions as possible, i.e., geometric and topological compositions that are novel in the system. Every time that exploit or explore modes generate a novel combination of emergent features, the agent in *shapeStorming* evaluates the design and generates a new design concept. Further details on these strategies are provided below. This paper reports on the effects of exploration, exploitation and incubation modes on the number and quality of solutions generated by this model.

4.1. Agents, ideas and teams

Following the IAS framework of creativity (Sosa et al., 2009), *shapeStorming* implements agent-idea interaction as a shape construction process starting from an initial set of *n*-number of two-dimensional shapes of *m*-sides that yields emergent polygons created by the intersection of lines and vertices. Six interaction processes across IAS levels are identified in (Sosa et al., 2009): agent-idea (Ai), idea-agent (Ia), agent-society (As), society-agent (Sa), idea-society (Is) and society-idea (Si). Three functions are aimed at, and are available by, targets within the same level in the IAS framework, namely agent-agent Aa, society-society Ss and idea-idea Ii (Sosa et al., 2009). In the version of *shapeStorming* discussed here, there are two variants of agent-idea (Ai) processes: *explore* and *exploit* modes. In *explore*, agent behaviour is implemented as the random location in a two-dimensional space of connected polylines from which closed geometries of *n*-sides are built. Intersections are sought between all lines of the geometries built. New polygons are created by the superposition of shapes which leads to the identification of new vertices or nodes in the intersections of line segments and thus generates emergent polygons. This shape arithmetic task in *shapeStorming* is illustrated in Figure 1; solutions are compared against each other by the number of emergent polygons and the number of sides of these polygons.

In *exploit* mode, agent behaviour in *shapeStorming* is guided by topological relations derived from previous solutions in an agent process of evaluation of emergent shapes. Evaluation characterizes the number of intersection points and their location inside, outside, in-line or in-vertex with respect to other shapes in the composition. A design concept in *shapeStorming* includes the topological relation of shapes and the number of emergent polygons with their respective number of sides. Such a simple design task adequately models a brainstorming problem: agents are assembled in teams and take turns to generate as many different solutions as possible from an initially defined number of polyline sets. Shape exploration in *shapeStorming* can be considered potentially creative inasmuch as emergent shape semantics "exists only implicitly in the relationships of shapes, and is never explicitly input and is not represented at input time" (Gross, 2001). Further details on the implementation of this model including pseudo-code of key functions is provided elsewhere (Sosa & Gero 2012).

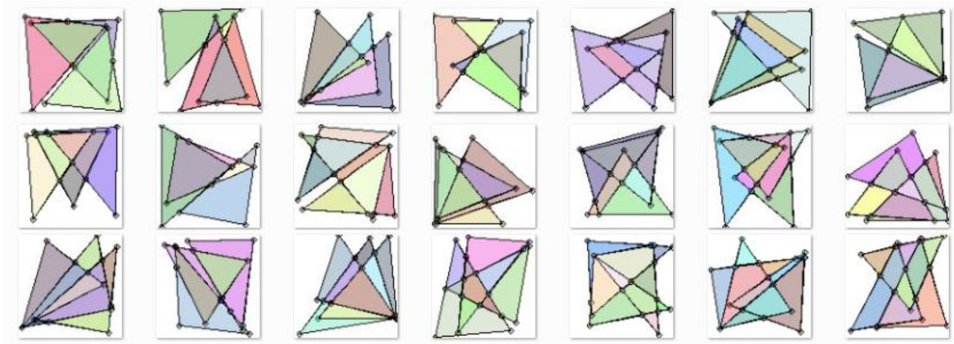


Figure 1: Shape emergence in *shapeStorming*, the output of a team of agents is assessed by the number of solutions and their quality (number of emergent shapes and sides)

In order to assess *shapeStorming* across a number of configurations, a range of results of running four conditions is presented in Table 1: in A, the system is run for 1,000 steps with 4 agents, 2 initial shapes of 3 sides; in condition B, the same setting is run for 10,000 steps; in condition C a third initial shape is introduced and in condition D the system is run for 100,000 steps. Ideational productivity is defined here by the number of design concepts generated by agents during a simulation. We further distinguish between concepts generated in exploration mode and exploitation mode.

Table 1. Total ideation in exploration mode in different configurations of *shapeStorming*

***shapeStorming* conditions**	**Ideational productivity**
A: 1,000 steps, 4 agents, 2 initial shapes, 3 sides	7.23
B: 10,000 steps, 4 agents, 2 initial shapes, 3 sides	9.38
C: 10,000 steps, 4 agents, 3 initial shapes, 3 sides	134.22
D: 100,000 steps, 4 agents, 2 initial shapes, 3 sides	15.35

4.1.1. Experimental settings

This paper shows results from two sets of experiments in *shapeStorming*, Experiment 1 aims to test hypothesis H1 by examining the effects of exploitation mode in ideational productivity at different stages of a brainstorming session in conditions A and B as defined in Table 1. Exploration length φ refers to the ratio of the introduction of exploitation steps to the total simulation steps and is examined here from 0.0 to 1.0 in 0.05 increments. This set of experiments seeks to reveal when is exploitation more likely to give increased ideational productivity and why.

Experiment 2 aims to test hypothesis H2 by examining the effects of varying incubation against different preparation stage lengths. Incubation rate μ stands for the ratio of the time when incubation is activated to the total simulation time and it is inspected here from 0.0 to 0.50 in variable increments in conditions A and B of *shapeStorming*. Experiment 2 seeks to explain the interplay between exploration behaviour and incubation in order to understand the effect of timing of the introduction of incubation in *shapeStorming*, as well as to grasp the fundamentals behind the timing of the incubation stage in *shapeStorming*.

5. Results

Results from Experiment 1 indicate the effects of introducing exploitation of design concepts in *shapeStorming* at a ratio of total simulated time, from exploration length $\varphi = 0$ to 1. When $\varphi = 0$ we artificially seed one base concept at initial time to enable exploitation. An increasing value of φ means that agent behaviour switches to exploitation at later stages of the simulation time, until $\varphi = 1$ when agents only perform exploration during the entire simulation. The effects of introducing exploitation in *shapeStorming* at different times are as follows: in condition A of Table 1, exploration-driven concepts continuously increase as a result of extending the length of exploration stage. Exploitation-driven concepts decrease as exploitation is delayed since the length of the exploitation stage is shortened. Overall ideational productivity in condition A increases as exploitation is delayed up to around 75% of the simulation time ($\varphi = 0.75$) when peak ideational productivity is reached. After this point, the gain of exploration-driven concepts is costly in relation to the sharp decrease of exploitation-driven concepts. Therefore, in conditions like A of short runs (1,000 steps) this advantage is relatively small (from 7.23 to 7.68 or +6% in these experiments).

The advantages of exploitation are more evident in larger simulations such as condition B of Table 1 (10,000 steps). Here, the advantage of exploitation increases considerably (from 9.38 to 18.1 or +93%). Similar to condition A, exploration-driven concepts increase as exploitation is delayed, but in contrast to condition A, exploitation-driven concepts show a significant increase as exploitation is delayed. This could be unexpected given the results of Experiment 1(A). This can be explained by introducing the concept of *critical mass of ideas*, which accounts for the gain in ideational productivity due to positive feedback effects between exploitation and a sufficiently large body of ideas from exploration. In terms of the ‘four-stage model’ of Wallas (1926), this can be interpreted as verification being more productive when coupled with sufficiently rich preparation and incubation stages.

Overall ideational productivity in condition B increases as exploitation is delayed up to around 75% of the simulation time ($\varphi = 0.75$) when peak ideational productivity is reached –a threshold similar to condition A. These results in Experiment 1 illustrate and provide a way to address the following well-known conundrum in facilitation of creative ideation sessions: building on existing categories of ideas is a productive approach until it takes valuable time that can be invested in seeking novel categories of ideas. That exploitation can have positive but differentiated effects on ideational productivity depending on the ability to build on a sufficiently large mass of ideas, provides a background to examine the effects of incubation in Experiment 2.

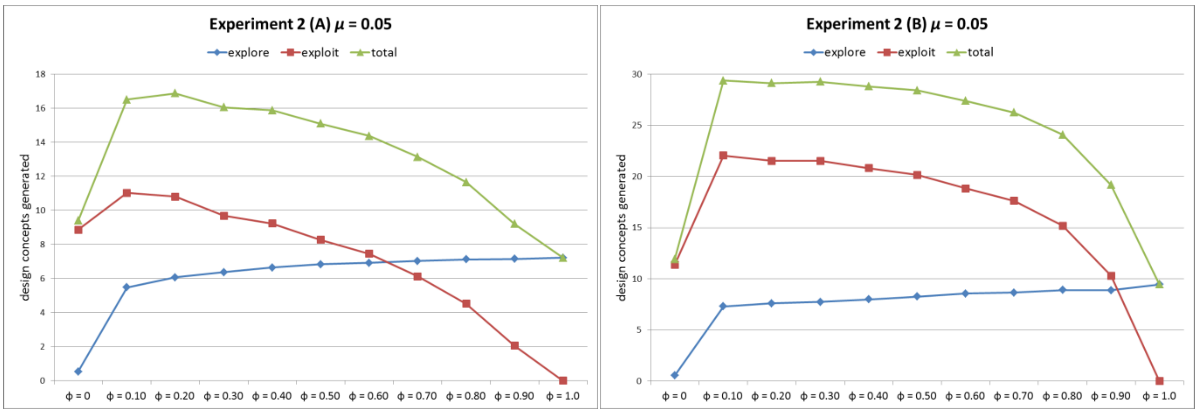
Experiment 2 inspects the timing between exploration, incubation and exploitation stages. Here, exploration length φ and incubation rate μ are varied. A sampling of μ from 0 to 0.50 are tested across all φ’s from 0 to 1 in 0.10 increments. The results, Table 2, indicate that by introducing incubation in condition A of Table 1, the gain in ideational productivity is significant.

Peak ideational productivity in condition A of Table 1 is achieved with a low incubation rate $\mu = 0.05$, that is, agents engaging in incubate mode only 5% of the total simulation time. The increase is a substantial 220%, from the 7.68 solutions generated in exploration-to-exploitation modes as shown in Experiment 1(A) to 16.88 when incubation is included in Experiment 2(A). By traversing the exploration length φ range from 0 to 1 in 0.1 increments, we find that the timing for incubation that produces peak ideational productivity in *shapeStorming* is when agents engage in exploration for a

20% of the total simulation time. Figure 2(a) shows the impact of incubation rate μ = 0.05 for the range of exploration lengths φ from 0 to 1.

Table 2 Peak ideational productivities of incubation rates μ across exploration lengths φ

incubation rate μ	exploration length φ	peak ideational productivity
μ = 0	φ = 0.75	7.68
μ = 0.01	φ = 0.20	15.35
μ = 0.02	φ = 0.20	16.17
μ = 0.03	φ = 0.20	16.42
μ = 0.04	φ = 0.20	16.53
μ = 0.05	φ = 0.20	16.88
μ = 0.10	φ = 0.20	16.5
μ = 0.30	φ = 0.10	15.5
μ = 0.50	φ = 0.10	14.07



(a) (b)

Figure 2. Experiment 2 with condition A and condition B, incubation rate μ = 0.05

This suggests that exploitation in *shapeStorming* is most productive when a combination of sufficient design concepts have been generated –both real concepts produced by exploration and possible concepts produced by incubation. After this threshold defined by 5% incubation plus 20% exploration in condition A of Table 1, it seems that agents waste their turns engaging in less productive incubation or exploration modes, when the larger gains come from focusing on exploitation. Experiment 2 reinforces the notion of *critical mass of ideas* discussed above, and the significant role of incubation in amplifying the value of exploitation, as well as in moving the inflection point from φ = 0.75 in Experiment 1(A) to φ = 0.20 in Experiment 2(A).

Experiment 2(B) replicates these findings when *shapeStorming* is run with condition B of Table 1 for a total of 10,000 simulation steps. With μ = 0.05, the exploration length φ range is varied from 0 to 1 in 0.1 increments. Compared to Experiment 1(B) where only exploration and exploitation modes are used and a mean 18.1 design solutions are generated, when incubation is incorporated in these long simulations, its impact is still considerable. Ideational productivity climbs around 160% reaching 29.38 mean solutions when $\mu = 0.05$ and $\varphi = 0.10$. Incubation even in exhaustive simulation runs have a positive effect in *shapeStorming*, Figure 2(b). This indicates that the effects of incubation may be dependent on the size of the problem space addressed in ideation; as a result, incubation is likely to have higher impacts when applied in shorter sessions in *shapeStorming*.

While incubation in *shapeStorming* doubles ideational productivity, it improves overall performance by two orders of magnitude, since it generates in only 1,000 steps (condition A of Table 1) similar results than those in 100,000 steps without incubation (condition D of Table 1).

6. Introspection

The work presented in this paper confirms via a computational model of group brainstorming the notion that incubation has a positive effect on ideation. It also suggests that the beneficial effects of incubation in ideation depend on a number of factors, and it provides insights for understanding the complex nature of incubation and its interaction with other creativity-related processes.

Our model shows that the combination of guided and random search may be only marginally better than purely random search in short runs, but its advantage increases as simulated time is extended. This points to a close interaction between exploratory and informed search processes over time. A process of 'building upon ideas' is more productive when it is activated after a sufficiently long initial period where a larger pool of initial ideas has been generated. According to our model, a significant increase can be obtained through exploitation even with a marginally larger pool of ideas previously generated by exploration. We refer to this as the "critical mass of ideas" (CMI), the principle that a sufficiently rich body or repository of initial ideas is a pre-condition for combinatory processes to generate a high number and variety of creative ideas.

A seemingly paradoxical outcome in creativity research is that the same number of individuals is likely to generate more and better ideas when working in isolation than when interacting in brainstorming sessions as a team (Isaksen & Gaulin, 2005). Although such results are consistent, no definite explanation has been offered until now, particularly since common sense suggests that interacting ideators have a higher potential to combine and build upon their ideas. The principle of "critical mass of ideas" (CMI) may provide a simple working mechanism for these results: in teams, group dynamics may prevent the formation of a sufficiently large body of initial ideas that others can build upon. In contrast, when working in isolation, individuals self-control the transition between exploratory and guided search. It is possible that teams may overcome this limitation by implementing adequate facilitation techniques that enable the formation of a critical mass of individual ideas that can be subsequently combined and improved by other teammates.

The second experiment presented in this paper demonstrates in a simple model of creative computational behaviour and a highly constrained domain representation, that even very low rates of incubation may carry a radical increase in the number of ideas generated in a brainstorming session. With very short incubation periods of only 5% of the total simulation length, when the incubation mode is activated around $1/5^{th}$ through the simulation, it produces the peak results in our model. This captures Edison's famous dictum that creativity consists of marginal levels of inspiration accompanied by an overwhelming majority of hard work ("Creativity is 1% inspiration and 99% perspiration"). Apparently, incubation represents a cost-effective way of manipulating ideas that were previously generated and they also serve as a pool of possible ideas that can be used later to generate novel ideas. When incubation is activated at the right time and for the right length of time, it seems to catalyse the combined search processes of exploration and exploitation by reaching the highest point of ideation significantly sooner than in equivalent runs without incubation. In other words, when incubation is activated, less randomness may be required in order to generate a sufficiently large pool of initial ideas upon which new solutions can be built. Incubation may thus serve as a type of ‘shortcut’, with the highest advantages seen in shorter time periods.

The notion that a small pool of ideas is unlikely to spark sufficient synergy to reach “the critical mass needed to overcome the overhead associated with (team) interaction” was proposed previously in a different context (Dennis & Valacich, 1993). Here it is suggested that CMI may be useful in understanding differences in ideational productivity between nominal and interacting groups (Isaksen & Gaulin, 2005), as well as the observed effect that “longer preparation periods give rise to larger incubation effects” (Sio & Ormerod, 2009). Our computational model suggests that CMI is a valuable theoretical construct worth analysing in future studies.

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Cognition II

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The Language of Abduction in Choosing Innovation
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Find Your Inspiration: Exploring Different Levels of Abstraction in Textual Stimuli
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COLLABORATIVE STIMULATION OF MEMORY RETRIEVAL IN CREATIVE DESIGN

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Abstract: Collaboration has often been attributed to encouraging creativity. This assumption is explored by investigating the influence of interactions between designers on creativity relevant cognitive processes. It is proposed that external design entities stimulate creativity relevant cognitive processes through collaborative stimulation. This paper specifically explores how the cognitive process of memory retrieval is stimulated through collaboration by memory stimulation. It is hypothesized that collaboration leads to more memory stimulation than working alone. A study using protocol analysis has been conducted to evaluate this claim.

Keywords: *collaborative creativity, creative cognition, memory*

1. Introduction

Collaboration has been often assumed to encourage creativity; a concept which can be seen in workplace practices and books. But there is often the unanswered question, "*How* does collaboration influence the creative process?" This work provides one perspective answering this question.

Collaborative creativity and creative cognition are the foundations this research is built on. One of the most well known areas in collaborative creativity is brainstorming. While brainstorming research has shown the method reduces the quantity and quality of creative ideas due to social inhibition and procedural issues (Diehl & Stroebe 1987; Mullen et al, 1991), it has also found that collaboration creates positive stimulating effects (Brown et al., 1998; Dugosh, et al., 2000). Non-brainstorming research refers to this stimulation as bridging (Sarmiento & Stahl 2008), or purposeful action to overcome an obstacle. Idea retention also improves by collaboration, through the effect of group remembering (Sarmiento & Stahl 2008).

How collaboration influences memory retrieval, beyond retention, is important as retrieving past memories has been identified as the fundamental element in new idea generation (Nijstad & Stroebe 2006). Concepts individuals are exposed to directly influence the ideas they remember, and collaboration increases exposure to a diverse set of concepts (Satzinger et al, 1999). In addition to diverse exposure, a collaborative group has a larger combined set of memories than an individual, meaning there is a more diverse set of memories from which to draw (West 2002).

The creative cognition approach was established by Finke, Ward and Smith (1996). Their Geneplore model divides creative cognitive process into generation and exploration, which occur in a cyclical manner, until pre-inventive structures become knowledge structures (complete concepts). Benami and Jin (2002) and Jin and Benami (2010) expanded the Geneplore model to engineering design by identifying applicable creative cognitive processes: memory retrieval, transformation, association (from generation) and problem analysis, solution analysis (from exploration).

However, a gap exists as work in creative cognition explores cognitive process of each designer (Finke et al., 1996; Jin & Benami, 2010), but does not explore the influence of collaborative interactions. On the other side, collaborative creativity examines team interactions, but treats individuals as "black boxes", not investigating individual cognitive processes (Pirola-Merlo & Mann 2004; West 2002; Sarmiento & Stahl 2008). Even Shalley and Perry-Smith (2008), who explore team creative cognition and how individual creative cognition is infused into it, treat individual creative cognition abstractly by not exploring individual cognitive processes. Similarly Stempfle and Badke-Schaub (2002), who take a cognitive approach to the engineering design process, break down thinking operations into categories but not individual cognitive processes. This work bridges the gap by proposing a model which extends creative cognition to collaborative creativity.

2. A model of collaborative stimulation in engineering design

The Collaborative Cognitive Stimulation (CCS) model is based on Jin and Benami's (2010) Generate-Stimulate-Produce (GSP) model of creativity in conceptual design. Their model consists of design entities, which stimulate cognitive processes (both generative and exploratory), which produce design operations, which generate new design entities (figure 1 left). The cycle continues until pre-inventive design entities (undeveloped concepts) mature to knowledge entities (the completed design).

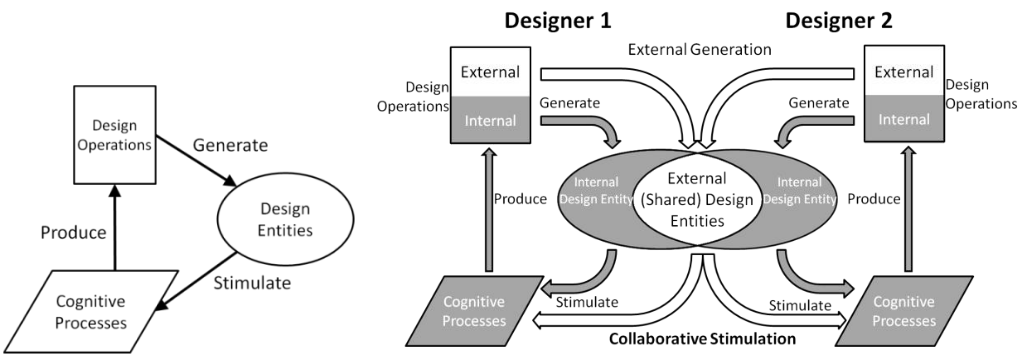

Figure 1. GSP Model (left); CCS Model (right)

The CCS model expands the GSP model to collaboration by proposing that interactions between designers occur through external design entities. It can be observed (figure 1 right) how each designer engages in the same individual processes, but ideas are shared through external design entities. The CCS model hypothesizes that external design entities stimulate cognitive processes through collaborative stimulation.

2.1 A closer look at collaborative stimulation

There are multiple types of collaborative stimulation, which can be divided into two categories: *staging* (which provides an initial set of conditions for cognitive processes to occur) and *promoting* (which encourages the individual to perform a cognitive process). Types of staging stimulation include *memory stimulation*: ideas developed stimulating memories in individuals (Nijstad & Stroebe 2006). This can occur collaboratively or individually. Also included is *seeding*: a design entity from a collaborator is infused into an individual's working memory. From this seeded idea, knowledge can be applied to new domains and new ideas generated (Nijstad & Stroebe 2006). Types of promoting stimulation consist of *accommodating*: an effort to incorporate a collaborator's ideas into their own as they are viewed as valuable or to come to a general agreement because of an argument (Jin et al. 2006). Another type of promoting stimulation is *clarifying*: an individual senses their collaborator does not understand an idea and the attempt to clarify their idea by explaining it in a different way, like using an analogy, which leads to further development of the idea. Analogies have often been used to explain concepts (Glynn & Takahashi 1998). Also included in promoting is *collaborative completion*: occasionally an individual is unable to complete a cognitive process set on their own therefore their collaborator fills this gap, by performing the cognitive process they are unable to complete. This has also been called bridging (Sarmiento & Stahl 2008).

Each type of collaborative stimulation is speculated to have a different influence on each cognitive process. The likelihood of each type of collaborative stimulation leading to the stimulation of cognitive processes is shown in figure 2. Only the stimulation of generative cognitive processes of memory retrieval (remembering an idea from the past), association (drawing relationships between two design entities), and transformation (alternating a design entity) (Jin & Benami 2010), have been explored thus far.

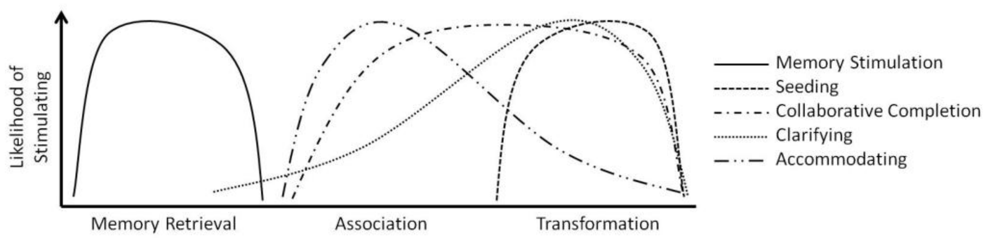

Figure 2. Illustration of relationships between collaborative stimulation and cognitive processes

This paper focuses on how collaboration influences the stimulation of memory retrieval. As can be seen from figure 2, collaboration is most likely to influence memory retrieval through memory stimulation. Therefore this type of collaborative stimulation will be investigated in detail.

3. Collaborative stimulation of memory retrieval

Memory retrieval occurs when a memory from the past (in long term memory) is brought into the present (working memory). Memory retrieval is important for creative idea production, as designers begin idea generation by remembering a past idea (Nijstad & Stroebe 2006). Memory retrieval can recall two kinds of memories: past memory retrieval and retention. Past memory retrieval consists of remembering ideas from the designers' past engineering or life experiences which have not yet been applied to the project. Retention consists of remembering ideas which were used earlier in the project, but then ignored or forgotten (Sarmiento & Stahl 2008).

Hypotheses

Two hypotheses regarding the stimulation of memory retrieval are proposed.

> H1: "External design entities generated by an individual's collaborators stimulate memory retrieval through the collaborative stimulation of memory stimulation"

> H2: "Design entities are more likely to stimulate memory retrieval in the collaborative setting than in the individual setting due to memory stimulation"

H1 proposes a process which occurs when a design entity from a collaborator stimulates a past memory retrieval or retention. A design entity consists of a form, function or behavior (or a mix of these three elements) (Benami & Jin 2002). In order to test H1, it will first be shown that collaborative memory stimulation exists, and secondly that memory stimulation from external design entities stimulates the cognitive process of memory retrieval. It should be noted that individual memory stimulation can also occur. Individual memory stimulation is different from collaborative memory stimulation, as it occurs when a memory retrieval is stimulated by the individuals own design entity, instead of a design entity from their collaborator.

H2 proposes that individuals collaborating are more likely to have design entities stimulate the memory retrieval process (either past memory retrieval or retention) than individuals working alone. It is believed that collaboration will stimulate past memory retrieval because there is increased exposure to diverse concepts (Satzinger et al. 1999) and a larger pool of memories between collaborators to be stimulated by design entities (West 2002). Retention of design solutions developed earlier in the project is believed to increase because of group remembering (Sarmiento & Stahl 2008). This is where the group provides a greater collective effort to retain ideas. Interestingly, in the individual setting, it has been observed that designers often do not retain their most innovative initial solutions and pursue less innovative ideas to completion (Jin & Benami 2010). H2 will be tested by comparing how often design entities stimulate memory retrieval in the individual and collaborative settings.

4. Experiment approach and results

4.1 Experiment design

In order to test the hypotheses, it was necessary to compare those who worked individually to those who worked collaboratively. An experiment was conducted on seven subjects, who were divided into the two groups, an experimental group that collaborated (two teams of two) and a control group that worked individually (three subjects).

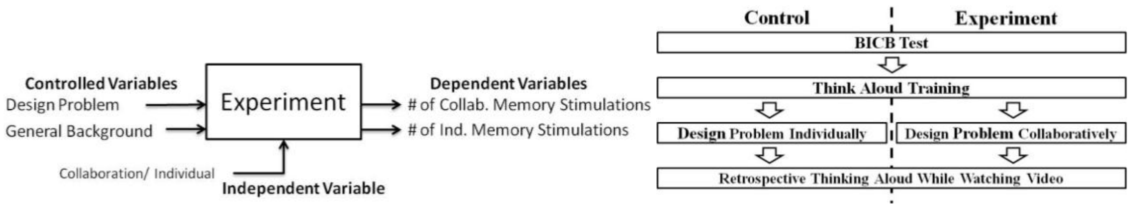

Figure 3. Experiment design (left) and experiment procedure (right)

The dependent variables of this study were the number of collaborative memory stimulation cases and the number of individual memory stimulation cases.

The independent variable in this experiment was whether the subjects were collaborating (the experimental group) or if they were working by themselves (the control group). The experimental group collaborated with each other in teams of two on the design problem, whereas the control group worked on the design problem alone.

The controlled variables in this experiment design were the design problem and general background of the subjects. The design problem given was to develop a system or device that would reduce traffic congestion (see full problem in appendix). The subjects had similar backgrounds being mechanical engineering majors with some exposure to design theory and methodology. Also, all lived in the greater Los Angeles area, so they were familiar with traffic congestion.

4.2 Procedure

The study of cognitive processes in design activity has been a common procedure in many studies. The general approach is to use protocol analysis, where subjects think aloud while they are designing, and then transcripts of their thoughts are analyzed (Cross et. al. 1997). To analyze collaborative activity, dialogue transcripts have been employed. Sometimes, actual protocol analysis is done, applying a coding scheme to the dialogue transcript (e.g. Stempfle & Badke-Schaub 2002) while other times the conversation is only analyzed for social interactions (e.g. Cross et al. 1997). However, these approaches do not identify specific cognitive processes occurring in the mind of the individual. There are two challenges to accomplishing this: (C1) How can a subject verbalize their thoughts and not influence their collaborator? (C2) How can cognitive processes be observed when individuals are required to talk with each other and thus cannot continuously verbalize their thoughts?

To address these challenges, a retrospective approach to protocol analysis was taken. The subjects were asked to retrospectively verbalize their thoughts from the design process while watching a video of their actions. Retrospective protocols have been found to produce similar results to concurrent protocols (Gero & Tang 2001). The video assisted in providing both verbal and visual cues, to help the individuals remember what they were thinking at that moment. Subjects were also provided with their sketches to assist their memory. As the verbalizations occurred after collaborating on the design problem, the subject's verbalizations did not impact their collaborator's thoughts (solving C1). Conducting the thinking aloud after collaborating on the design problem also allowed the subjects to collaborate in a natural environment, and allowed for continuous verbalization of their thoughts (solving C2).

Before coming to the study, participants were given the Biographical Inventory of Creative Behaviors (BICB), to determine their individual creative potential. This test was reviewed with other creativity tests by (Silvia et al. 2011), and found to be both quick and effective. The results of the BICB were used to create control and experimental groups with similar creative potential and to set up teams which had similar average BICB scores.

When first arriving at the study, participants were given training in verbalizing their thoughts. This training session consisted of working through several simple problems, while thinking aloud. Then participants in the experimental group were given a design problem with their partner, while individuals in the control groups were given a design problem to solve alone. Participants were provided with a pen, paper, and the design problem statement. Both the control and experimental groups were recorded on video as they worked through the problem.

Immediately after the completion of the design problem, the subjects were given the video and asked to retrospectively verbalize their thoughts while watching it. The retrospective verbalization of their thoughts was recorded for later transcription. While the control subjects could have done the more traditional concurrent think aloud technique while going through the design problem, in order to ensure similarity between the control and experimental groups, they performed retrospective thinking aloud as well. The entire procedure is shown in figure 3 (right).

4.3 Data analysis

The video and audio recordings were saved, and the audio recordings of the retrospective analysis were transcribed after being divided into 30 second segments. Dividing the transcripts into segments allowed the comparison of specific points in the retrospective audio to specific points in the video, which was particularly valuable in the collaborative setting. A protocol analysis approach was taken to analyze the transcripts. The typical approach to protocol analysis is to segment the entire episode (Gero & McNeill 1998). However, as the authors were interested in only the stimulation of the memory retrieval by design entities, a hybrid three step approach was taken to reduce analysis time: identifying design entities, cases of memory retrieval and cases of memory stimulation.

4.2.1 Identifying Design Entities

A design entity was identified as an idea having a form, function, and/or behavior (Benami & Jin 2002). Sometimes, design entities were accompanied by sketches, which assisted in identification. For example, consider the protocol below where a subject in the control group describes a design entity just created. “I was thinking, yeah, you can have, yeah, multiple layers of traffic. High speed, medium speed, and low speed.” In this protocol, the design entity could be identified as having the form of multiple layers (show in figure 4). It also had the behavior of a different speed for each layer and the implied function of reducing congestion.

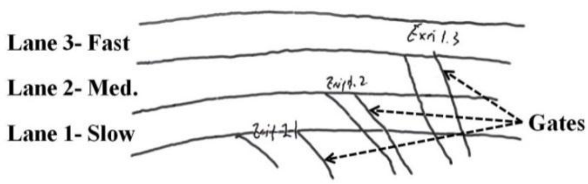

Figure 4: Sketch of Multiple Layers of Traffic

4.3.2 Identifying Cases of Memory Retrieval

A second sweep was done through the protocol to identify all the cases of memory retrieval, which consists of the two categories of past memory retrieval and retention of earlier memories. For example, two collaborators (J and M) were working on a design entity they called “Active GPS”. The active GPS would direct drivers to their destination and reduce traffic by assigning cars to different routes. M starts the by suggesting the concept again, after the idea had been conceived by J earlier.

> M: I’m down with GPS?
>
> J: Ok, we might as well use the GPS then. Except this wouldn’t be all that different from the current GPS, although it would have active management rather than just warning, warning people

M’s protocol for this conversation was as follows: “I decided to go with the GPS which kind of felt better. So here we... So once we chose the GPS, we kind of expanded the idea.” This is an example of memory retrieval, with the specific case of retention, as J and M are returning to the design entity active GPS. However, M also has a new case of past memory retrieval which follows the conversation. “So now I was just kind of thinking of having some incentives for people doing what you tell them to do. Because in my experience if you tell something to do something and they see a solution, and think that it is better, the overall good is something they don't keep in mind.” Here, when considering how the active GPS would work, M was drawing from his memory of situations where people would not do what is in the best interest of others seeking their own best interest.

4.3.3 Identifying Cases of Memory Stimulation

To find memory stimulation cases, the protocol was examined for design entities followed by memory retrieval. If the design entity inspired the memory retrieval, then the case was determined to be memory stimulation. Memory stimulation could occur collaboratively and individually. Collaborative memory stimulation occurred when the inspiring design entity was developed by a collaborator. Individual memory stimulation occurred when the inspiring design entity was created by the subject. Collaborative memory stimulation only occurred in the experimental condition.The “Active GPS” example just mentioned is a case of collaborative memory stimulation. The design entity of “Active GPS” stimulated M to have a memory retrieval of his past experience interacting with individuals; specifically that “the overall good is something they don’t keep in mind”. A case of individual memory stimulation occurred immediately after the first example of “multiple traffic layers”. The subject’s protocol follows: “So, at this time I was thinking some kind of gate traffic that could determine if the vehicle was exiting, or could make some sort of sound if the vehicle was exiting. Or if the vehicle was not exiting, then the gate won't open. There won't be any physical connections on this road. I realize it’s almost impossible, it’s like Battle Cruisers, it’s like airplanes get in get out at the same time. You have to have elevators to raise and lower” This example shows how the design entity of “gate” stimulated the memory retrieval of “Battle Cruiser”. This memory led to a solution analysis that “gates” would not work. This is a case of individual memory stimulation, as the design entity “gate” was created by the subject.

4.4 Results

In analyzing the data, it was found that memory retrieval was stimulated by the collaborative stimulant of memory stimulation as described. The experimental condition averaged 2.25 collaborative memory stimulations per designer (SD=1.71) and 2.50 individual memory stimulations per designer (SD=1.29). The difference between these two is not statistically significant; t (2) =0.33, p = 0.05. These results are shown in figure 5 (left).

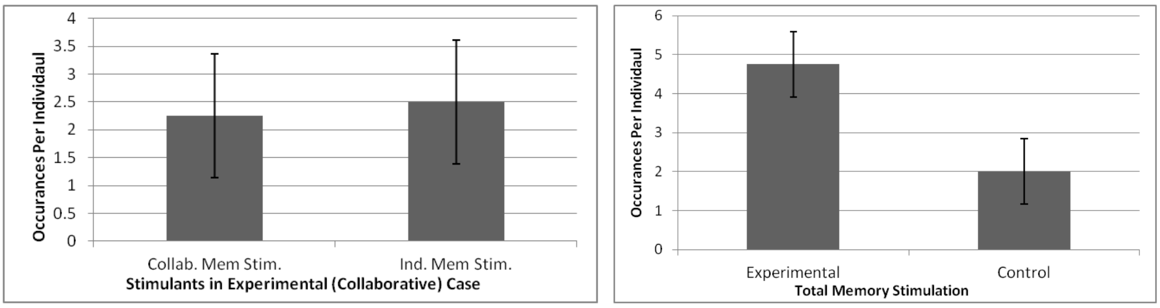

Figure 5: Experimental memory stimulation breakdown (left) and control vs. experimental (right)

In comparing the control group to the experimental group (figure 5 right) for memory stimulation occurrence, it was observed that the control group had 2.0 memory stimulations per person (SD=1.00), whereas the experimental group had 4.75 memory stimulations per person (SD=2.21). Using a t-test to compare the results the difference is statistically significant; t (5) = 2.2, p = .05.

Three other pieces of data collected were the BICB scores, the total number of considered solutions, and the time on the problem. Complete solutions were taken as being unique ideas (made up of one or multiple design entities), with form, function and behavior (Jin & Benami 2010) providing an answer to the design problem. The experimental group had an average BICB of 7.5 and generated 3 solutions per designer. The control group had an average BICB of 11.3, and generated 12.3 ideas per designer. Collaborative exercises lasted an average of 25 minutes (ranging from 21 to 30 minutes) where as individual exercises lasted an average of 35 minutes (ranging from 22 to 43 minutes).

5. Discussion and conclusion

From the results, it appears that both H1 and H2 are accurate. Through the analysis it was clear that design entities stimulated memory retrieval through memory stimulation, verifying H1. It was also found in the experimental case that individual and collaborative memory stimulation were about equally as likely to occur when collaborating. It was observed that design entities are more likely to stimulate memory retrieval through memory stimulation in the collaborative setting, than in the individual setting. When using a t-test to compare the number of memory stimulations occurring in the control and experimental cases, the difference was found to be statistically significant, verifying H2. This is interesting as the control group created more solutions, spent more time on the problem and had a higher average BICB score, which one would think would lead to more memory stimulation. These considerations emphasize the important influence of collaboration on memory stimulation. It should be noted because of the small number of data points (7 participants) these results should be taken with caution. The findings are important though, as memory retrieval provides the foundation on which designers build new ideas. By improving the opportunities for memory retrieval through collaborative stimulation, the potential of the designer's ability to generate creative ideas increases. In conclusion, while the data from this experiment trends that the hypotheses are correct, much work remains to be done. First, a second verification of the findings in this study should occur with more subjects (providing more data points) and multiple coders (to check inter-coder reliability). An experiment involving 17 subjects has already been conducted, and the authors are currently coding the results. Second, details on the additional collaborative stimulants need further development. Third, after the stimulation of generative creative cognitive processes has been defined, it should further be explored how collaboration stimulates the exploratory cognitive thought processes Jin and Benami (2010) identified. This will provide a more complete answer to the question posed at the beginning of this paper "*How does collaboration influence the creative process?*" This work is at the tip of a very exciting iceberg, discovering new depth about the collaborative creative process in design by taking a cognitive approach.

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THE LANGUAGE OF ABDUCTION IN CHOOSING INNOVATION

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Abstract: The selection of an innovation project to take forward for product development, is a complex, strategic, managerial decision which shares one key part with concept ideation and evaluation in design: assessing creativity. This problem is especially pronounced for products that do not yet exist or have never been mass-marketed. In this paper, we go beyond the question of how to select or identify the most creative project to consider the following: How can this decision be affected by forms of logical reasoning? Through a qualitative content analysis of committees selecting an innovation project to take forward, we show how forms of logical reasoning have an impact on the assessment of creativity and can alter the characterization of whether a project is creative or not.

Keywords: *decision-making, logical reasoning, innovation management*

1. Introduction

1.1. The problem of choosing innovation projects

Before an innovative product hits the market, decision-makers were trying to decide whether the project put before them has innovation potential and whether they should put the firm’s resources toward developing a product. This is the problem of selecting innovation projects. Decision-makers engaged in decision-making applications of this type are making choices about potentially attractive projects such that after the decision is taken, their firm would devote considerable resources. It should be noted, however, that analysis of such projects is often carried out with the sole intention of supporting senior leaders’ viewpoints rather than proving or disproving an investment hypothesis (Harreld, O’Reilly III, & Tushman, 2007; Sadler-Smith & Shefy, 2004). The problem for these decision-makers is to minimize Type-I errors (not approving good projects) while avoiding Type-II errors (approving bad projects) altogether. This type of decision shares an important aspect with the problem of selecting the most creative concept (e.g., from a design ideation stage), which is the problem of identifying what is creative, that is, what is novel and useful, to take forward for further development. Like the standard context for studies on assessing the creativity of new concepts, researchers in strategic business management aim for reliable ways to distinguish a good project from a bad project. However, the low reliability of metrics to forecast the innovation potential for any project and the desire for substantive proof of the returns on innovation in the form of profits or efficiency boosts can bias a decision-makers' choice towards more risk averse or incremental outcomes when selecting from several potentially innovative projects. Empirical evidence of decision making processes in industry points to just this conjecture; decision-makers tend to apply variables amenable to deductive analysis including product timing, staffing and platform when evaluating innovative projects (Krishnan & Ulrich, 2001). Innovation evaluation techniques likewise employ highly deductive analysis requiring a substantial amount of information aiming to prove or disprove premises established by precedence (Udell, 1989). Similar empirical metrics are applied in assessing creativity in design projects (Maher, 2010; Shah, Smith, & Vargas-Hernandez, 2003). This paper takes on the question of how assessments of creativity can be influenced by forms of logical reasoning. Previously, we have shown a statistically significant difference between groups choosing an innovation project between a deductive and inductive or an abductive reasoning frame (Mounarath, Dong, & Lovallo, 2011). Our experiments showed that introducing an abductive reasoning frame assists in overcoming decision biases leading to higher rates of acceptance of innovation projects with no significant increase in Type-II errors (Mounarath et al., 2011). In this paper, we delve further into this problem by examining the language of the discussion within the committee as they are making the decision and the efficacy of introducing an abductive reasoning frame on individual and group level decisions in selecting innovation. Based on prior results, we predict a higher likelihood of project acceptance for individuals who apply an abductive reasoning frame, but, in this paper, we base the data on the language of abduction in the deliberations.

1.2. Logical forms of reasoning

The three forms of reasoning considered in this study are deduction, induction, and abduction. Briefly stated, deduction is a form of logical reasoning from a premise and an observation leading to a conclusion that is guaranteed to be true. An induction is a general principle derived from the observations. An abduction is the most likely explanation for a set of observations. Examples of these three forms of logical reasoning in the context of selecting an innovation project can be seen in the table below:

Table 1. Three logical forms of reasoning considered in this study

1. **Deduction**	2. **Induction**	3. **Abduction**
• Inaccurate location-based apps are not needed • This is a location-based app with inaccurate position data • This app is not needed	• This is a location-based app • This app is useful • All location-based apps are useful	• This app is one of the most useful • Location-based apps are useful in everyday life • This app is a location-based app

While there is a broad and deep literature on the formal logic of these forms of reasoning, the literature is nearly silent on how these forms of reasoning might appear in natural language. To enable the identification of these forms of logical reasoning in natural language dialog, we postulate their forms of linguistic realization based on the formal logic principles underlying them. We start with the two most straightforward ones, deduction and induction. Because deductive reasoning leads to a definite conclusion, we believe that an appropriate linguistic realization for deduction is an explicit appraisal or judgment of the product (Dong, Kleinsmann, & Valkenburg, 2009). Because deductive logic is guaranteed to be true or false, the direction of the decision must likewise be clear, either accept or reject. Induction involves the establishment of a general principle based on the observations. We believe that induction would be realized linguistically by a process of semantic densification (Maton, 2011), such as by packaging up a series of concepts into a single nominal group or linguistic technicalization, the use of a common word with a specialized meaning specific to the context of discussion. For example, when designers use the word ‘requirements’, they technicalize the use of this word both in the context of design and in the context of the specific design problem, that is, what requirements are in design processes and the specific ones associated with their current design project.

The most complicated form of logical reasoning to identify in natural langauge is abduction, particularly since what counts as abduction in design is not entirely agreed upon. Abductive reasoning in design emphasizes the projection of a possibility rather than the explanation of observations through a plausible hypothesis. Dorst (2011) proposes that abduction in design consists of creating new frames for a new ‘something’ that addresses the design problem, a new ‘how’ or a new ‘working principle’ to account for the new ‘something’, or bringing in a new framing from the outside. It is important at this point to identify the similarities and differences between a design frame and a decision frame. Design frames provide ways of ‘seeing’ to establish the parameters of the design problem and its solution, or both, and set up a rationale for why courses of action were undertaken. Decision-making frames guide or limit the decision-making process by including or excluding information. The important difference between the two is that design frames impose an order on the current situation to explore possibilities, which results in new possibilities or ‘moves’ (Stumpf & McDonnell, 2002). This is the type of abductive design framing that Dorst refers to. Likewise, Roozenburg, citing Habermas, explains that such abduction in design is best described as innovative abduction as opposed to explanatory abduction, because innovative abduction entails a new, unexplained fact (e.g., the proposed project) for which a rule is produced to explain the fact (e.g., why the project proposed would exist) (Roozenburg, 1993). Roozenburg concluded that innovative abduction is the only appropriate form of abductive reasoning in design, because design entails determining the set of conditions for which the conceptualization of the product would be true. Adapting these theories about abduction to the empirical analysis of abduction in natural language, we define abduction as framing and projecting the conditions of possibility for the existence of the proposed product. We used this definition to produce criteria to code for abduction in the transcripts.

2. Methodology

2.1. Experiment design

An experimental and quantitative methodology was chosen as it provided the opportunity to create the right conditions to test the underlying theory and hypotheses of the research questions posited. We described the experiment design completely in another paper (Mounarath et al., 2011), and summarize the key parameters here. The experiment is a 2×2 factorial design with the factors (independent variables) being the reasoning frame (RF) as either deductive/inductive or abductive reasoning frame and the voting rule (VR) as either single vote to accept or a consensus vote to accept. Two founding directors were assigned at random at the beginning of each experimental session. The founding directors, unknowingly, were given the special role of indoctrinating the *abductive* or *deductive/inductive* reasoning frame by reading out an address to the board at the commencement of session. The abductive address emphasized "*a possible future in 2-3 year's time wherein further development of a project will lead to something new that becomes adopted and leads to a sustained change in behavior or behavioral patterns*." In contrast, the deductive address emphasized determining "*whether each project matches people's needs with what is technically feasible and what a viable business strategy can convert into market opportunity and customer value*." Twelve groups consisting of 5 participants per group reviewed 7 projects (with controls implemented to reduce grounding bias) to decide which project would be worthy of investment for further development. Individuals and groups could select none, some, or all of the projects for further development. The 7 projects consisted of submissions from students enrolled in a final-year capstone design studio in the Bachelor of Design Computing at the University of Sydney who elected to participate in this study. Projects chosen for the study, by the instructor of the course AD, have similar levels of technical feasibility, novelty, and potential customer value so that the determination of creativity and innovation, and therefore project selection, would not be obvious. The projects were:

1. A daily medication box that reminds patients to take medication by SMS
2. A mobile phone application that assists the visually impaired to navigate using Google Maps
3. A child's necklace that helps parents to track where their child is and with whom
4. A beer holder that monitors alcoholic consumption rate to avoid (or detect) inebriation
5. A mobile phone application to assist in tracking urban re-vegetation
6. A jacket with sewn-in electromechanical navigation aids using data provided by Google Maps
7. A device that activates appliances using gestures and wireless communication

Decisions can be affected by the manner in which choices are presented, which is known as the framing effect (Gilovich, Griffin, & Kahneman, 2002). We minimized this framing effect by having a standard template for the presentation of the projects using line drawings of similar quality and completeness as practicable. Groups were given exactly 5 minutes to discuss each project.

To obtain individual decisions on project acceptance, each individual was given assessment sheets, both before and after group deliberation. The assessment sheet consisted of five-level Likert scales and a sixth question for the accept/reject decision. The questions were as follows:

8. I think this project is novel
9. I think this project is creative
10. I think consumers will be accepting of this product
11. I think this project has market potential
12. I think this project is technically feasible
13. I think this project should be accepted

For questions 1 to 5, a score was allocated to each response: Strongly disagree = 1; Disagree = 2; Neutral = 3; Agree = 4; Strongly agree = 5, and a binary for question 6. The sum of responses 1-5 assigned to each project after committee deliberation provided the basis for the analysis predicting the influence of the reasoning frame and decision rule on the total score assigned to each project. Group-level decisions of accept/reject were identified with a show of hands at the end of deliberations. To motivate participants to make optimal decisions, we structured the reward such that they would receive a higher monetary reward if they selected the same projects experts had (which could have been none, some or all).

2.2. Coding development and scheme

We followed a three stage process to code the transcripts. Given that the research literature on the linguistic realization of logical reasoning in natural language is non-existent, in the first stage, we started with theoretically-grounded criteria, as described above, for ways in which deduction, induction, or abduction could be linguistically realized. RM and AD read several transcripts, highlighting portions of the text realizing a deductive, inductive, or abductive reasoning frame. In the second stage, they met to discuss the initial criteria and associated examples to determine if the coding scheme provided sufficient coverage of instances of forms of logical reasoning in natural language and clarity to reduce disagreement. Based upon this discussion, a final set of criteria was produced to code the transcripts. A spare transcript was coded and arbitrated with further clarification of the criteria until the inter-coder reliability (based on Krippendorf's alpha and Cohen's kappa) on this transcript was higher than 0.80, which is considered acceptable (Lombard, Snyder-Duch, & Bracken, 2002). The final coding scheme is shown in Table 2.

Table 2. Coding scheme for reasoning frame

Reasoning Frame	Criterion	Example
Deductive	Drawing a conclusion based on implicit or explicit premise but observation explicit	*Because GPS do exist today and we have seen this sort of stuff existing already, so it's not a completely new idea, I guess.*
Deductive	Stating the premise and/or observation for a deductive conclusion in relation to established decision criteria	*I think that iPhone apps are like everyone has an iPhone so you're already tapping into a huge potential clientele and then after that I mean lots of old people like 80 percent of old people go to nurseries and all that kind of stuff and like flowers and plants, so they're going to like it.*
Deductive	Personal judgment on the value of the project if decision maker accords the judgment sufficient priority in determining acceptance or rejection	*It's just another gadget though. I don't think that it's going to work. I don't think it's that big.*
Inductive	Generalization based on specific instance	*We're so lazy, that anything that saves us walking up to switch the light switch on and off is everyone's.*
Abductive	Reframing users/users' needs in a different way than as proposed in the project brief	*I think this would be good for sick people who are like alone. They don't have any friends or families and this helped them to remind them to take their medicine.*
Abductive	Framing conditions (causal precedents) for future (im)possibility of the project	*You're already looking at the necessity for a widespread use from the very beginning to make this work.*
Abductive	Framing or simulating alternative contexts of use	*But you can also use it for like busy people for terminal disease or something like that.*
Abductive	Reframing the product as a different kind of product from what is actually	*Let's say it's not a jacket anyway. I don't think the jacket matters right now. Because it does make a point*

Reasoning Frame	Criterion	Example
	proposed	*because you're not looking at a full map. You're looking at just lights blinking.*
Abductive	Modifying structural or behavioural aspects of the product	*Unless there's a lid on there's not even going to be vaguely effective. If there's a lid just that like seals.*
Decision	Accept, reject or unknown decision (abduction only) preceded by a form of logical reasoning	*But on the other hand I see … direct selling this to mothers who are really afraid, that sort of market. That's about the only thing I see and because it's cheap they could turn a profit from it. I don't think it's very good.*

RM and AD both coded all the transcripts for form of logical reasoning and decision direction according to the criteria described in Table 2. Because discussions were limited to 5 minutes, almost all of the content was relevant; there was very little idle banter. We were careful not to code discussions that were only about the analysis of a project without the committee member according sufficient priority to the analysis as the basis of an evaluation. For example, in discussing a device to help parents track their children, a committee member states, "*You don't just know where your college kid is. You know where someone else's kid is too. It gets a bit too-- I have some privacy issues with it.*" While there is a clear negative tone in the needs analysis (location of child), it is not clear how the analysis contributes to a conclusion based on logical reasoning, and thus it was not coded for a reasoning frame. In short, we were not simply coding product appraisals (Dong et al., 2009); rather, we were aiming to code instances of logical reasoning. The Krippendorf alpha (Hayes & Krippendorff, 2007) and Cohen's kappa coefficients across all the transcripts were calculated after both coders completed a transcript. When they were below the 0.80 threshold, the transcript was re-coded until an acceptable level was reached, which is a stricter methodology than generally required (Lombard et al., 2002). The final inter-coder reliability statistics are reported in Table 3 and Table 4 (Cohen's kappa only due to correspondence between α and κ in Table 3).

Table 3. Inter-coder reliability for reasoning frame

Group	1	2	3	4	5	6	7	8	9	10	11	12
α	.8244	.9001	.9747	.8295	.8196	.8487	.8410	.851	.8737	.9487	.8746	.8458
κ	.824	.9	.975	.829	.820	.849	.841	.8508	.874	.949	.874	.846

Table 4. Inter-coder reliability for decision direction

Group	1	2	3	4	5	6	7	8	9	10	11	12
κ	.824	.883	.924	.805	.836	.791	.842	.852	.812	.932	.875	.830

3. Results

The effect of taking a deductive or abductive frame is that a deductive reasoning frame leads to project rejection and an abductive reasoning frame is used to support project acceptance. This is exemplified by the following discussion between two committee members about the mobile phone application that assists in tracking urban re-vegetation. In the excerpt, we italicize portions of the dialog that realize deductive or abductive frames. In the deductive framing, there is a tendency toward rejecting the project, whereas the abductive reasoner tries to identify potential contexts of use and users. Further, this case is representative of many discussions wherein abductive reasoning is used to counter negative deductive reasoning or when the discussion is trending toward rejecting the project. Deductive: So wouldn't all sort of the success of this hinge on lots of users using it, like wanting to use it? So *there has to be a demand*. *If there's not,it's totally useless, because it relies on users going around and taking photos of plants*. And say you're in an area where it wasn't taking off,it wasn't popular, then the whole thing just failed, because why would you use it when there's one or two plants around the whole of Sydney? And *then you wouldn't have any sort of motivation to find*...Abductive: But then I think also you've got to take into consideration-- like *maybe around Sydney it's a bit different when you're in a city, but, I mean, if you take like an entire country*, for example, I think there are definitely more specific areas where there's obviously a lot more vegetation, plant life. I mean, yeah, it's not something that's definitely for everyone, but I just think there would be a lot of-- there are a lot of people who just try and-- *it could be everyday people who are just trying to find a certain plant*, and *people who are interested*. I don't know. I really like the technical side of this one, and I...In deductive framing, the committee members generally start from a premise, often unstated, describe one or more characteristics of the proposed project as satisfying the premise to draw a conclusion. Premise: Products with limited features are not suitable for the market. [Implied by decision criteria] Observation: *... more features than this, so this is very, very basic. Too basic.* Conclusion: *No, this will definitely need a lot more details.* In contrast, in abductive framing, the committee makes one or more observations about the proposed product, but rather than reaching a logical conclusion, the committee members attempt to explain through questioning, proposing, or hypothesizing the conditions of possibility for the existence of the product. In the following excerpt, a committee makes an observation about a problem with the pricing for a proposed product. To explain that this is not actually an issue, the committee member proposes a plausible scenario personal and context of use. Observation: *You need the gadgets though, the actual sense of. That might be a problem in terms of pricing.* Hypothesis: *Just aim for rich people. … I mean rich people like new things because they always want to show it off to their friends and stuff. [unintelligible] pour me a drink. Make me a sandwich. Pretty cool.* Perhaps the most important consequence of taking an abductive reasoning frame is that abduction can change a committee member's preference toward a project: In my self-evaluation I wasn't that keen on it but now that I think about it, *homeowners that you've got a garden will work out what kind of plant you'll put in there will be a great resource*. We performed statistical analyses to determine the effect of the reasoning frame and the voting rule on project acceptance. An OLS regression, Equation 1, was used to determine the effect of the following independent variables: (i) percentage of abduction per project; (ii) percentage of deduction per project; (iii) voting rule; and, (iv) reasoning frame, on the dependent variable, total score per project assigned by each committee member. The regression variables are: (i) LR = percent of form of logical reasoning; (ii) $p_1 - p_7$ are dummy (project) variables that take on the value of 0 when the project is not being observed and 1 when the project is being observed. Project 4 serves as the basis for these dummy variables since it has the lowest rate of acceptance. The coefficients for the rest of the variables are interpreted as whether or not there are significant differences from Project 4's acceptance rate; (iii) VR is the dummy variable for the voting rule with the permissive project acceptance rule (C=1) coded as 1, and the conservative project acceptance rule (C=5) coded as 0; and (iv) RF is the dummy variable for the reasoning frame, with the *abductive reasoning* frame coded as 1, and the *deductive/inductive reasoning* frame coded as 0. We combined these two reasoning frames due to the extremely limited cases (less than 5) of inductive reasoning in the data. The total recorded observations of abduction or deduction per project were aggregated between the coders, RM and AD, followed by a determination of the average occurrence of logical reasoning per project (LR).

$$\text{TOTAL SCORE} = con + \beta_1(LR) + \beta_2(p1) + \beta_3(p2) + \beta_4(p3) + \beta_5(p5) + \beta_6(p6) + \beta_7(p7) + \beta_8(VR) + \beta_9(RF) \quad (1)$$

Table 5. OLS regression with Total Score per project as the dependent variable

Independent Variable	% Logical Reasoning per project (LR)	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Voting Rule (VR)	Reasoning Frame (RF)	Constant (con)
OLS (LR = % Abduction per project)	2.081*** (0.568)	5.360*** (0.547)	3.558*** (0.568)	2.090*** (0.542)	Base Case	4.487*** (0.540)	1.157** (0.540)	4.120*** (0.542)	-0.678** (0.292)	0.839*** (0.289)	12.833*** (0.494)
OLS (LR = % Deduction per project)	-2.591*** (0.555)	5.44*** (0.542)	3.391*** (0.544)	2.128*** (0.536)	Base Case	4.363*** (0.536)	0.735 (0.541)	4.050*** (0.535)	-0.689** (0.289)	0.943*** (0.288)	15.148*** (0.528)
p-value	* $p<0.10$ ** $p<0.05$ *** $p<0.01$										

The results of the OLS regression (model significant at the $p<0.01$ level) confirm that the effect of all four independent variables are significant ($p<0.05$ *two-tailed*). The key results relevant to this study is that the coefficient of the percentage of abduction per project (LR) indicates that groups under abductive framing tend to put a total score 2.08 greater than those that are under the deductive framing. The coefficient of the percentage of deduction (LR) indicates that groups under deductive framing tend to put a total score 2.59 less than those that are under the abductive framing. What is significant about this result is that reasoning frames are an effective intervention confirming our prior findings (Mounarath et al., 2011), that is, an abductive reasoning frame tends to result in a higher level of project acceptance whereas a deductive reasoning frame tends to result in a higher level of project rejection. We similarly ran a probit analysis (Equation 2) with the same regression variables to determine the probability of project acceptance.

$$\Pr(\text{accept}) = \Phi[con + \beta_1(LR) + \beta_2(p1) + \beta_3(p2) + \beta_4(p3) + \beta_5(p5) + \beta_6(p6) + \beta_7(p7) + \beta_8(VR) + \beta_9(RF)] \quad (2)$$

Table 6. Probit regression with Individual accept/reject decisions as the dependent variable

Independent Variable	% Logical Reasoning per project (LR)	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Voting Rule (VR)	Reasoning Frame (RF)	Constant (con)
Probit (LR = % Abduction per project)	0.856*** (0.309)	6.137 (105.477)	5.637 (105.477)	4.563 (105.477)	Base Case	6.077 (105.477)	3.940 (105.477)	5.745 (105.477)	0.266* (0.153)	0.523*** (0 .152)	-6.408 (105.477)
Probit (LR = % Deduction per project)	-1.015*** (0.305)	6.244 (104.732)	5.631 (104.732)	4.641 (104.732)	Base Case	6.119 (104.732)	3.840 (104.732)	5.790 (104.732)	0.291* (0.152)	0.595*** (0.156)	-5.596 (104.732)
p-value	* $p<0.10$ ** $p<0.05$ *** $p<0.01$										

The results of the probit regression (model significant at the $p<0.01$ level) are consistent with that of the OLS regression and confirm our priors with the key results being that the percentage of abduction per project ($p<0.05$), percentage of deduction per project ($p<0.05$), voting rule ($p<0.10$) and reasoning frame ($p<0.05$) all have a significant effect on the likelihood of acceptance/rejection of projects by individual committee members. Due to lack of space, we do not present the full statistical analysis to show that percentage of logical reasoning per project (LR) was not statistically significant when analyzed at the group level. In other words, there is no causal relationship between the frequency of occurrence of abductive or deductive forms of logical reasoning and each committee's final accept/reject decision. The implication of this finding is that in a committee structure, having too few people who are abductive 'design thinkers' can result in a decrease of project acceptance. This may depress innovation if the committee ends up letting an opportunity for innovation pass by. In the "fuzzy front end of design" wherein groups of people are (still) trying to decide what is an innovative product or service under incomplete information, this research shows that cognitive strategies have a significant influence on decisions.

4. Conclusions

We described a qualitative content analysis of forms of logical reasoning in natural language. We applied a set of criteria for the analysis of forms of logical reasoning to experiments on committees selecting innovation projects, which entailed judging the creativity, novelty, market acceptance and technical feasibility of the projects. Consistent with our prior statistical analysis, we showed that abductive reasoning generally leads in or is used to support project acceptance, whereas deduction is associated with project rejection. Further, committee members applied abductive reasoning to counter negative deductive logic by other committee members. We do not prescribe abduction as the preferred mode of reasoning in choosing innovation; rather, we point out that the determination of the innovation of projects is altered by the form of logical reasoning. If firms wish to accept more innovation projects at early stages of development, they may do well to inculcate abductive forms of reasoning in the selection process so as not to 'kill off' potentially lucrative and innovative projects prematurely. Recognizing when forms of reasoning occur may also help committees to take opposing strategies so as to minimize Type-II errors (Gebert, Boerner, & Kearney, 2010).

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FIND YOUR INSPIRATION: EXPLORING DIFFERENT LEVELS OF ABSTRACTION IN TEXTUAL STIMULI

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Abstract: The selection of inspirational sources is a crucial step while designing, which potentially can enhance creativity. However, empirical investigations have demonstrated a dual-effect that some stimuli might have during idea generation. Therefore, it is valid to discuss whether designers are disregarding other stimuli, such as textual representations. To test the impact of different textual stimuli during ideation phases, we exposed novice designers to three types of written stimuli, with different abstraction levels. The results demonstrate that participants exposed to distant textual stimuli tended to generate a higher number of more flexible and original ideas. The most 'appropriate' stimuli seem to be the ones that enabled the establishment of enough association links with the problem, yet keeping a sufficient level of abstraction for the exploration of creative ideas. Looking into alternative stimuli, with different levels of granularity, can potentially raise designers' awareness about the usefulness of other valuable inspirational sources.

Keywords: *textual stimuli, abstraction levels, originality*

1. Introduction

Research has continually demonstrated that designers' creative performance during idea generation is influenced by formerly acquired knowledge (Liikkanen and Perttula, 2006). Purcell and Gero (1992) described two main sources from where designers retrieve pertinent knowledge for their tasks. The first is knowledge resulting from everyday encounters, in a more serendipitous manner. The second, knowledge that arises from intentional learning, therefore structured and specific domain oriented. Both types of knowledge can play an important role in the design process. Under this perspective, the inclusion of specific stimuli can potentially influence the way one retrieves, interprets and transforms information. Ultimately, the exposure of stimuli during idea generation has the potential to prompt access to different associations and the exploration of creative ideas.

Inspiration has been defined as "the process that takes place when somebody sees or hears something that causes them to have exciting new ideas or makes them want to create something, especially in art, music or literature" (Oxford Advanced Learner's Dictionary, 2000). This definition of inspiration can also be extended to design. In this case, a moment of inspiration during a complex problem-solving can bring a feeling of accomplishment and it can bring reassurance. However, finding the inspiration is not necessarily a straightforward procedure, as there is no certainty that an inspiration source will lead to a highly creative and successful outcome. To understand the nature of a problem, designers often search for similar solutions within the same domain, which helps them establishing a benchmark position of what has been done before and what could be improved. However, instead of being inspirational, these examples can result in restrictive frames of reference that will obstruct possible creative exploration. Therefore, external stimuli have both the potential to stimulate the generation of new ideas, as well as to anchor the reasoning process to existing solutions. Consequently, it is important to thoroughly investigate the influence of inspiration sources on idea generation.

In the search for new stimuli, designers prefer using visual representations (Gonçalves, Cardoso and Badke-Schaub, 2011). Conversely, textual stimuli, for instance, seem to generally be disregarded as a potential inspiration source. It is understandable that designers prefer to search for inspiration in visual stimuli. Designers are considered visualizers (Mednick, 1962), as they are generally highly competent in the use of images.

Whilst the extensive use of visual representations in design has been proven, it is still unclear whether equivalent textual counterparts could also prompt the generation of creative results. It is important to consider that any potential stimulus holds two important elements crucial to the creation of an appropriate stimulation: content - what the stimulus conveys; and representation - how the stimulus is shown (Sarkar and Chakrabarti, 2008). Consequently, it is important to investigate the possible impact of textual stimuli in design idea generation. The objective of our study was to understand the possible influence that textual stimuli, with different levels of abstraction, might place upon novice designers during an idea generation exercise.

1.1. The role of textual representations in design

Language plays important roles in our thinking process and, thus, it influences design (Mougenot and Watanabe, 2010). As source of inspiration, language can support the mental manipulation of abstract concepts and stimulate the creative process. Despite being a highly ordered system, language can offer enough ambiguity to stimulate the creative generation process and is potentially a valuable stimulus for design (e.g., Chiu and Shu, 2007 and 2012).

Nagai and Noguchi (2002) examined the role of keywords in the creative process, by using drawings to generate visual images for design solutions. According to their study, drawings are considered low-level information and abstract keywords (portraying feelings or intangible concepts) high-level information. In order to produce visual information from textual input, a higher level of abstraction may be required. This may contribute to the explanation of why so many designers prefer to work with visual stimuli instead of textual when generating ideas.

Goldschmidt and Sever (2010) have empirically shown the positive influence that text can have during idea generation when used as stimuli. They found that groups exposed to textual stimuli exhibited higher originality ratings, when compared with the control group. These results suggest that the use of textual stimuli can be potentially beneficial for inspiration in creative design idea generation.

1.2. The role of different levels of abstraction in design

Plucker and Beghetto (2004) argued that, for creativity to flourish, there must be a balance between domain general and domain specific knowledge. As they explained, people who tackle problems using domain-general approaches may be constraining themselves to superficiality, without even coming near of the gist of the problem. Conversely, those that usually approach problems in a domain-specific manner may be shutting down the access to fresh and different perspectives. Consequently, although specific design knowledge is a valuable and indispensable asset in design problem-solving, other domains can complement the development of creative ideas.

In an experimental study in the area of software intensive systems, Zahner et al. (2010) developed an experimental study where they came across similar conclusions. The authors examined the role of concrete and abstract stimuli in fixation, during the development of new ideas. Their results indicated that a certain level of abstraction can be helpful in a divergent phase (but generally not in a convergent phase). Abstract stimuli contributed to the production of novel ideas but decreased their usefulness and fit to the problem, which indicates that a latter re-evaluation of the ideas is needed.

Regarding the use of general and specific design domain knowledge within the realm of analogies, Christensen and Schunn (2007) demonstrated that the use of within-domain exemplars can constrain creativity. When using design-related stimuli, designers used more within-domain than between-domain analogies, which resulted in a smaller exploration of different alternatives. Conversely, the ambiguity offered by between-domain exemplars led to the expansion of more diverse solutions. Therefore, we set out to investigate the role of different levels of textual abstraction, potentially used as inspiration stimuli during an idea generation exercise.

2. Experimental set up

We performed a study with 68 novice designers, bachelor and master students from an industrial design-engineering course. The participants were asked to carry out an idea generation exercise. All participants received the following design brief:

"Your task is to think about how human transportation will be like in 2050. You are kindly asked to draw as many different ideas as you can in 45 minutes".

The design brief provided was intended to enable the generation of diverse ideas without being particularly attached to current examples of human transportation. Participants were asked to illustrate their solutions through sketches and text/keywords (for further clarification of their ideas) and to number each sketch in a chronological manner. To investigate the influence of textual stimuli we devised three written excerpts, which presented three levels of abstraction. The 68 participants were randomly allocated into the following conditions:

- Control (n=18): This group did not have access to any given stimuli beside the design brief.
- Textual related stimuli (n=19): This group (henceforth referred as 'related') received a textual stimulus: a description of the 'Straddling Bus', an example of a transportation concept for the near future (1-5 years), by Shenzhen Hashi Future Parking Equipment Co., Ltd.
- Textual distant (n=20): The textual distant group (i.e. 'distant') was presented with a textual stimulus, which contained an excerpt from the book The Wonderful Wizard of Oz by L. Frank Baum. In it, Dorothy, the main character, is lifted by a cyclone while inside her house. The concept of a cyclone was used due its distant relation with transportation, as it conveys the notion of movement.
- Textual unrelated stimuli (n=19): This group (i.e. 'unrelated') was given a textual description of a mirage. Although this choice was arbitrary, it has an intentional relation with the cyclone, as both of them are weather phenomena.

As we did not want to impose the stimuli, these were included along with the design brief in a ‘subtle’ manner: “You can choose whether you would consider (or not) this text when generating ideas”. The aim was to suggest they could read the text and use as they saw fit.

3. Data analysis

Two independent expert judges assessed the participants’ drawings, regarding: fluency of ideas, flexibility and originality. These are three of the four basic elements of divergent thinking, ‘elaboration’ being the fourth (Guilford, 1950). Fluency is defined as the quantity of ideas produced and was measured by counting the number of comprehensive ideas, portraying the purpose and functionality of a solution in sufficient detail. Sketches that did not offer clear indication of their functions and purpose were disregarded, even if these were enumerated by the participants as ideas.

Table 1. Categorization scheme of type of entities, transport modes and power for the generated ideas

Type of entity			Transport mode					Powered							
Single unit	Infra-structure	System	Terrestrial-above	Terrestrial-under	Aerial	Fluvial	Tele-transport	Human	Solar	Wind	Electrical	Fuel/gas	Nuclear	Mechanical	Animal

Flexibility is considered to be the capacity to switch between different domains of ideas and thus, being able to alter how a problem is approached. Prior to the analysis of idea flexibility, the sketches were clustered into four main categorical groups, each one divided into further sub-categories. There were 16 possible classifications (Table 1) and each idea could be allocated to more than one sub-category (e.g., a car would be a *single-vehicle*, *terrestrial-above*, and *powered by fuel/gas*). This categorization system enabled the analysis of flexibility in two ways:

14. Comparison of the frequencies of use of certain categories over others, between conditions.
15. Comparison of a general measurement of idea flexibility, adapted from an approach used by Jansson and Smith (1991): flexibility was computed by counting the number of completely diverse solutions to answer the design brief. A high number of different approaches by participant reflects higher flexibility exploring wide-ranging solutions for the same problem. Conversely, participants who explored a small set of categories received a low flexibility grade.

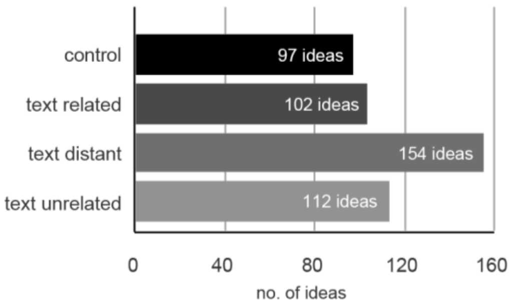
Originality, within Guilford’s construct (1950), refers to the capacity to develop novel and uncommon ideas. Originality is considered an important factor to define creativity, along with the usefulness and appropriateness of the idea (Amabile, 1996). Following the approach applied by Mednick (1962), an original idea was defined as an uncommon response to the design brief and was assessed by the statistical infrequency of each solution. Thus, originality is inversely correlated to the probability to be generated by the participants: one idea was considered less original if it was produced by a large number of participants, whilst another idea was more original if it was generated by a limited number of participants. From the total number of ideas generated across the four conditions (467 ideas in total), 82 completely original ideas were found, whilst the others were reoccurrences of these. After prior analysis, it was observed that the maximum number of reoccurrence of an idea was 30 times, which established the lowest level of originality. Consequently, the originality scale used in this study ranged from 1 occurrence (very original) to 30 occurrences (not original). Furthermore, as the participants generated more than one idea, an average of the reoccurrences of each idea was calculated, resulting in the final score.

4. Results

In the following section, the results obtained from the analysis of Fluency, Flexibility and Originality are presented. A One-way analysis of variance (ANOVA) was used to compute the results, as it was necessary to analyse four groups.

4.1. Fluency

The analysis revealed that there was no significant difference between the four conditions (F (3, 72) = 1.41, p = .248), despite the apparent numerical difference. The 'distant' group generated the highest amount of ideas (i.e. 154 ideas, Figure 1a). The lack of significance derives from the inconsistency of the number of ideas produced between individuals under the same experimental condition. In the 'distant' group, for instance, there were participants who were highly stimulated by the given text excerpt and created approximately 20 ideas, whilst other participants in the same condition generated a much more reduced number. The same inconsistency is patent in the other conditions.



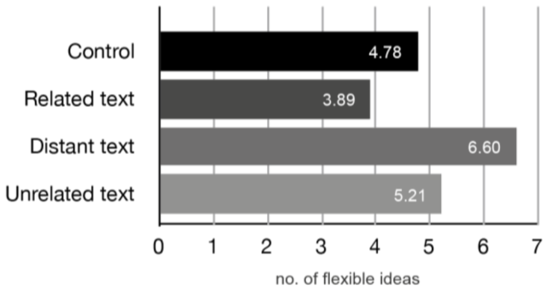
	Mean	SD	Total # ideas
Control (N=18)	5.39	2.57	97 ideas
Text related (N=19)	5.37	2.14	102 ideas
Text distant (N=20)	7.70	5.99	154 ideas
Text unrelated (N=19)	5.89	4.00	112 ideas

Figure 1. Fluency of ideas

4.2. Flexibility

As aforementioned, flexibility was assessed in two ways. Firstly, we analysed how differently the categories were explored by the groups, according to the categorization scheme explained on section 3 (table 1). Results showed significant differences in the use of four sub-categories: *Single vehicle* (type of entity) (F(3, 72) = 5.35, p < .005); *Aerial transportation* mode (F(3, 72) = 8.70, p < .001); *Wind-powered* (F(3, 72) = 5.76, p < .005); and *mechanical-power* (F(3, 72) = 6.04, p < .001).

Subsequent analysis revealed that, in the case of *single vehicle* categories, the 'related' condition developed significantly more ideas portraying an apparatus (instead of developing an *infrastructure* or *system*) than the 'control' (p < .01). In the same way, the 'distant' condition also had significantly more *single vehicle* ideas than the 'control' (p < .05). Regarding the generation of *aerial transportation* vehicles, the 'distant' condition (who received the passage about the cyclone in *The Wonderful Wizard of Oz*) developed significantly more airborne vehicles than the 'control' (p < .01), the 'related' (p < .01) and the 'unrelated' groups (p < .05). The 'distant' condition generated significantly more *wind-powered* vehicles than the 'control' (p < .05) and the 'related' conditions (p < .01). Finally, there were significant differences in the development of *mechanical-powered* ideas, in which the 'distant' group devised much more ideas within this category than the 'control' (p < .01) and the 'related' ones (p < .01). Furthermore, a second analysis was performed to assess which were the groups who performed better regarding the overall score of flexibility. The analysis revealed that there was a marginally significant difference between the different groups (F(3, 72) = 2.28, p = .087). Further analysis showed a medium-seized effect, η_p^2 = .087, which indicates that the ANOVA would be significant providing a larger sample. An examination to the overall flexibility means indicated that the 'distant' group performed better than any of the other conditions (x= 6.60), whilst the 'related' group received the lowest score in flexibility (x= 3.89) (Figure 2).

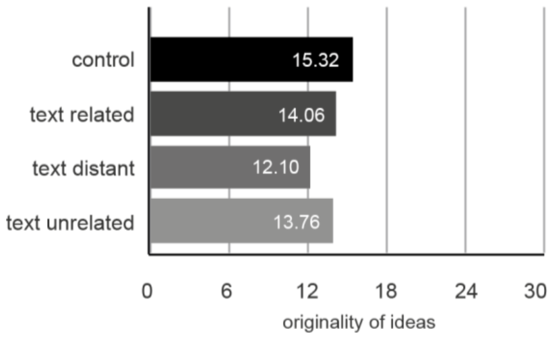


	Mean	SD
Control	4.78	2.34
Text related	3.89	2.23
Text distant	6.60	4.54
Text unrelated	5.21	3.41

Figure 2. Flexibility overall

4.3. Originality

Regarding originality, results revealed a marginally significant difference for the between-groups (F(3, 72) = 2.81, p = .098). Once again, despite the ANOVA itself only being marginally significant, it is likely that it would have turned out significant given a slightly larger sample, as indicated by the medium-sized effect, η_p^2 = .083 (Figure 3).



	Mean	SD	Rank
Control	15.32	3.73	4
Text related	14.06	4.30	3
Text distant	12.10	3.15	1
Text unrelated	13.76	4.41	2

Figure 3. Originality scoring: on the figure on the left ‘1’ represents a very original idea and ‘30’ not original at all.

The analysis of originality scores demonstrated that the ‘distant’ group (x= 12.10) had the best performance in the generation of unusual ideas (a higher mean value refers to lower originality, whilst a lower mean value indicates higher originality, Section 3). The high standard deviations and a meticulous analysis of the sketches generated suggested that even the participants with better original scores could not maintain a consistent level of originality across their entire process. In fact, participants from the ‘distant’ group produced recurrent ideas as the other groups, but they were also able to generate more unusual ideas.

5. Discussion

5.1. Fluency

Regarding the fluency of ideas, there was no statistical difference between the four conditions. However, numerically speaking, the ‘distant’ group generated more ideas than the other groups. The textual stimulus used in this condition (excerpt from the novel *The Wonderful Wizard of Oz*) may have played a role in such a high production of ideas. In fact, and accordingly the high standard deviation values, there was a large variation in terms of fluency. In all experimental conditions, whilst some participants generated a large quantity of ideas, others produced scarcely any. This may suggest that the given stimulus was not as inspiring for some as it was for others. As previously mentioned, designers are widely-known as preferring visual material and hence some of these participants may have not successfully recognized the text stimulus as a viable inspiration source.

As prior research has supported, high ideation fluency is related to the development of successful ideas, whose probability will be higher when many ideas have been created. Independently of how feasible the concept is, the generation of many solutions may provide the exploration of other approaches and promote more creative results. According to our results, the textual stimulus with a distant reference to the problem may have enhanced the fluency of the participants' ideas, when compared to exposure to a related or an unrelated stimulus, or no stimulus. Furthermore, as shown in Figure 1, it seems that there is an optimal stage regarding the use of less abstract and more abstract stimuli and the fluency performance. As we move from the very concrete/related example to a more abstract/distant one, fluency improves. However, when the abstraction of the stimulus reaches a level of (un)relation that is beyond a between-domain example (in reference to the problem at hand) fluency seems to decrease.

5.2. Flexibility

Only marginal significances were observed in regard to flexibility between the groups. Participants who received the 'related' stimulus produced significantly more ideas that entailed a *single vehicle* when compared to the 'control' group. The example of a single apparatus may have prompted the 'related' group to generate more ideas exploring this sub-category. On the other hand, the 'distant' condition also produced more *single vehicle* ideas than the 'control' group, although they did not receive a description of a public transport, but an excerpt about a cyclone. As a result, the 'distant' condition created a significantly higher number of ideas in the categories of *aerial transportation* and the use of *wind-power*, when compared with practically every other condition. Such high frequency on these categories can potentially be explained by the *recency-effect*, which is a principle that assumes that the last perceived elements/words of a text will be easier to recall or considered more important. Thus, the verb *carry* in the end of the 'distant' excerpt - "(…) and there it remained and was *carried* miles away as easily as you could *carry* a feather (…)" may have prompted the participants to apply the cyclone as a mean of transportation and to explore airborne or wind-related solutions. The *mechanical-powered* transportation was significantly more explored by the 'distant' condition than by the 'control' and 'related' groups (who did not create any idea devising that sub-category). This result is even more intriguing as this sub-category includes almost exclusively ideas related with catapults, where the transportation is made by 'throwing' people from one location to another. Although this sub-category is not directly related with aerial transportation *per se*, a relation with airborne solutions can be made and it is interesting that the narrative describing a cyclone enabled the exploration of so many diverse solutions.

Subsequently, regarding the general comparison of idea flexibility between the four groups (and taking into account the only marginally significant results), the 'distant' condition tended to be more flexible than the other groups. The 'distant' group seem to have developed more ideas that fell in different sets of categories, especially when compared to the 'related' condition, who had the lowest levels of flexibility. Once again, a pattern seems to emerge from figure 2: on the one end of the spectrum, the 'related' stimulus may have fixated the participants from that group to repeat certain within-domain types of ideas, impeding further exploration; on the other end, the 'unrelated' stimulus may have been too vague or irrelevant for the participants, not yielding enough links to establish possible associations between stimulus and problem. At the midpoint, the 'distant' stimulus seemed to have encouraged enough abstraction from the more obvious solutions, yet enabling sufficient cues to relate with the problem at hand.

5.3. Originality

In regards to originality, the 'distant' group seemed to have devised a higher number of unusual ideas when compared to the other conditions. This suggests that the exposure to the distant text excerpt resulted in higher originality. Our results are in agreement with Goldschmidt and Sever' findings (2010), which demonstrates the usefulness of text as a possible source of inspiration. Nevertheless, it is important to note that in this study, an original idea was considered to be a singular and atypical response, disregarding its feasibility or usefulness. A detailed observation of the devised sketches revealed that a number of the original ideas were, occasionally, also possibly inappropriate (although this was not thoroughly assessed). Therefore, analysing originality is not enough to assess how creative and valuable an idea is and further research on this should follow. Nevertheless, originality is an important factor in creativity and, once again, a pattern is visible from these results (Figure 3), although reversed (due the inversion scoring in originality, as explained in section 3). These results seem to indicate that between very concrete and very abstract stimuli lies an 'optimal' range of abstraction that makes a stimulus an appropriate trigger for the generation of original ideas.

6. Conclusions

Indubitably, visual representations are essential within the design realm. Its role is of high importance in order to communicate with others and to create rapid understandings (Malaga, 2000). Visual representations are the one preferred 'language' of designers, architects and artists. Nevertheless, research has demonstrated the dual-effect visual stimuli can provoke, both positive and negative (Cai, Do and Zimring, 2010). Hence, it is reasonable to reflect on the role that other possible sources of inspiration may play during idea generation and why designers overlook such potential stimuli. According to our results, and leastwise within the setup described here, written stimuli have the potential to enhance creativity in terms of fluency, flexibility and originality of ideas. It is, therefore, important to reflect on the role of diverse inspirational stimuli, and encourage novice designers to appropriately choose and use the myriad of possible stimuli available.

Concerning the role of abstraction in stimuli, we argue that inspiration can be provided both by domain-specific and domain-general stimuli. As Plucker and Beghetto (2004) explained, creativity is potentially both context-dependent and independent, with its combination being the most appropriate for the development of creative ideas. Designers, intuitively or by education, tend to firstly look for inspiration in the most immediate domain of the problem and only further on, expand their inspiration search to other areas. Searching for similar solutions to a design brief offers an overview of what has been done and what remains unexplored, and may be the first step to originate diverse ideas. However, a broader perspective of the problem and an appropriate choice of information brought from another domain can support creativity. Naturally, a too strong focus on domain specific knowledge can bring designers to a design fixation behaviour. Conversely, a too abstract and domain general information can impede designers from fully answering the problem (Plucker and Beghetto, 2004). Thus, there is an optimal situation, with a balance between domain specific and general, or between too related and abstract stimuli, as demonstrated in this experiment. The 'distant' group, who received a stimulus that combined concreteness and abstraction, tended to perform better in terms of ideation fluency, flexibility and originality, in relation to the other groups.

Hence, and congruent with previous research, this study suggests that as the content of the textual stimulus becomes more abstract, more diverse and potentially more creative ideas can be produced. However, as we increased the abstraction level, such type of stimulus can also become too unrelated to enable the participants to establish any link between stimulus and problem presented. Consequently, an unrelated example, with no links to the problem at hand, might not be inspirational.

Further research will continue to investigate the role of inspiration sources in design ideation, with the ultimate aim of supporting the appropriate selection and use of available inspirational stimuli material.

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A VISUAL REPRESENTATION TO CHARACTERIZE MOMENT TO MOMENT CONCEPT GENERATION IN DESIGN TEAMS

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Abstract: This paper aims to increase our understanding of concept generation through interpersonal interactions in a design team. Prior research has either looked into the inter-relations between concepts generated, or into identifying specific interpersonal response behaviors. There is a lack of explanation of how design concepts are generated moment-to-moment from the interpersonal interactions between designers. This paper presents the development of a visual notation called the Interaction Dynamics Notation for representing moment-to-moment concept generation through interpersonal interactions. This notation was developed through a video-observation study conducted with two teams each consisting of three engineering design graduate students engaged in a concept generation activity. Collective improvisation was used to bridge concept generation and interpersonal behaviors into a single point of view for developing the notation. The patterns of interaction revealed by the visual notation are described and the value of the notation as a representation system is discussed.

Keywords: *visual representation, interpersonal interaction, concept generation*

1. Introduction

Engineering design and development in practice is often conducted in teams. Researchers have noted this move towards team designing (Kleinsmann & Valkenburg, 2005; Valkenburg, 2000) as a way of dealing with the increasing complexity of products, and the demand for shorter product development cycles to stay competitive in the market. What do engineering design teams actually do over the period of the product development cycle to create new products? If we video record their work space over the duration of design activity and replay it, we would see team members moving around, interacting with each other and with a number of different objects and tools. Through these interactions, information and ideas circulate among the people on the team, concepts are generated, prototypes are created and tested, and products are specified. This paper presents a visual representation for analyzing how design concepts are generated moment-to-moment through interpersonal interactions in a team. We focus on concept generation because it is these concepts that hold the promise of what could potentially become innovative products. Developing innovative products through engineering design is key to a company's success because companies need to compete successfully in the changing marketplace.

2. Prior research

Most researchers aiming to study what engineering design teams actually do when they are generating concepts, have focused on the concepts themselves and their evolution through the engineering design process. For example, Cross (1997) described combination, mutation, analogy and first principles as mechanisms for evolution of concepts. Goldschmidt and Tatsa (2005) used linkography to analyze the linkages between concepts generated in a design studio and found that concepts with greater linkages have a greater influence on the final product. Van der Lugt (2003) found that concepts with greater number of associations to other concepts and which are formed by direct contribution of more participants are regarded as more creative. But again, what are the designers' behaviors that influence such concept generation patterns? A few researchers have looked into this topic. Hargadon and Bechky (2006) identified help seeking, help giving, reinforcing and reflective reframing behaviors in professional firms that influence the collective creation of concepts. Lempiala (2010) identified treating radical ideas as jokes, silencing ideas, demanding proof, and focusing on detail as obstructive practices in professional concept generation teams. Bergner (2006) identified framing, limit-setting and limit-handling as behaviors influencing concept generation performance in teams. These two strands of research - one focusing on concept generation patterns and the other focusing on designers' interpersonal behaviors in a team - have not been brought together. Our understanding of how design concepts emerge through the moment-to-moment interpersonal interactions of designers in a team remains incomplete. This paper presents a method to analyze both the development of concepts and the interpersonal interactions of designers together as they occur over the course of time in concept generation sessions.

3. Need for a visual representation

How does one capture and analyze moment-to-moment concept generation interactions? Research using a moment-to-moment analysis of how one moment leads into another with respect to idea generation activity, though less common than other approaches, does exist. For example, Matthews (2009) used conversation analysis to study how brainstorming rules affected the social order in concept generation teams. Conversation analysis (CA) is suitable as a method for a moment-to-moment analysis of changing social order in brainstorming groups because CA analyzes how conversation is organized in terms of one talk-in-turn leading to the next and so on (Schegloff, 2007). While CA provides an established way to analyze moment-to-moment progression of talk in design interaction, it suffers from the disadvantage of being text-based when it comes to capturing and representing concept generation in engineering design teams. Engineering analysts frequently use visual representations such as free body diagrams in mechanics, flow diagrams in fluid dynamics, and control volume diagrams in thermodynamics to analyze complex real world problems. Visualization, defined as a representation of information in a visual-spatial medium (Hegarty, 2004) confers many benefits over verbal representation of information. In an article aptly titled 'Why a diagram is sometimes worth ten thousand words', Larkin and Simon (1987) point out that diagrams, such as the free body diagram, provide the advantages of localization of information, minimal labeling of elements and perceptual enhancement as compared to verbal explanations. The advantage of a visual representation has not been applied in the past to capture and analyze moment-to-moment concept generation interactions in design teams. Linkography developed by Goldschmidt (1990) to assess productivity of design teams is one visual representation that has been applied to study how concepts are linked to one another over time (Van der Lugt, 2001). However, it does not address how these concepts emerge from designers' interpersonal interactions.

4. Developing a visual representation system

4.1. Collecting empirical data

The concept generation activity of two teams was observed in order to develop a visual representation of how concepts emerged through their interpersonal interactions. The study used two teams instead of one to provide a greater variety of concept generation interactions, but they were not selected to differ on any specific parameters. The study was conducted in a laboratory setting at the Center for Design Research at Stanford University because it afforded a shorter time to collect data and advance rapidly into analysis. It was also set-up for simultaneously capturing close-up videos of all participants. This enabled a detailed analysis of individual verbal and non-verbal behaviors. The participants were engineering graduate students recruited from a graduate course in team-based design that approximated industry design project conditions. The students had prior industry experience and were familiar with each other. Familiarity was considered necessary to approximate the interaction quality in a real design project. The teams were provided with Legos and were given a task to generate as many concepts as they can for a safe and entertaining toy. Legos was provided along with writing and sketching materials in order to prototype and share ideas. The duration of the task was about 40 minutes. The team design activity was recorded on video. Video is well suited to capture moment-to-moment real-time interactions between people. It provides a permanent record of the transient interactions that makes them amenable to repeated viewing and further analysis.

4.2. Analyzing concept generation interactions

4.2.1. Collective improvisation as a point of view

After gathering video data, a point of view was needed to serve as a focus of analysis. Collective improvisation was chosen as the point of view. Improvisation by definition puts an emphasis on moment-to-moment behaviors as it cannot be planned ahead of time. Moreover, improvisation has been associated with concept generation in design (Faste, 1992; Gerber, 2007, 2009). Also, the process principles from collective improvisation focus on interpersonal interaction behaviors that will enable a group of individuals to generate narratives together. Thus, collective improvisation serves to bridge concept generation and interpersonal behaviors into a single point of view.

4.2.2. Development of coding schemes to identify ideas, speaker turns and interaction segments

Coding schemes were developed to categorize verbal and non-verbal behaviors relevant to moment-to-moment concept generation. While a number of coding schemes were prototyped, the key coding schemes that were retained for further analysis were the coding schemes for identifying ideas, speaker turns and interaction segments. These coding schemes were iteratively refined through application to the video data by two independent coders. The identification of ideas and interaction segments is discussed in greater detail below.

Consecutive speaker turns that were related to one another by the virtue of one turn being a response to another, which in turn was a response to another speaker turn, were grouped together into segments called as interaction segments. Interaction segments were topically related chains of consecutive interpersonal responses. The coding of interaction segments highlighted the topical continuity element of interpersonal interaction. This topical continuity element was important to analyze how one idea expression connected semantically to future idea expressions that were related to the development of the same product concept.

Ideas were identified as expressions of possible alternatives. An idea could indicate a possible product configuration or a scenario, or even a possible process alternative. Coding of ideas involved identifying the notion of possibility in a speaker's expression. The dimension of possibility enables us to use cues of modal verbs – could, can, might, may (Halliday, 1970; Papafragou, 2006). The notion of possibility derives from Eris' work on question-asking in design activity (Eris, 2002) and the C-K (Concept-Knowledge) theory work of Hatchuel and Weil (2003; 2009). While ideas were coded from the perspective of individual expressions, concepts were coded as product solutions that were expressed through either a single idea expression or through an aggregate of idea expressions.

4.2.4. Trials of various representation systems

Once ideas, interaction segments and speaker turns were identified, the resulting data were visualized using different representation systems in order to test which representation system was suitable for identifying patterns of behavior that characterize moment-to-moment concept generation. The representation systems tested for visualizing data were cartesian graphs, state transition diagrams, concept Linkography, as well as a tabular text-based representation. Out of these, the state-transition diagram seemed promising, but it had the drawback of needing annotation to code interpersonal response types. After unsuccessful trials of existing representation systems, a new notation system, the Interaction Dynamics Notation was derived from Force Dynamics Notation (Brandt, 2004) and improvisational principles.

4.2.5. Development of a visual notation system based on force dynamics

The key principles that guide interpersonal responses when working in a improvisation group are saying 'yes and' to build on others' offers, not blocking other people's expressions, supporting your partners, not writing the script in your head, and maintaining an awareness of others' responses (Spolin, 1963). Thus, improvisational responding relies on not putting up barriers for others' ideas, and instead supporting their expressions and elaborating on their ideas. This notion of putting up barriers and overcoming barriers is well visualized in the Force Dynamics Notation from the field of Cognitive Semiotics. Force Dynamics Notation is used to visualize the meaning encapsulated in a narrative plot. We adapted the notation to visualize a concept generation conversation as a plot in which participants block each other, or say 'yes' to each other's ideas, or support each other's ideas. The following section describes the Interaction Dynamics Notation as it was called after adaptation. This notation system resulted from iterative refinement and application to the dataset of the two concept generation conversations recorded on video. Figure 1 below compares the Interaction Dynamics Notation with the different representation alternatives prototyped.

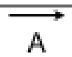
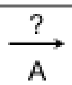
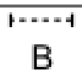
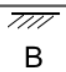
	Attributes				
	Captures sequence of events over time	Captures moment-to-moment occurrence of events	Captures links between ideas	Captures speaker turns	Captures types of interpersonal responses
Concept Linkography	Yes, units are visualized in the order in which they occur over time	No	Yes	No	No
Time series cartesian graphs	Yes, with time as the horizontal axis	No	No	Yes	Yes
State Transition Diagrams	Yes, units are visualized in the order in which they occur over time	Yes	Yes	Yes	Yes, but as annotations
Tabular text-based visualization	Yes, response types are written in the order in which they occur over time	Yes	No	No	Yes, but as annotations
Force Dynamics Notation	Yes in a narrative plot	Yes in a narrative plot	No	No	Yes in a narrative plot
Interaction Dynamics Notation	Yes, units are visualized in the order in which they occur over time	Yes	Yes	Yes	Yes

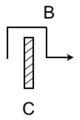
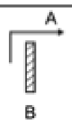
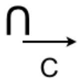
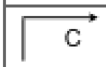
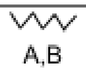
Figure 1. A comparison of different representation alternatives prototyped for visualizing the development of concepts through interpersonal interactions

5. Interaction dynamics notation

The Interaction Dynamics Notation is a visual representation of interpersonal responses in a concept generation interaction. It consists of 12 symbols. Table 1 lists the different symbols and the type of responses they represent.

Table 1. List of the symbols used in the Interaction Dynamics Notation. The alphabets below the symbols represent the different individuals participating in the design interaction

Symbol	Name	Description	Example
	Move	A 'move' indicates that a speaker has made an expression that moves the interaction forward in a given direction.	A: I need to buy Legos (at) home. Think about how therapeutic it would be.
	Question	A question indicates an expression that elicits a move. A question projects onto the next response and constrains the content of that response because the next response needs to answer the question.	A: Where should we start?
	Hesitation	Hesitation indicates an expression that is drawn out over time and is not completed. It denotes self-inhibition on part of the speaker.	B: Yeah or not erm (0.8s) there's something erm (1s) when we give (0.4s) yeah.
	Block	Block indicates an obstruction to the content of the previous move. For a block to be felt, the coder needs to feel that the response in someways obstructed the flow that was established by prior moves.	B: Maybe have something which looks like a computer but you can just type your name or do a simple math, a calculator in the shape of a computer kind of. C: Er, but I don't know, I mean, considering the age segment we are targeting 3 to 7 years.
	Support for move	Support-for-move indicates that the speaker understands and/or agrees with	C: Safe and entertaining (bending forward to write).

Symbol	Name	Description	Example
		the previous move.	B: Safe and entertaining, yes.
	Support for block	Support indicates an acceptance of a block by another person.	A: But that's also, I think that's already done. C: Yeah, its already there. B: Ok.
	Overcoming	Overcoming a block indicates that though a block was placed in front of a move, a speaker was able to overcome the block and persist on course of the original move.	C: Er, but I don't know, I mean, considering the age segment we are targeting 3 to 7 years. B: So 7 years they go to school, they would learn A,B,C right?
	Deflection	When a speaker blocks a previous speaker's move, that speaker or another can deflect the block with a move that presents an alternative direction for the interaction.	B: So when you say we need to divide the age-group, but you cannot have like 3, 4, 5. A: No, no of course not, but I mean you might have a few different (concepts).
	Interruption	An interruption is indicative of a speaker being interrupted by another speaker or at times by himself.	B: Should we start generating some concepts now? A: Yeah (interrupted by X) X: 10 min are gone.
	Yes and	A move is considered to be a 'Yes and' to the previous move if it accepts the content of the previous move and adds on to it.	A: What about... if we made a toy that incorporates girls and boys. Its like a house that has a car with it kind of like enables the guys to play with the girls? C: I think that's a good point to have some sort of a educational point in it.
	Deviation	Deviation indicates a move that changes the direction of the conversation from the one implied by the previous moves.	C: But we need to remember it. C: This is not the buildable room (deviating from previous topic)
	Humor	Humor indicates instances of shared laughter in teams.	A: I don't know I probably would have swallowed but (All of them laugh)

In Interaction Dynamics Notation, observable speaker expressions (verbal and non-verbal) are interpreted and assigned symbols to create a descriptive visual model of the interaction. The assignment of symbols is conducted based not on what the expression is from the point of view of the person making it, but on what the expression is taken to be and responded to by others in the team. So what we are modeling is not a series of speaker expressions but rather a series of speaker responses. Thus, the Interaction Dynamics Notation is a visual model of an unfolding interaction. The idea expressions that were identified earlier through the coding scheme are then colored in red in the visual representation. This facilitated the modelling of both the ideas and the types of interpersonal responses in a single representation.

6. Interaction patterns indicated by the visual representation

Figure 2 gives a snapshot of the Interaction Dynamics Notation applied to a section of the conversation of Team 1 from the study.

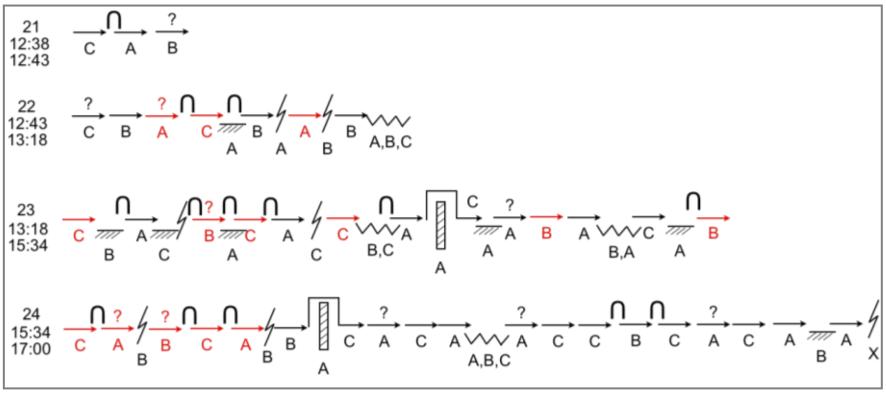


Figure 2. A snapshot of interactions occurring from 12.38 min to 17.00 min into the idea generation session of Team 1. The red responses are idea expressions. The numbers 21 to 24 indicate the interaction segments with start and end timestamps given under them. The letters A, B, C and X under the symbols indicate individuals who are giving those responses

The Interaction Dynamics Notation revealed the following patterns of interpersonal interaction.

1. Concept generation interactions propagated through transitions between ideas and facts - In concept generation interactions, not all expressions were idea expressions. Since idea expressions are expressions of possibility, the responses in black that were not coded as ideas can be called as facts or expressions of certainty. These expressions consisted of personal stories told by individuals, statements of general facts, or statements of future certainty. Thus design interactions in the two teams propagated through transitions between idea and facts.

2. There existed moments of sustained idea expression - There were moments when ideas occurred in a sequence. At the start of interaction segment 24 (Figure 2), A, B and C participated in an idea sequence where consecutive responses were ideas. This was identified as a moment of sustained idea expression. In the two teams whose conversations were studied, such moments of sustained idea expression started with a move, a question or a 'yes and' response. 'Yes and' responses, questions and interruptions were observed to occur within idea expression sequences. The improvisational response 'yes and' indicated building on others' responses. However, the representation revealed that this 'building on' not only led into an idea sequence, but also out of it. This occurred when participants shared a personal story or reinforced the idea with a general fact that itself was not an idea expression. Moreover, sustaining an idea sequence involved much more than a 'yes and' response. Questions, support and humor occurred along with 'yes and' in idea sequences. Interruptions occurred as well. Individuals cut each other's conversation turns, probably in an excitement to share their ideas. Of all the ideas expressed in concept generation interactions, 70 % in Team 1 and 63 % in Team 2 occurred in sequences. But this study does not indicate whether idea sequences lead to concepts that are more influential in the design process. While the representation helps in identifying moments of sustained idea expression, further research needs to be conducted to understand their role in the design of innovative products.

3. There existed moments of sustained disagreement - The representation revealed sequences of blocking in concept generation interactions indicating moments of sustained disagreement (Figure 3).

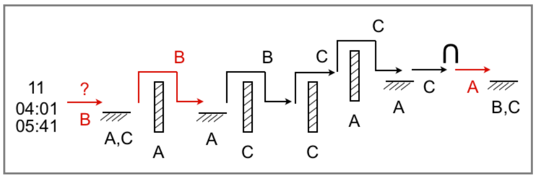


Figure 3. A sequence of blocking responses occurring in interaction segment 11 in Team 2

Blocking presents an obstruction to the preceding expression. It can be likened to limit response identified by Bergner (2006). While Bergner identified limit responses and counted them, this representation goes further to actually visualize how participants deal with blocks and resolve them in their interaction. Most blocks occurred as single expressions that were followed by overcoming or deflection response. However, at times a sequence of blocks as shown in Figure 3 was identified. Here B expressed an idea that was blocked by A. Though B tried to overcome it, he was met with persistent blocks from C, who in turn was blocked by A. In the end, A supported C's overcoming response. When the disagreement was resolved, idea expressions emerged through the interaction.

4. Blocking was not always detrimental to concept generation - Sometimes, ideas were expressed in response to a block such as in the example presented in Figure 4.

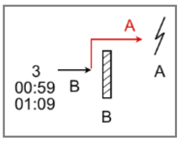


Figure 4. An idea expressed as a response to a block in Team 2

This indicated that blocks did not necessarily inhibit ideas. Methods such as brainstorming encourage individuals to withhold judgment and thus discourage blocking. However, the representation revealed that in concept generation conversations blocks did occur, they were resolved by the team, and at times they led to further idea expressions. It was observed that most blocks whether single or in sequences were resolved by the participation of the person whose response was blocked. The person either gave an overcoming or deflection response, or supported such a response given by another team member.

7. Conclusion

The Interaction Dynamics Notation when applied to the two teams in this study revealed certain patterns of interpersonal interaction such as moments of sustained idea expressions, the occurrence of improvisational 'yes and' responses within idea sequences as well as with transitions between ideas and facts, moments of sustained disagreement, and the use of ideas to negotiate blocks. However, it suffered from two limitations. The notation imposed a linearity of representation on conversations which were at times not linear with overlapping speaker turns. Also, it was limited to the relationship between consecutive responses. There were times, when a team member responded to a move, a question or an idea expressed earlier in the interaction. This relationship could not be captured as it was not between consecutive responses. Despite these limitations, the notation was effective in differentiating interpersonal interaction patterns accompanying idea expressions during moment-to-moment concept generation activity.

It is possible for researchers to not use a visual notation and go directly from video into a verbal representation of patterns through the use of appropriate coding schemes. However, by the use of an intermediate visual representation, the moment-to-moment temporality of concept generation interactions is maintained. Moreover, the Interaction Dynamics Notation uses visual symbols that represent interpersonal responses using familiar metaphors, for example blocking is represented by a wall, overcoming is represented by going over the wall, support is represented by the ground symbol used in engineering free body diagrams, and 'yes and' is represented by the using of the 'AND' symbol from logic. This makes the notation easy for humans to read and contributes to its effectiveness as a visual record of concept generation interactions.

The value of the Interaction Dynamics Notation then lies in its ability to model ideas expressed through moment-to-moment interpersonal interactions in a lucid visual manner. It contributes to design research by providing a representation system that enables a combined analysis of concept generation and interpersonal behaviors in design teams.

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Evaluation

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AMABILE'S CONSENSUAL ASSESSMENT TECHNIQUE: WHY HAS IT NOT BEEN USED MORE IN DESIGN CREATIVITY RESEARCH?

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Abstract: Amabile's Consensual Assessment Technique (CAT) has been described as the "gold standard" of creativity assessment; been extensively used within creativity research, and is seen as the most popular method of assessing creative outputs. Its discussion within scholarly research has continued to grow year by year. However, since 1996, a systematic review of the CAT has not been undertaken, and, within design journals, appears not to have occurred, in relation to design, or more broadly, the creative industries in general. Yet, the consensus of domain judges is a prevalent methodology for design education, and professional design awards. This paper presents the findings from a systematic literature review of the CAT covering works from 1982 to 2011. It details key journals and authors publishing or citing CAT related studies, and highlights the limited number of CAT studies within design journals, with suggestions for why this may be the case.

Keywords: *consensual assessment technique, creativity, design research*

1. Introduction

For the past thirty years Amabile's (1982) Consensual Assessment Technique (CAT) has been used as a reliable and valid measure of creativity. It has been described as the "gold standard" of creativity assessment (Baer & McKool, 2009); been extensively used within creativity research, and is seen as the most popular method of assessing creative outputs (Kaufman, Plucker & Baer, 2008). Its discussion within scholarly research has continued to grow year by year. However, since 1996, a systematic review of the CAT has not been undertaken, and, within design journals, appears not to have occurred, in relation to design, or more broadly, the creative industries in general. This paper presents the findings from a systematic literature review of the CAT covering works from 1982 to 2011.

1.1. Background to the CAT

By emphasising the subjective element in creativity assessment, Amabile's CAT is at the opposite end of the assessment spectrum to other approaches to creativity assessment, most notably the Torrance

Test for Creative Thinking (TTCT). Yet, it is helpful to give some background history regarding the development of the CAT, in relation to TTCT.

Although a significant body of work had been completed on creativity, the majority of studies, at that time, had focused on the psychology of individual creativity. Amabile (1982) argued that you could not truly understand creativity without taking the social context of creativity into account: relationships with others, particular environments, externally imposed working constraints, etc. When Amabile began her enquiry into the social dimension of creativity she was faced with a research design problem: many of the accepted research method were not appropriate for social studies on creativity, for example like the TTCT. There were a number of reasons for this. The TTCT, and other divergent thinking tests, are about quantifying those aspects that set people apart, they aim to define and quantify the micro and macro factors that distinguish one individual from another. In contrast, researching the social context of creativity requires the need to define and quantify group characteristics beneficial for comparing a control group against a test group. Thus, there was a need to minimise individual difference, in order to test hypotheses about how one group may react differently to another, given changes in their social environment. The lack of an acceptable research methodology meant a new method to assess creativity need to be evolved, and to prove its validity. This was the purpose of the CAT. For the sake of argument, if we accept the basic definition of creativity, that creativity produces work that is both new and useful, we could state that our initial criteria for assessing creativity is how new and how useful the final output is. From such a position we are left with several questions: what is the appropriate assessment criterion for new and useful? How should assessors evaluate new and useful, and how do they do this with transparency and objectivity. Amabile argued that objective criterion did not currently exist (and may never exist) on which to assess creativity in this way. Moreover, that the judgements required to assess creativity "…can ultimately only be subjective" (1982, pp. 1001), and with an appropriate group of judges, "…is something that people can recognize when they see it." (1982, pp.1001). From this came and operational definition of creativity, upon which the CAT is based: "…a product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was create or the response articulated" (1982, pp.1001). Using this as a working definition Amabile moves away from the notion of objectivity in assessment and towards subjectivity. The question then is to what degree can judges actually agree on each other's subjective opinions? By basing the criteria within the judges' subjective opinion, this also negates the need for explicit criteria. As long as the judges are in agreement, then that is enough; they may not know specifically why a product has a certain level of creativity but if they agree that is does, then this shall form the basis for evaluation. Given such a radical departure from creativity assessment norms at the time, the consensual assessment technique was developed to evaluate whether such levels of agreement actually exist and to what degree they were reliable and consistent. Over a five-year period, Amabile conduct several studies using the CAT. With a wide range of groups represented from primary, secondary, and undergraduate education, the total numbers of students engaged in the research were 423. These groups either took part in a study to assess artistic or verbal creativity. A range of assessors recruited from academia, working practice and education judged this work. The total number of judges over the five years was 125; each judge was free to use his or her own subjective definition of creativity with which to assess the work. From these studies, Amabile concluded that high levels of judge agreement existed regarding creativity rating, with the results showing significant reliability when using the CAT. Furthermore, judges were able to distinguish 'creativity' from other aspects of the work such as aesthetic appeal and technical execution. With these findings in place, the CAT was used as the basis for research into the social impact on creativity. It is beyond the scope of this paper to detail the findings from this research, but a number of studies found negative relationships between external evaluation and surveillance on creativity (Amabile, Hennessey & Grossman, 1986; Hennessey, 1989; Amabile, Goldfarb & Brackfield, 1990). While such findings are disputed (we are now aware of several caveats regarding these early works), the value of the CAT as a research method has continued to evolve. In more recent years, creativity researchers (Baer, Kaufman & Gentile, 2004) have extended the CAT to less stringent experimental conditions than Amabile and others initially used. Such studies suggest satisfactory results could be achieved with less than 13 judges. Equally, Kaufman, Baer, Cole & Sexton (2008) have explored the use of non-expert raters for the CAT, and find that the requirement for expert judges still holds. However, despite this background within creativity research, the use of the CAT as a measure of creativity within design research appears relatively small. For example, within the published proceeding of invited papers for Design Creativity 2010, only one citation was given for the CAT (Collado-Ruiz & Ostad-Ahmad-Ghorabi, 2010b). The main aim of this study is to consider if this is an accurate reflection of the use of CAT in design research. In order to do so, a comprehensive database of CAT citations will be developed with which to:

- Identify key journals publishing CAT studies
- Identify key authors publishing CAT studies
- Identify the use of CAT within a range of design journals

2. Method

The CAT reference database was built using Reference Manager and Zotero to import citations from a number of databases, namely: PsycINFO, ISI Web of Knowledge and Google Scholar. Details and rationale are provided below. Key journals were defined as those with more than five citations for CAT within the last 30 years; key authors were defined as first authors with more than 10 citations for CAT within the last 30 years.

2.1. Why use Google Scholar rather than other databases?

Google Scholar has its advocate and critics. The reason for its inclusion in this study was as a direct result of the low number of citations to be found in more esteemed databases such as PsycINFO and Web of Knowledge for the consensual assessment technique. Given the aims of this study to undertake a systematic and comprehensive review, such omissions were major concerns. Without discounting the inaccuracies and limited data available via Google Scholar, its database offered the most comprehensive list of references related to the consensual assessment technique. Given this, the strategy used was to gather all of the related sources available via Google Scholar, and then check for duplications within PsycINFO and Web of Knowledge. The search criteria used were the term "consensual assessment technique", with the following restrictions: articles excluding patents, any time, at least summaries, English only documents. The result was 737 citations that matched these criteria.

2.2. Problems with downloading multiple citations from Google Scholar

Currently, Google Scholar only allows downloading one reference at a time, but with the application of a Zotero plugin for Mozilla Firefox multiple downloading is feasible. Unfortunately, this does have restriction and it was not possible to download all 737 citation from Google Scholar in one go. This highlighted a number of counting inaccuracies between Google Scholar, Zotero and Reference Manager; with the possibility that either Google Scholar was not correctly counting the references (as has been suggest by other researchers), or something was getting lost in the process of exporting. Given that the Zotero figure was higher than the initial 737 the decision was taken to accept the

Zotero figures as the more accurate: the total number of citation exported to Reference Manager was 745.

2.3. Cleaning the Reference Manager Data Base

The database was cleaned for duplications: leaving a total of 742 citations in the database. Despite setting the search criteria for papers written in English, a further 19 citations were identified that the titles suggested were written in a different language. These papers were deleted from the data base. Furthermore, 10 papers had data that was undecipherable in the form of symbols, and were also deleted from the database; leaving a total of 713 references in the database.

2.4. PsycINFO

In contrast to the several hundred citations for CAT within Google Scholar, PsycINFO returned 45 citations for the Consensual Assessment Technique. Within this list none of the design journals in this study were cited. After accounting for duplicates between the Google Scholar database and PsycINFO, of the 45 citations, only 39 could be found. This led to the inclusion of the following 6 references: Conti et al (1996); Baumgarten (1997); Mannarelli (2000); Liu & Shi (2007); Batey & Furnham (2009); Tan (2009); leaving a total of 719 citations in the database.

2.5. Web of knowledge

Similarly to PsycINFO, Web of Knowledge returned 54 citations for the Consensual Assessment Technique. Accounting for duplicates between the updated Google Scholar database 51 were found. This led to the inclusion of the following 3 references: Corko &Vranic (2007); Hennessey & Amabile (2010); Kaufman (2010); leaving a total of 722 citations in the database.

2.6. Design research journals

Nineteen journals were chosen to represent design research for this review. They were as follows: Artifact; CoDesign; Design Issues; The Design Journal; Design Philosophy Papers; Design Studies; Form; International Journal of Arts and Technology; International Journal of Art & Design Education; International Journal of Design; International Journal of Design Sciences & Technology; International Journal of Technology and Design Education; Journal of Design History; Journal of Design Research; Journal of Engineering Design; Leonardo; Scientometrics; Social Studies of Science; Technoetic Arts.

3. Results/findings

3.1. CAT citations

Based upon the database described above, Figure 1. shows the growth of CAT citations relative to design related journals from 1980 to 2011.

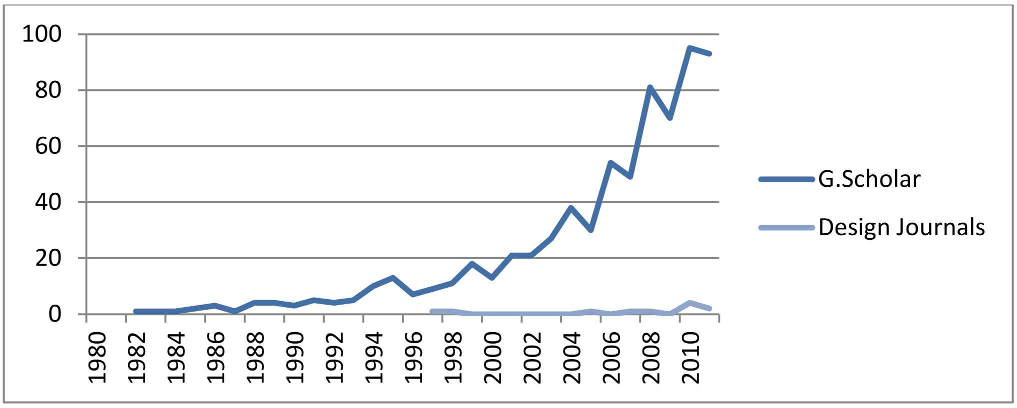

Figure 1. CAT citation in design journals relative to other journals

3.2 CAT citations with design journals

In searching for specific reference to the consensual assessment technique within design journals a total of 11 papers were identified. Of these 11 papers two operationalize the CAT within their studies, and state this specifically (Christiaans & Venselaar, 2005; Pektas, 2010). Three papers use judges to evaluate creative outputs, but these are not directly related to the CAT in terms of procedures (Verstijnen et al, 1998; Kokotovich, 2008; Collado-Ruiz & Ostad-Ahmad-Ghorabi, 2010a). The remaining papers up to 2011 make reference to Amabile's 1982 or a CAT work to support a point within their papers, but CAT was not part of the study (Cross, 1997; Jeffries, 2007; Cropley & Cropley, 2010; Jeffries, 2011; Howard, Culley & Dekoninck, 2011; Lau, 2011).

3.3 Key journals publishing CAT studies

From the 722 database three journals stand as key contributors to the debate on the Consensual Assessment Technique (number of citations in brackets). These are:

- Creativity Research Journal (55)
- The Journal of Creative Behavior (25)
- Psychology of Aesthetics, Creativity, and the Arts (18)

The caveat to this claim is that 207 of the reference in the database were without data on journal, books, chapter or thesis. However, 515 citations remained with these details, and it was decided that this number of citations formed a reasonable basis on which to proceed. Those with 5 or more reference to the CAT were as follows:

- Journal of Personality and Social Psychology (11)
- Roeper Review (11)
- Creativity and Innovation Management (11)
- Personality and Individual Differences (8)
- Thinking Skills and Creativity (7)
- Design Studies (7)
- Journal of Research in Personality (6)

3.3 Key authors publishing CAT studies

From the database of CAT citations six first authors account for 91 of the papers as follows (number of citations in brackets):

- Kaufman, J. C (22)
- Baer, J (17)
- Dollinger, S. J (15)
- Amabile, T. M. (13)
- Hennessey, B.A (13)
- Plucker, J. A (11)

4. Discussion

In an earlier section of this paper, for the sake of argument and word space, a definition of creativity being based on outputs that had the dual quality of originality and usefulness was suggested. Many readers will likely be familiar with this type of definition; equally aware of the controversy surrounding how researchers' define core characteristics like originality and the type of evidence required to assess creativity (Runco, 1999). Indeed, a number of works have begun to categories creativity in more precise terms, such as Big C creativity, Little C creativity, mini c creativity (Beghetto & Kaufman, 2007), and have different expectation associated with each of these terms regarding originality and usefulness, and the sort of study population they can be applied to: for example, kindergarten pupils, students in higher education, professional practitioners within a field.

The focus, however, on creative output is not the only means to define creativity; other categories of research explore the creative process, the creative person, or the creative environment (Isaksen & Murdock, 1993). An argument can be made (for some creativity researchers this argument is generally accepted) that to validate findings in these three other areas, inference needs to be shown with the creative output (Kaufman & Baer, 2002). By doing so this places the primacy of creative output at the heart of creativity assessment. As mentioned above, such a decision is controversial. It may also partly explain the low use of the CAT in design research.

The CAT is a measure of creativity that is firmly placed within notions of creativity as an output. With a degree of contrast (as a broad generalization) much focus within design research has been given to "understanding designing as a process" (p.1, Nagai & Gero, 2012). Such broad distinctions are not to be taken as a sign of polarity: while offering theoretical value, the 4 P's of creativity research (product, process, person, press) clearly interact and influence each other in practical terms.

Indeed, the number of methods with which to measure creativity are considerable and varied (Batey & Furnham, 2006): from protocol studies, self-report measures, divergent thinking tests, to creativity assessment by domain experts, and each method has its strengths and limitations. For example, Protocol analysis enables researchers to explore the type of cognitive processes and decisions participants make during an activity, for example when sketching ideas for a design. Such study is crucial to our understanding of the creative process. Equally, self-report measures offer a valuable and established approach to creativity research (Lau, 2011; Batey, Furnham, & Safiullina, 2010). Some researchers have argued that given an emphasis within design education for expert judges to form consensual assessments on creative outputs, data gathered by self-reports offer an alternative perspective on creative potential (Jeffries, 2007; Kaufman & Baer, 2002). Self-report data enables researchers to examine an individual's self-image in relation to their creativity, and such factors are important for theoretical and pedagogic reasons. There are, however, acknowledged challenges to the use of self-report instruments such as, not being easily verifiable, and open to "halo" effect bias on the part of the participant (Brown, 1989; Lubart & Guignard, 2004).

Notwithstanding the value of alternative method to researching creativity, perhaps an emphasis on the process of design creativity has overshadowed methodologies that relate more to the creative output? The rationale for asking this question is based on the small number of CAT studies in design journals relative to creativity journals and number of CAT citations within the wider community of scholars.

The counter argument is that those studies within design journals that cite the CAT often directly address this issue of product relative to process; notably Cross (1997) and Christiaans & Venselaar (2005), but in both cases this could well be traced back to Christiaans earlier research in 1992. Thus, one could argue that the value of creative output methodologies, and by extension the CAT, has had is supporters within design research for some time.

Of those studies that cited CAT in design journals, from the 11 papers identified, only two directly made use of the CAT. In both cases the reliability of the CAT was, for the most part, above the standard 0.7 levels required for inter-rater reliability (ranging from 0.66 to 0.81; 0.81 to 0.86). Whilst these are favourable, the number of expert judges varied from 10 graduate industrial design students to 3 design academics. Selection of judges in terms of level of domain expertise, and how many judges should be used in a study is a point of debate. Issues around the use of novices relative to expert judges have for and against arguments; equally the number of judges has varied in CAT studies throughout the years.

The issue of validity, however, is more problematic, particularly in the light of debates surrounding the domain specificity/generality of creativity, and the role task selection plays in creativity assessment (Byrne, 2011). For example, the task set; the amount of time given to complete the task; a subject's level of intelligence; the domain identity of the judges; the researchers' method of distinguishing high from low levels of creativity using CAT scores; a judges rating of highest and lowest works relative to their own tacit standards of creativity within the domain; all these considerations could have an impact on CAT validity in relation to design creativity. Unfortunately, it is beyond the scope of this current paper to address each of these issues adequately; they are highlighted here to foster the discussion regarding the CAT and its value to design research.

Lau's 2011 paper for the Journal of Design Research is of particular interest at this point. Clearly, this is a paper that undertakes a detailed review of methods to assess creativity and relate them to design. It covers a wide range of works that fall within self-report measures, divergent thinking tests, creative problem solving, and specifically discusses the creative output, or end product, as a measure of creativity within design. The connection to CAT is established indirectly through citing Hennessey's work (1994), however, given the detailed focus within the paper on TTCT, Creative Problem Solving, and other methods, it is interesting to consider why there is no direct discussion of the CAT. Indeed, the issue of subjective judgement and assessment criteria are fundamentally reframed by use of CAT methodology, as mentioned earlier in this paper. In this respect, does the philosophical stance of the CAT devalue the method from the perspective of design research? Yet, the consensus of domain judges (often using their subjective opinion and expertise) is a prevalent methodology for assessment in design education, and professional design awards (of which creativity is either an implicit or explicit expectation).

4.1 Limitations and areas for future research

The results extracted from this study are limited in a number of ways. Firstly, the type of design journals searched, while comprehensive, may have overlooked some publications. Secondly, for practical reasons the focus on first authors was a useful way to gather key authors related to CAT, but this does not reflect the role of second author or et al, and further work here may change the emphasis on key figures within this area of research. Thirdly, and finally, there is a need for a keyword search of abstracts. Both the PsycINFO and Web of Knowledge are able to provide abstracts, but this was not available via Google Scholar. In practical terms, gathering the abstract from 722 papers is a long term aim, but using the key journal data identified here, these journals show 159 papers with CAT citations. A keyword search of these abstract would be feasible, and clarify if, and how, the CAT was used in these studies.

5. Conclusion

Amabile's Consensual Assessment Technique (CAT) has been described as the "gold standard" of creativity assessment, and has been extensively used within creativity research during the past 30 years. Yet, the key finding of this paper highlight a limited number of CAT studies within design journals. The reasons for this are unclear. Whether this is because the CAT is tied to a definition of creativity built upon creative output and the subject opinions of judges, or a number of specific concerns regarding its validity as a measure of design creativity are discussed.

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SITUATED CREATIVITY INSPIRED IN PARAMETRIC DESIGN ENVIRONMENTS

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Abstract: Current literature shows that there is a lack of empirical evidence support the understanding of design creativity in parametric design environments (PDEs). Situated creativity which regards the changing context of design environment has been suggested to be an index for design novelty and unexpected discoveries. In PDEs, the nature of its dynamic design process expresses frequent change of design situation, which is potentially beneficial for evoking situated creativity. Aiming to explore situated creativity inspired in PDEs, this study proposes a theoretical framework based on Gero's FBS model in which the method of protocol analysis is adopted. Furthermore, a pilot study involves two students in a design experiment has been conducted to test the framework. In the end, several preliminary results regarding the relationship between situated creativity and parametric design processes have been developed.

Keywords: *situated creativity, parametric design, FBS model*

1. Introduction

Parametric design is increasingly popular in the architectural design industry recent years. In parametric design environments (PDEs), by changing parameters, particular instances can be altered or created from a potentially infinite range of possibilities (Kolarevic, 2003). But will these possibilities inspire design creativity? Previous studies on design creativity in PDEs show that parametric tools advance design processes in a variety of ways (Iordanova, Tidafi, Guité, De Paoli, & Lachapelle, 2009; Schnabel, 2007). However, the relationship between design creativity and PDEs remains controversial. Analysis of literature shows that there is a lack of empirical evidence supporting the understanding of creativity inspired in PDEs.

Situated creativity which regards the changing context of design environment is described as an index of design novelty (Tang & Gero, 2001) and making unexpected discoveries(Suwa, Purcell, & Gero, 1999). Gero (1998) defines design situation as "where you are when you do what you do matters", which means designers cognition behaviour during design process is affected by their interaction with design environments and responds to the changing design situation. Parametric design is a rule-based, dynamic design process controlled by variations and constraints. Therefore, we are wondering whether designers' situated creativity is evoked by the dynamic characteristic of parametric design. Aiming to explore this issue, this study proposes a theoretical framework based on Gero's FBS model (Gero, 1990) in which the method of protocol analysis is adopted. Furthermore, a pilot study involves two students in a design experiment has been conducted to test the framework. In the end, several preliminary results regarding the relationship between situated creativity and parametric design processes have been developed.

2. Background

2.1. Protocol analysis of parametric design

Parametric design is a new digital design method increasingly applied in architecture, and characterised by parametric relationship control, rule algorithm design and multiple solution generation (Karle & Kelly, 2011). Previous studies on designers' behaviours in PDEs show that parametric tools advance design creativity in a variety of ways: for instance, evidence indicates that the generation of ideas is positively influenced in PDEs (Iordanova, et al., 2009); Schnabel (2007) shows that PDEs are beneficial for generating unpredicted events and can be responsible for accommodating changes. However, researchers have typically studied design behaviour in PDEs mostly by observing students interactions with PDEs in design studios or workshops. Arguably, this approach can hardly provide an in-depth understanding of designers' behaviours in PDEs. This empirical gap will be addressed in the present study by adopting the method of protocol analysis.

Protocol analysis is a method widely used for cognitive studies into designers' behaviour during design processes (Cross, Dorst, & Christiaans, 1996; Ericsson & Simon, 1980). It has been applied across a variety of design environments (Kan & Gero, 2009; Kim & Maher, 2008). The general procedure of protocol analysis is that the protocol data (in this case, the video-recorded information of designers' behaviour) collected from the experiment is transcribed and segmented; a customized coding scheme is then applied to categorise segments. In the following section, we will introduce the function-behaviour-structure (FBS) model (Gero & Kannengiesser, 2004) to create a customised coding scheme, where the characteristics of parametric design are reflected.

2.2. Situated creativity

Generally speaking, creativity is to generate or produce something that did not exist or was not known before (Gero, 1990). Creativity expressed in design processes is a complex issue. One of the idea proposed by Clancy (1997) is design situatedness which means designers' concept is affected by the changing design context--- includes what designers "see" and their interpretation of design situation. Moreover, design situatedness includes a concept of constructive memory (Dewey, 1896). It claims that memory in a design process is constructed in responds to the current design needs, and keeps adding to existing knowledge or experiences. Tang and Gero defined situated creativity as design novelty provoked from design situation and design situatedness (Tang & Gero, 2001). They proposed a method of using protocol analysis to study designers' situatedness creativity in sketch environments, the results shows that expert designers have statistically more novelty of design situatedness than the novice in the perceptual, functional and conceptual levels. Some other studies suggest that designers use sketches as a basis for reinterpreting what had been draw, and their concept changes are influenced by the change with design environment (Schon & Wiggins, 1992).

Based on Tang and Gero's (2001) definition of situated creativity and Clancy's (1997) concept of design situatedness, in this study situated creativity is defined as new varieties and unexpected discoveries inspired by the changing design situation during design process (the scope is within the context of a single design process rather than considering the influence of other social context).

2.3. Situated creativity in PDEs

Design media or environment is absolutely related to creativity (Mitchell, 2003). By changing parameters or switching between geometry modelling and rule algorithm interface, design context is changing frequently in PDEs. This dynamic characteristic of parametric design presents its unexpectedness, uncertainty and changeability feature, which is potentially beneficial for changing of design situation and evoking situated creativity. Therefore, the relationship between situated creativity and characteristic of parametric design needs to be explored.

3. Theoretical framework development

In this study, Gero's FBS model (1990) is introduced as the foundation for theoretical framework development. Since publication, FBS model has been applied to a variety of studies on designers' behaviour. Later, Gero & Kannengiesser (2004) further developed the FBS model into a situated FBS ontology by introducing interaction in three worlds : the external world, interpreted world and expected world. Although the situated FBS model are claimed to be able to capture more meaningful design processes (Kan & Gero, 2009), in this study, we still adopt the original FBS model for the following reasons: Firstly, this study focuses on the reformulation processes where situated creativity is supposed to be expressed. Reformulation processes have already been clearly demonstrated in the original FBS model; therefore, it is not necessary to apply the more complex situated FBS model. Secondly, the 10 variables of situated FBS model (5 variables in original FBS model) as coding scheme would be too detailed for a 40 minutes conceptual design.

3.1. Reformulation processes

Among the eight design processes indicated in FBS model (Figure 1), three reformulation processes are suggested to be the dominant process where situatedness is expressed (Gero, 1998). Reformulation process means transition from structure back to function, expected behaviour and structure, which indicates generation of design intention based on structure related consideration. Evidence show that reformulation processes can potentially lead to creative results by introducing new variables or a new direction (Kan & Gero, 2008).

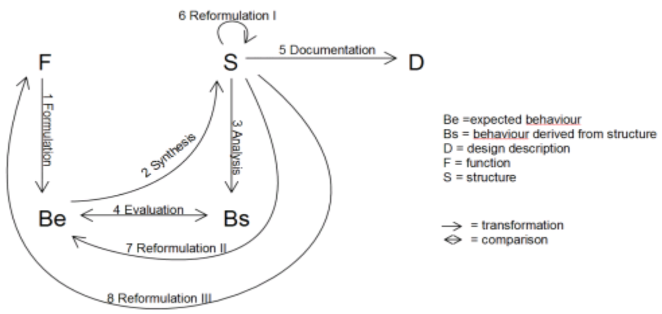

Figure 1. FBS model (Gero & Kannengiesser, 2004)

In PDEs, besides thinking from the perspective of design knowledge, designers also consider from the aspect of rule algorithm. At the rule algorithm level, designers think about the way to make use of parametric tools to serve their design concept. For instance, they will consider the establishment of parametric relationship, the selection of component to achieve certain purpose, etc. Furthermore, there is reformulation process exist at the rule algorithm level as well: the reformulation of rule algorithm reconstructs the relationship of the parametric logic and introduces new variables into the rule relationship. Figure 2 is a theoretical framework for exploring situated creativity in PDEs. This framework interprets situated creativity mainly from three reformulation processes. Each of the reformulation process is represented by new variables and old instance respectively from perspective of structure, behaviour and function, which provided basis for coding scheme development.

1. Reformulation 1 process: reformulation of the design state space in terms of structure or introduction of structure variables. Empirical studies shows that the reformulation of structure is the predominant type of reformulation process (McNeill, Gero, & Warren, 1998). In PDEs, reformulation of structure variables includes: new variables of new structure elements, new parametric relationship and new parameters; old instance includes changing of geometric elements, parameters and parametric relationship.
2. Reformulation 2 process: reformulation of the design state space in terms of behaviour or introduction of behaviour variables. In PDEs, reformulation of expected behaviour variables includes: new variables of intention for achieve certain design knowledge or rule related purpose; old instance includes changing of constraints, change of rule related intention, etc.
3. Reformulation 3 process: reformulation of design state space in terms of function variables or introduction of function variables. This process has potential to change the expected behaviours and structure, however, it rarely happens. In PDEs, reformulation of function includes: new variable of function intention and interpretation of requirement; old instance includes revisiting the design brief.

3.2. Unexpected discoveries

With the changing design context, unexpected discovery as essence of situated creativity (Suwa, et al., 1999) also needs to be explored. Parametric design are suggested to be beneficial for generating unexpected events and accommodate for constant changing (Schnabel, 2007). Unexpected discoveries happen mostly from the introduction of new variables, and these new variables sometimes depend on old revisit instance. For instance, Suwa & Purcell (1999) describe unexpected discovery as a "new" perceptual actions that has a dependency on "old" physical actions. Similarly, in this study, we define unexpected discoveries as a "new" behaviour intention depends on an "old" structure action. Another aspect helps us understand the situated creativity is constructive memory, which is mainly based on old instance. Figure 2 indicates the location of unexpected discovery and constructive memory as well.

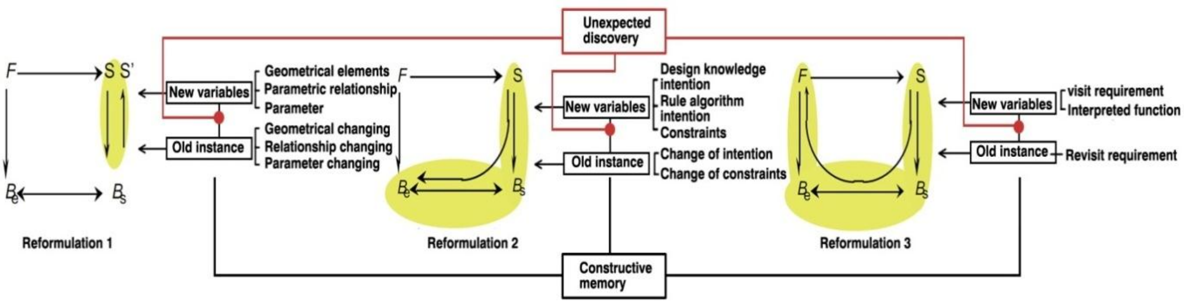

Figure 2. Theoretical framework for exploring situated creativity in PDEs (After Gero's FBS model)

4. A pilot study

4.1. Experiment setting

Aiming to test the theoretical framework, this study proposed to use protocol analysis to explore situated creativity in PDEs. In devising an experiment to collect protocol data from PDEs, 2 students are involved to complete a design task using commercial parametric design software (Grasshopper in this study) in 60 minutes. Each of participants, all master of architecture students, has had at least two years of parametric design experience. The expectation is that some typical design behaviour patterns which may inspire situated creativity in PDEs will be identified.

The experiment environment is a computer, a pen and paper, with two video cameras. The design task is to generate a conceptual form for the tower part of a high-rise building. During the design process, both "think aloud" and "retrospective method" are applied to collect protocol data. Designers' verbalization and design actions are video-recorded for later use as protocol data. Generally, the two students show a good ability of manipulates forms in Grasshopper as well as representing the advantages of parametric design. The main modelling time is respective 36 minutes and 49 minutes.

4.2. Protocol analysis

For the pilot study of the two students, we use a customised coding scheme developed based on FBS model to code cognitive behaviour of the designers. The segmentation is according to semantic meaning in terms of function, behaviour and structure. There are respectively 199 and 174 segments from the two protocol data, and over 80% of the meaningful design processes can be coded. The coding scheme is developed based on Gero's FBS model (Gero & Kannengiesser, 2004) where characteristic of parametric design are reflected. The main category is function-behaviour-structure, and each category is divided into design knowledge based level and rule-algorithm based level (as shown in table 1).

Table 1. Coding scheme

Category	Sub-category	Name	ID	Description
Function (F)	Design knowledge	Requirement-old	F-D-Ro	Considering or revisiting the requirement
		Requirement-new	F-D-Rn	Read design brief
		Interpret function-new	F-D-In	Initial definition or interpretation of function
Structural Behaviour (Bs)	Design knowledge	Intention-new	Bs-K-In	behaviour interpreted from structures
		Perceptual-Old	Bs-K -Po	Revisit model
		Perceptual-New	Bs-K -Pn	First attention to model
	Rule algorithm	Intention-new	Bs-R-In	Attention of existed rule
Expected behaviour (Be)	Design knowledge	Intention-New	Be-K-In	Interpret expected behaviour from design knowledge
		Constraints-new	Be -K-Cn	Setting constraints
		Constraints change-old	Be-K-Co	Changing constraints
	Rule algorithm	Intention-new	Be-R-In	Interpret expected behaviour form rule making
Structure	Design	Intention-New	S-K -In	Expected structure, including geometry

(S)	knowledge			element making
		Geometry change-old	S-K-Go	Changing geometry
	Rule algorithm	Intention-new	S-R-In	Define components used to generate element
		Parameter -New	S-R-Pn	Setting parameters
		Parameter change-old	S-R-Po	Changing parameters
		Relationship-New	S-R-Rn	Setting parametric relationship
		Relationship change-old	S-R-Ro	Changing parametric relationship

4.3. Results

1. In order to better understand the relationship between "old" instances, "new" variables and situated creativity, four types of transitions are proposed as shown in table 2. "New" means the first time a design instance appeared, while "Old" means a design instance appeared after the first time. During design process, it is very likely that a "new" intention is inspired by an "old" instance. That is also an interesting process potentially introducing new variables and reconstructing design problems.

Table 2. Four type of transition

Type	Name	Example
Type1	New to New	Be-K-In> S-K -In
Type2	New to Old	S-K –In> S-R-Po
Type3	Old to New	Bs-K–Po> S-R-Pn
Type4	Old to Old	Bs-K –Po >S-R-Po

Although reformulation processes have been suggested to have more possibilities of introducing new variables and indicate situated creativity in sketch and traditional CAD environment (Gero, 1998), there is a lack of empirical evidence to support the role of reformulation processes in PDEs in terms of situated creativity. Figure 3 & 4 illustrate the percentage of eight design processes in FBS model in terms of the four transitions types between new intentions and old instances (see table 2). The vertical axis represents the percentage of the eight design processes occupied in total design processes. What we want to find out is the differences of reformulation processes allocated in the four transition types. Protocol data analysis shows that both of the two students have exhibited more reformulation processes (sum of reformulation1, 2 and 3) in type1 and type 3 transitions than in type 2 and 4 transitions. In type 1 and type 3 transitions, new variables are introduced. Therefore we believe that reformulation processes in PDEs also indicate the introduction of new variables and potentially provoke situated creativity.

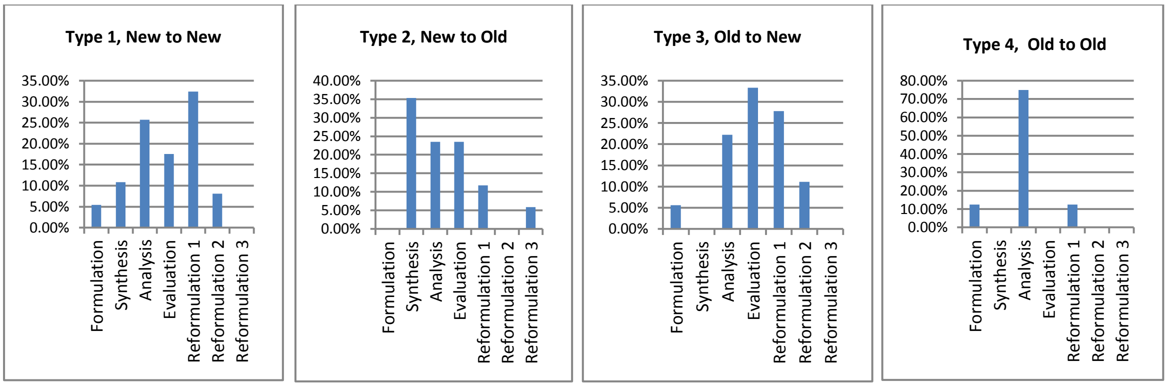

Figure 3. Four types of design process of student 1

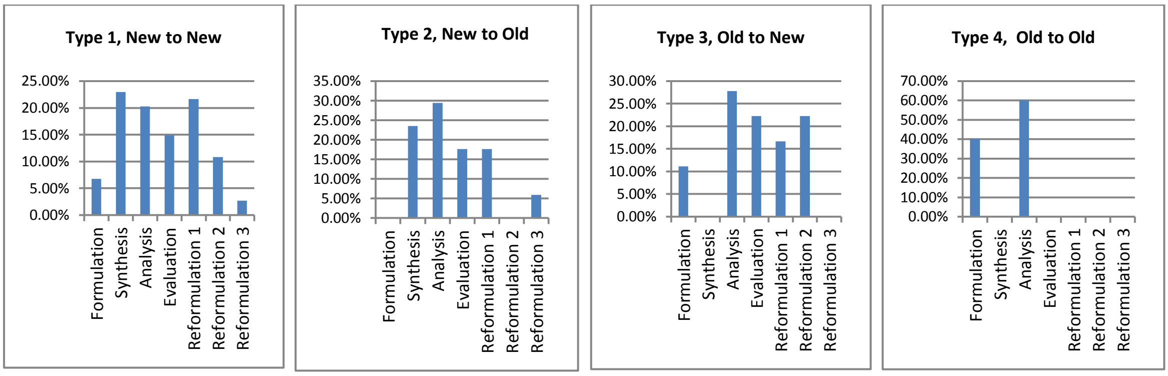

Figure 4. Four types of design process of student 2

2. Figure 5 and 6 illustrates the distribution of reformulation processes and unexpected discoveries along the whole design process. The vertical axis represents the percentage of reformulation processes occupied in the eight design process and the percentage of unexpected discoveries transitions in all the four types of transitions. The horizontal axis represents the design time: For student 1, we calculate the coding every three minutes, so that the max number of horizontal axis 12 means 36 minutes. Student 2 spent 49 minutes on the main model, so we calculate every 4 minutes--because we count percentage, it doesn't matter for the different division of time. What we would like to know is the relationship between the unexpected discovery and reformulation processes, as well as their distribution along the whole design process. As shown in Figure 5 and 6, the two students both have three reformulation processes during the whole design process. The same as previous studies in sketch and CAD environments (McNeill, et al., 1998), reformulation 1 in PDEs is the predominant reformulation type. However, compared to sketch environment in which reformulation 2 diminished during design process, reformulation 2 distributed averagely during parametric design processes. That might because there are more activities on perceptual and evaluation in PDEs due to the changing design context. The unexpected discovery in this study is defined as a "new" behaviour intention depends on an "old" structure action. Figure 5 and 6 shows that the unexpected discovery distribution during design process is very similar with the reformulation processes. That means reformulation processes are beneficial for inspiring unexpected discovery in PDEs. From detail coding, the most likely happens unexpected discovery pattern is S-R-Po> Bs-K-In. This pattern means

unexpected discoveries usually happens when designers change a parameter and then evaluating whether the change is appropriate from design knowledge perspective.

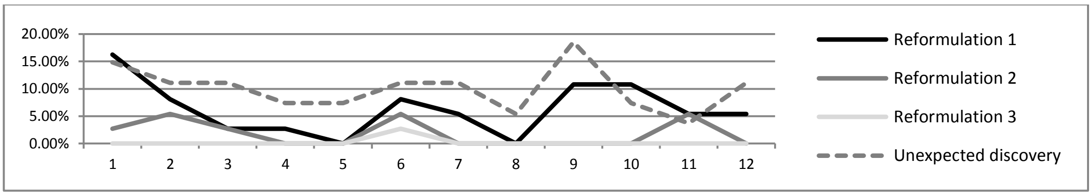

Figure 5. Reformulation processes of student 1

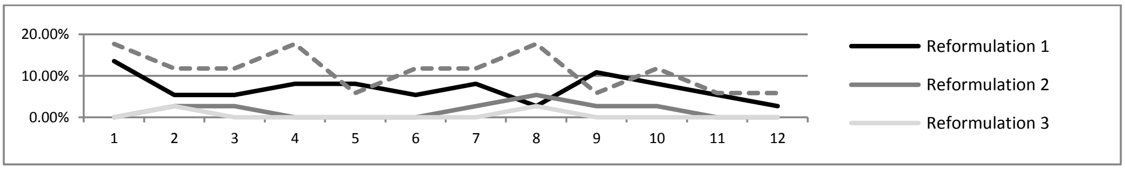

Figure 6. Reformulation processes of student 2

3. Designers' thinking shifts between design knowledge and rule algorithm level during the whole design processes. Figure 7-9 demonstrates distribution of these two levels in reformulation processes. Vertical axis represents the percentage of coding in the two levels in reformulation processes. Horizontal axis represents design time which is the same as Figure 5 & 6. Figure 7 shows that in reformulation 1 process, both of the two students consider rule-algorithm level more than design knowledge level. Moreover, in the end of the design session, rule algorithm thinking is rising. Figure 8 shows that in the reformulation 2 processes, the percentage of rule algorithm and design knowledge is almost similar. Additionally, there is relatively little reformulation 3 happens (figure 9).

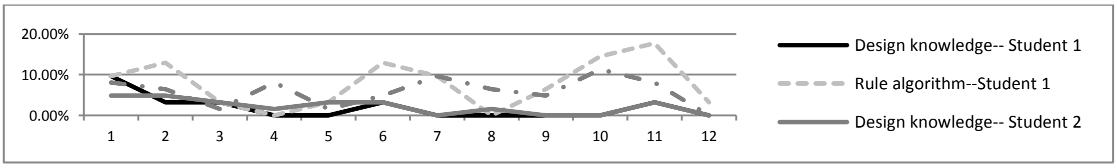

Figure 7. Two design levels in Reformulation 1 processes

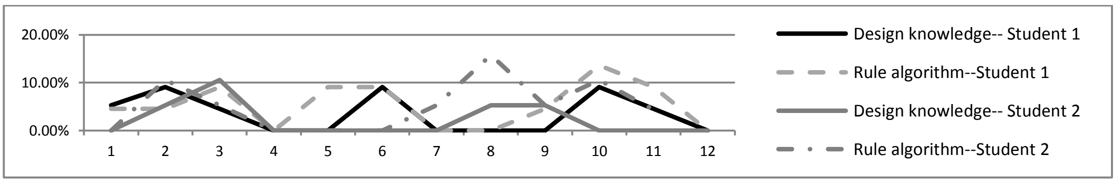

Figure 8. Two design levels in Reformulation 2 processes

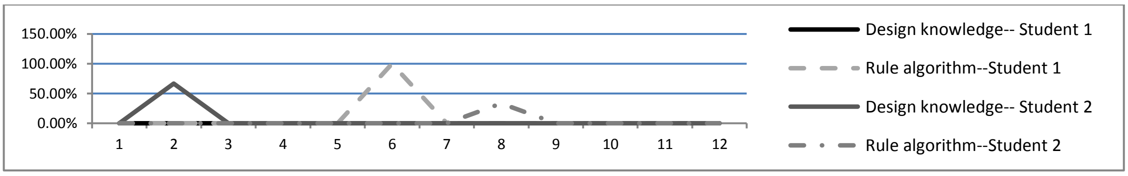

Figure 9. Two design levels in Reformulation 3 processes

5. Conclusion and future work

This study proposes a theoretical framework for exploring situated creativity in PDEs. To test the framework, some preliminary results from a pilot study show that:

- Reformulation processes plays dominant role in introducing new varieties and potentially inspire situated creativity in PDEs;
- Reformulation processes are beneficial for inspiring unexpected discovery in PDEs. Among the three reformulation processes, the predominant type is reformulation 1. In addition, the most likely happened pattern of unexpected discovery is evaluating from design knowledge perspective which have a dependency on parameter changing.
- Design knowledge thinking and rule algorithm thinking transfer during the whole design process. The rule algorithm activities in PDEs have significant impact on reformulation 1 process. Additionally, there are relatively little reformulation 3 process happens.

The next stage of this study is to conduct a main study with a larger number of designers in order to identify designers' behavior patterns in terms of situated creativity. In the main study, we will compare designers' behavior in PDEs with traditional modeling environments to further explore the role of parametric design plays in evoking situated creativity. Results of the main study will help to test the validity of the theoretical framework and explore factors inspire situated creativity during parametric design process.

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A PROPOSAL OF METRICS TO ASSESS THE CREATIVITY OF DESIGNED SERVICES

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Abstract: An emerging thread of research is represented by the attempt of quantitatively assessing creativity, its dimensions and how it influences the design process. The endeavour of previous works has consisted in the assessment of creativity concerning designers, methodologies, concepts and products. As the scope of engineering design is expanding so to include not traditional aspects of the product development process, the paper proposes metrics tailored to evaluate the creativity of services. Such metrics are built as a result of the extension and adaptation of previously formulated criteria, including the evaluation of novelty and usefulness. An exemplary sample of successful innovative services is considered, giving rise to a considerable variability of creativity scores. The outcomes may represent a starting point for a wider discussion about which dimensions of creativity majorly impact the success of products and services in the marketplace.

Keywords: *creativity assessment, design of services, degree of novelty*

1. Introduction

The measurement of creativity can support the selection of innovative products and solutions, thus it concerns one of the most relevant topics in the research agenda of the design community (Gero, 2010).

The interest of the engineering design community is going beyond the development of methods and tools to support traditional design activities and several scholars are focusing their research efforts towards the identification of customers' needs (e.g. Weber, 2008), with a value-centred approach (e.g. Cascini et al, 2011; Zhang et al., 2011). In this sense a considerable attention has to be attributed to the design of original services. As well, in the last decades, the literature has observed a large number of contributions aimed at establishing more robust links between products and related services. Several methodologies and tools have been introduced and further developed to fit the exigencies of the so called "servitization" trend, e.g. Product-Service Systems (Tukker & Tischner, 2006), total-care products (Alonso-Rasgado et al., 2004), Service-Product Engineering (Sakao et al., 2009).

The relevance of creativity within service design has been plainly recognized in literature, e.g. Kaner & Karni (2007) have proposed specific approaches dedicated to stimulate idea generation in this field. The same authors, following an established school of thought, include service planning within the whole set of engineering disciplines, thus assessing that creativity in service innovation takes into account the same factors considered in other design contexts. Hence, in this paper the authors assume that investigating service creativity requires no speficic determinants to be mapped.

Besides, the application of methodologies traditionally devoted to foster creativity within product development, for instance TRIZ (Chai et al., 2005), have been experienced to produce innovative services. Given these premises, the assessment of service creativity results a subject requiring investigation, since no previous research has been performed according to authors' survey in the literature and personal knowledge.

The manuscript is organized as follows. Section 2 briefly reviews the main approaches and aims within the research devoted to assess design creativity. Section 3 illustrates the schema advanced by the authors to measure the creativity of services by extending some metrics, recently defined to assess the creativity of products. Section 4 describes the application of the upgraded method for a sample of successful innovative services. Section 5 concludes the paper with a discussion about the achieved outcomes and the future work to be carried out.

2. Overview of the approaches to assess design creativity

Creativity is acknowledged as a fundamental ingredient for the completion of engineering design tasks, but its assessment results a quite recent, besides much debated, subject. The studies aimed at assessing the creative level of designers belong to a more developed branch of research, by benefitting of decades of experiences and models pertaining to other research domains. An interesting survey by Thompson & Lordan (1999) discusses the useful outcomes of the knowledge about creativity accumulated within psychology and management in the perspective of building models for engineering design.

However, a full understanding of the influence of natural talent and dedicated training is still missing, as witnessed by the open issues reported in a recent work performed by Charyton et al. (2011), who focus on engineers and designers with the aim of improving educational programs. With reference to engineering design, the initial efforts have been dedicated to evaluate the contribution provided by design methodologies and tools, claiming to foster creativity and innovativeness. Verhaegen et al. (2011) argue that no standard technique has been yet defined and acknowledged to conduct tests for evaluating the effectiveness and the creativity stimulation of design methodologies. Besides, the research efforts are progressing towards the refinement of the employed metrics. Still according to Verhaegen et al. (2011), the pioneering work of Shah et al. (2000) has opened up a thread of research aimed at assessing the creativity of the ideas generated during a design task. For instance, a subset of their metrics has been recently revised by Oman & Tumer (2011) in order to rank the novelty and the quality of solution concepts. Chiu & Salustri (2010) review previous experiences in academics addressed at measuring the creativity of design projects and carry out further tests. They extrapolate that novelty and usefulness are the most agreed assets of creativity; they consequently evaluate the projects made by their students on the basis of judgements on those assets provided by peers and experts. Still focusing on novelty and usefulness, Sarkar & Chakrabarti (2011) put forward a proposal to quantitatively assess creativity of products. Its main strength stands in the employment of objective metrics, which do not require evaluations of individuals. The suggested model exploits a previously developed functional model to characterize the degree of novelty, i.e. SAPPhIRE (Srinivasan & Chakrabarti, 2009) and multiple criteria to estimate usefulness including the urgency of the need to be satisfied, the potential quantity of people interested in the product, the duration of the employment of the system or of the provided benefits. The final assessment of creativity results by multiplying the degree of novelty and the three levels of usefulness according to the cited dimensions.

Given the advantages consisting in a major repeatability of the outcomes in light of substantially objective metrics, the authors decided to adopt the model advanced by Sarkar & Chakrabarti (2011) as a starting point in the perspective of measuring the creativity of new service definition.

3. Extension of the reference metrics to assess the creativity of services

The extension of the creativity metrics by Sarkar & Chakrabarti (2011) to the assessment of innovative services requires to modify and adapt the criteria related to novelty and usefulness evaluation. The following paragraphs describe an original proposal that preserves intent and structure of the selected reference model, but is tailored to be applied to any kind of immaterial innovation, with a specific focus on services.

3.1. Modified criteria to assess novelty

The first step of this research consisted in evaluating whether the chosen reference model could be employed for design outcomes not represented by physical artefacts. The major hurdle resulting by the experiment was the difficulty in referring elements and procedures pertaining services to the constructs which constitute SAPPhIRE model (Table 1) and whose transformation along generations of systems determine the degree of novelty. According to a first test conducted by the authors, categories might be easily used to describe the mechanisms involved in the delivery of services treating the negotiation and the maintenance of tangible products (e.g. shops specialized for the selling of certain goods, car rental, boiler cleaning). In these cases, the benefit provided by the service approximately corresponds to the need satisfied by the functions of the treated artefact, as well as several elementary constructs can be likewise identified. On the other hand, the definition of the functional components required by the schema can be hardly accomplished if pure services (e.g. healthcare, education) are involved, with a particular reference to SAPPhIRE terms regarding physical structures. In order to overcome such limitations, a redefinition of the elements constituting SAPPhIRE model has been carried out by means of an abstraction process. Whereas a tangible product is composed by elementary objects and more sophisticated parts, a service is structured in various procedures and operations that allow the final fruition of the expected benefit. The physical system, as a whole, can be associated to the service itself, activated by the foreseen preliminary phases and according to the designed interface between the provider, the beneficiary and any other stakeholder (intermediary, adviser, buyer). Similarly, the outcomes of the interaction resulting by the working of a technical system can be related to the perturbations observed as a consequence of the service delivery. On the basis of the above considerations, the redefinition of the SAPPhIRE elements to fit the modelling of services is reported in Table 1, which compares the original formulation and the tailored new description.

Table 1. Elementary constructs for the working of products and services according to the SAPPhIRE model

SAPPhIRE item	Original definition for products and technical systems	Redefinition for services
Parts	Physical elements and interfaces that constitute system and environment.	Phases constituting the service negotiation and delivery. Items involved in the negotiation.
Organs	Properties and conditions of system and environment required for interaction.	Properties and conditions of phases and environment required for the delivery of the

		service.
Effect	Principle that governs interaction.	Principle that governs the delivery of the service.
Phenomenon	Interaction between system and its environment.	Interaction between the service provider and the customer
State change	Change in property of the system (and environment) that is involved in interaction.	Modification of the state of the stakeholder (beneficiary, provider, intermediary, etc.) and of the environment as result of the service delivery.
Input	Physical quantity (material, energy or information) that comes from outside the system boundary, and is essential for interaction.	Amount of tangible objects and intangible resources not given by the provider that is essential for interaction.
Action	Abstract description or high-level interpretation of interaction.	Abstract description of the benefit provided by the service delivery.

3.1.1. Explanatory application of the proposed categories within the video rental industry

The following example, which involves different kinds of services developed in the home video industry, aims at illustrating how to individuate the novelty degree concerning different components of the service-oriented SAPPhIRE model. The video rental outlets have introduced the possibility to watch new movies at home at the chosen timing, supplying therefore unprecedented benefits (innovation about Action) for film enthusiasts.

Since then, alternative business models satisfying the same customer need have offered novel features or radically redefined the ways through which the service is provided. For the purpose, three options are compared, namely traditional Blockbuster video stores, the DVD-by-mail service offered by Netflix and more recent web-based movie providers, such as Movielink and Cinemanow (Dick, 2006).

Blockbuster rental stores were requiring the customer to visit its outlets, choosing the favourite available film and returning the video support (at the beginning videocassettes, then DVDs) when the movie had been watched. The disc rental proposed by Netflix consists in a flat-fee service activated by subscribers, who have to order a list of movies (to be periodically updated) sent via mail with a maximum amount of DVDs available at the customer’s home. The remaining films of the rental queue are posted by Netflix upon the receipt of the previous ones, since the customer has to post them back. Eventually, web-based providers allow to download movies that can be viewed on computers or on connected TV sets for a certain amount of time, after which the file containing the video elapses.

The distinction between the services delivered by Netflix DVD-by-mail and Blockbuster stores can be interpreted through modifications of the following categories:

- Parts (in terms of the sequence of activities): planning a series of movies to be watched vs. choosing films one by one; paying monthly fees vs. paying at each rent;
- Organs (in terms of conditions of the phases that enable the delivery of the service): return of the DVDs that allows subsequent deliveries vs. possibility to rent a plurality of discs at once;
- Phenomenon: active and lasting relationship between the customer and the provider vs. interruption of the negotiation when the movie has been returned;
- State change (in terms of the state of the provider): enabling the posting of new movies when the previous ones are sent back vs. passive state of the service provider;
- Input (in terms of the information provided by the customer): continuous update of the list of the desired movies vs. periodical rental of movies chosen at each negotiation.

On the other hand, the Effect that governs the supply of the service results unchanged, since both the rental options require the delivery of a physical object, i.e. the disc.

With respect to the introduction of the Internet-based delivery of movies, the Effect is conversely modified, since digital copies of the videos have replaced physical supports and the user does not need to return any item.

3.1.2. Matching the modifications of the elementary constructs and the degree of novelty

The criteria to distinguish among systems with very high, high, medium and low degree of novelty can remain unchanged with respect to Sarkar & Chakrabarti (2011). Therefore, very-high originality is supposed to be brought by services with innovations at the Action level, for which the residual elementary constructs do not play any role in the determination of the novelty. Low novelty is deemed for new services, for which modifications occur just at the Parts or Organs level. Whereas transformations take place also at the Effect or Phenomenon level, the degree of novelty becomes medium. Further changes concerning State Change or Input give rise to high novelty.

In the followings, when assessing creativity through quantitative metrics, the score assigned to very high, high, medium and low degree of novelty, will be equal to 4, 3, 2 and 1 respectively.

3.1. Metrics to assess usefulness

The criteria introduced by Sarkar & Chakrabarti (2011) to measure the usefulness of systems can be considered as general purpose metrics. The importance of the fulfilled benefits is evaluated according to the suitable level of needs in terms of the hierarchical scale developed by Maslow. In order to categorize services through the proposed criterion, a slightly modified version is proposed with respect to the reference model to assess creativity, thus encompassing a wider range of benefits than those currently satisfied by products and material artefacts. It is also possible to replicate the metrics concerning the usefulness in terms of the arena of potential recipients of the service and the duration of the expected benefits. Such criteria give rise to coefficients expressed in terms of continuous variables ranging from 0 to 1. However, the determination of such issues is often affected by the impossibility to establish such values with exactness, due to a lack of information whereas demographic, statistical or census data are not available. With regards to such limitation, a ranking is hereby introduced to classify, through discrete variables, the amount of service recipients and the rate of use or of the duration of the benefit.

Table 2 summarizes the proposal of the present paper to cluster the three dimensions of usefulness for services and provides suitable examples for each category. Together with each reported category, the quantitative scores to be employed for the final determination of creativity are reported in brackets.

Table 2. A proposal to assess the urgency of fulfilled needs, the relevance within the population and the duration of the benefits with regards to services

Degree of importance	*Example*	**Expected beneficiaries**	*Example*	**Rate of use or rate of duration of the benefit**	*Example*
Life saving and support, wellness (5)	Healthcare	The whole community or a large majority (4)	Muslims in Arabic countries	The whole time (5)	Benefits by nutrition
Compulsory activities (food, rest, hygiene) (4)	Contract cleaners	About half of the population (3)	Women or men	Daily or several days in a week, for a considerable amount of time (4)	Sport training for athletes
Shelter, safety, transportation and	Press	Consistent groups of the population	Pensioners	Daily or several days in a week, once or more	Public toilet

social interaction (3)		(2)		times, commonly for brief periods (3)	
Fulfillment of personal needs and services required for job-related issues (2)	Intranet	Restricted groups of the population (1)	Billionaires	Periodically or seasonally (2)	Vacations
Entertainment and recreation (1)	Cinema			Once or few times in a lifetime (1)	Mountain rescuing

4. Measurement of the creativity of successful services

A sample constituted by seven services, attaining success as witnessed by a plurality of literature sources, is hereby reported to show the applicability of the proposed metrics for assessing creativity. Such sample is a subset of a larger group of twenty success stories, which has been examined by the authors in details. The residuals are not reported for the sake of brevity; the selection has been performed with the aim of presenting at least one example for each score of novelty and usefulness. The cases are described in the following Subsection, which provides useful hints for the subsequent evaluation of creativity.

4.1. Set of employed successful services

The Body Shop (Hartman & Beck-Dudley 1999; Kaplan 1995, Kim & Mauborgne, 2005; Livesey & Kearins 2002, Martin 1998) is a large franchise in the cosmetics industry, which has transformed the sector by offering natural-scented items characterized by their practical way of use. The Body Shop has banned the hiring of top models and “eternal beauty” promises from its advertising campaigns, resulting in a textbook story to show the potential success of ethical business models. From a functional viewpoint, the innovation of the service has resulted in the large diffusion of different kind of cosmetics, beyond structuring a tailored selling environment for the franchised outlets.

Cirque du Soleil (Bennet 2005; Harvie & Hurley 1999, Higgins & McAllaster 2002, Kim & Mauborgne, 2005; Peterson 2007) is a Canadian company initially raised by artists involved in street entertainment, which has proposed sophisticated circus performances, avoiding shows with animals and international stars. Their entertainment proposal can be considered as a mix between circus and theatre, since the presented shows are enriched by sorts of plots. In this way, Cirque du Soleil has revolutionized the circus environment and the way the spectator is involved in the show.

Curves® Fitness Company (Goodman & Focault 2006; Kim & Mauborgne, 2005; O’Toole 2009) is a franchise of gymnasia, attended by women requiring sport activity for wellness purposes and scared by the competitive environment of traditional outlets. The gymnasia are simply equipped with few basic and practical training tools. Curves® has resulted in an alternative to videocassettes purchased for home training, deemed too challenging for carrying out a constant and careful sport activity. In this sense, Curves® has resulted in a considerable innovation, not just from the viewpoint of the environment and the use of gym tools, but also by modifying the interaction between the trainee and the trainer (from virtual recorded videos to direct interaction).

Direct Line (Channon 1998; Kim & Mauborgne, 2005; Oakley 1997; Willcocks & Plant 2001) is a British insurance company specialized in selling policies and other financial services by phone or web. The elimination of brokers has resulted in a different sequence of tasks in charge of the insured parties, a different kind of interaction between the policy holders and the company, a different way for the organization to manage the customer portfolios. Benefits have resulted in not negligible reductions of the policies price, which have determined the success of Direct Line.

Facebook is a well-known social network, giving the opportunity to a multitude of users to share information and feelings. Given its enormous success, witnessed by the greatest number of subscribers among all the social networks, Facebook can be considered a milestone in the history of communication with a vast range of potential developments and employments, as reported, e.g., by Bozkir et al. (2010).

Formule 1 (Fiorentino 1995; Kim & Mauborgne, 2005; Verweire et al. 2007) is a low-cost hotel chain, founded by the French company Accor. The hotels offer small-sized, but comfortable and clean rooms and minimize extra services, such the availability of common accessories and the opening time of the reception. Self-organized travellers and business voyagers have become the core clientele of this sort of hotels, who require just a bed in a quiet environment. The main changes with respect to traditional hotels concern the kind of environment and the decreased interaction between the staff and the visitors.

Eventually, Netjets (Budd & Graham 2009; Kim & Mauborgne, 2005) has introduced the fractioned property of private airplanes. Rich people or big companies can buy flight time rather than private jets. This results in a dramatically simpler administrative management of the travel. Times required for urgent transportation are not significantly higher than those carried out through private jets. The modifications with respect to previous business models include the sequence of activities in charge of the customer, the interaction between the client and the company (picking up the passengers instead of providing the jet), the resources required for the travel organization, the way the company changes its state after it has been contacted by the service user.

4.2 Creativity assessment

With the aim of assessing the creativity of the above-mentioned exemplary services, the provided description allows to individuate the SAPPhIRE categories subjected to change. Table 3 summarizes whether, for each illustrated service, modifications have been observed; the analysis is limited to those issues resulting relevant for the determination of the degree of novelty. Table 4 shows the final assessment of creativity, multiplying the scores assigned with reference to the level of novelty (resulting by the examination reported in Table 3) and the three components dedicated to estimate usefulness.

Table 3. Redefined SAPPhIRE categories undergoing changes in exemplary service innovations: the label “Yes” stands for observed modification, “No” if no transformation is revealed, “N.R.” whereas any variation would not impact the assessed degree of novelty

Case study	Action	Parts	Organs	Effect	Phenomenon	State change	Input
Body Shop cosmetics	No	Yes	Yes	No	No	N.R.	N.R.
Cirque du Soleil	No	No	Yes	No	Yes	No	No
Curves fitness company	No	Yes	Yes	Yes	Yes	No	Yes
Direct Line	No	Yes	Yes	Yes	Yes	Yes	No
Facebook	Yes	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.
Formule 1 hotels	No	No	Yes	No	Yes	No	No
NetJets	No	Yes	No	No	Yes	Yes	Yes

Table 4. Final assessment of creativity for the sample of surveyed services with reference to previously established scores: the case studies are ordered according to decreasing creativity

Case study	Novelty	Degree of importance	Expected beneficiaries	Rate of use or rate of duration of the benefit	CREATIVITY
Curves fitness company	3	5	2	5	150
Direct Line	3	3	2	5	90
Body Shop cosmetics	1	4	3	3	36
Facebook	4	1	2	4	32
Cirque du Soleil	2	1	4	2	16
Formule 1	2	4	2	1	16
NetJets	3	2	1	1	6

5. Conclusions

The paper proposes a metric to evaluate the creativity of innovative services, which has been developed by extending the model proposed by Sarkar and Chakrabarti (2011) to assess products in terms of novelty and usefulness, i.e. the most acknowledged determinants of creativity within engineering design. The possibility to measure the creativity of both physical artefacts and intangible goods allows to estimate the originality of a large series of design activities. In a broader sense, such kind of metrics could allow the characterization of innovations impacting the user's value and experience according to their creative content.

The presented preliminary experiment is intrinsically affected by two kinds of limitations. Firstly, a greater quantity of case studies should be analyzed to prove the usability of the proposed metrics. Additionally, the outcomes of the described creativity assessment should be compared against results obtained with other, albeit more subjective, criteria. Nevertheless, the small subset of data presented in Table 4 is sufficient to show that very different creativity scores can be associated to successful services from disparate industrial fields. It is well known that the diffusion of innovation depends on many factors and not just on the usefulness and the originality of an invention. The outcomes of the present study confirm once again this phenomenon, whereas the creativity ranking reported in Table 4 does not clearly match the commercial success and the social impact of the investigated services.

According to these considerations, the future research will be aimed at comparing the presented results of service creativity with different metrics and establishing the most influential dimensions of originality and usefulness in light of designing projects supposed to thrive in the marketplace.

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SITUATED DESIGN THINKING: EXPERIENTIALLY BASED DESIGN APPROACHES

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Abstract: We do not design things in a vacuum, but rather, it is done in a dynamic relationship with people, their environment, cultural, sociological and ideological dispositions (Fulton-Suri, 2002). There are vast areas of human experiences that have barely begun to be explored, in particular those that are related to people's emotional responses to objects in the context of industrial design in Singapore. The literature review will show that there is little explicit knowledge to understand people's experiences and emotional responses that would be helpful to designers in making predictions about designing products, although there are some useful frameworks available to help us think about these issues. This study was conducted to investigate how the knowledge of the experiential properties of users can be effective in the area of product design. It is divided into two parts with the first being the literature review on experiential design approaches and sensorial elements in product design, and the second being the application of the findings to the design of a product. This study looks at user experiences with products in a holistic, experiential base approach, linking these experiential characteristics which are subjective, and relating them against the formal objective qualities of a designed object, to better understand the intangible perceived values that people afford to products. The outcomes of the study indicated that subjective experiential descriptors can be related to specific formal qualities of a product, creating specific product experiences. This will assist product designers to create lasting, memorable product experiences.

Keywords: *situated, emotive, experiential*

1. Introduction

There is a wealth of information on the area of design methodology and processes structures, functionality and usability approaches but very limited when it comes to experiential approaches in product design.

The study looks at user experiences with products in a holistic, experiential base approach, linking these subjective experiential characteristics with and relating them to the formal qualities of a designed object, to better understand the specific intangible perceived values that people afford to products and vice-versa.

2. Experimental based design approaches (EBD)

"Consumers today don't just buy a product; they buy value in the form of entertainment, experience and self identity.A cognitive interplay of our senses and our environment that would create pleasurable and lasting experiences" (Sweet, 1999).

Examples of published reports in this area of EBD approaches includes product personalities (Jordan, 1997, 2002) product playfulness (Lieberman, 1977; Webster and Martocchio, 1992, Noyes and Littledale, 2002), product luxury experiences (Kuethe and Reinmoeller, 1999, Nonaka and Reinmoeller, 2000), emotional experiential needs (Harada, 1997; Lee, 1999, Nagamachi, 1999), product pleasure (Tiger, 1992; Green and Jordan, 1999; Jordan, 1998b, 1999, 2000) and emotional benefits (Desmet, Tax and Overbeeke, 2000).

3. Formal qualities of a design project as it relates to experiential concepts of this study

The term 'designed object' is defined as a product that is the outcome of a design process (Vihma 1995). Formal product qualities referred to here are those that can be objectively measured or that have a clear and fairly unambiguous definition within the context of design. Green and Jordan (2000) describe six categories that make up the elements of a product's formal qualities. They are the product's color, form, graphics, materials, sound and interaction design. According to Green & Jordan, these six elements make up a product's formal qualities and are the building blocks from which the overall design of an object is created.

How the six elements interrelate can be illustrated when we take the example of a digital hi-fi stereo system that is available in the market today. The product's sound qualities in term of its music fidelity as well as the sound the CD cover makes when the eject button is depressed equates to the user's perception of perceived product quality. If the section that our fingers touch are made of cheap plastic i.e. material, then the perceive quality is low. There is a trend towards an increase use of metals in electronic goods (Kamrani, 2000). The use of fabric on the speaker housing, the form of the main stereo casing and the various optional colors they come in, right down to the interface with not just the hardware but the software of the digital are factors that contribute to the overall desirability of the product. Vihma (1995) also describes the elements that constitute the formal qualities of a designed product that encompasses Jordan's six elements of color, form, graphics, materials, sound and interaction design. She uses Bense (1971) semiotic model to analyze designed products that breaks down into four main categories of the hyletic or material dimension, the syntactic or technical, graphic and sound specification dimension, the pragmatic or functional, usability, interface dimension and the semantic dimension which includes morphetics or the product's form and color. These formal product properties as described by both Green et.al (2000) and Vihma (1995), when used with the frameworks of Tiger (1992) and Jordan (1999) underscores a relationship between the product's formal qualities and the four experiential concepts of users.

4. Research question

A difficulty with affective concepts in the realm of experiential and emotional context is that they are probably as intangible as they are appealing. The concepts of hedonic, experiential, sensorial, and emotional issues are somewhat undifferentiated. They are referred to as collective nouns for all types of affective phenomena. Design literature reviews tend to refer to these when studying anything that is so-called intangible, non-functional, non-rational or non-cognitive. Given the subjective, qualitative nature of experiential issues, my research question would be as follows;

- Do the subjective experiential concepts of the Physiological, Sociological, Cultural and Ideological experiences of users influence specific objective formal properties of a product?

5. The four experiential concepts

Fulton Suri (2000) describes a dynamic relationship between the design of products and people that takes into consideration, the context of the environment, sociological, cultural and ideological dispositions of users.

5.1 Physiological experience (Pe)

This category of experiences is dealing with the physical aspects of product use. Ergonomics and anthropometrics would come under this heading. This category of experiences is related to the body and its interaction with physical elements in the environment, derived from the body’s sensory organs such as touch, smell, taste and feelings of pleasure (Tiger, 1992).For example, in a potentially dangerous environment like a chemical plant, protective clothing such as hard hats, steel cap shoes and gas masks can be physiological need products. These products must not be clumsy or uncomfortable otherwise they become dangerous and ineffective. They therefore must provide a positive physiological experience otherwise people will avoid wearing them. Another example of this category experience is those hand held devices that people hold and use. They could include PDAs, pens, toothbrushes, calculators, computer keyboards, shavers, remote controllers, door handles, body massage equipment and many more. The presence of many products on the market that makes use of silicon rubber finishes are catering to this category of sensual physiological tactile experience of touch. In cases where the products come into direct contact with the body, such as a shaver or personal body massagers, the product must feel nice against the skin of the user, which will add to the positive quotient of the physiological experience with the product.

5.2 Sociological Experiences (Se)

This category of experiences refers to the relational aspects of product to people, people to people as well as individual to society relationship pleasure models (Taylor, Roberts and Hall, 1999). This category brings together the context of how products may facilitate social interaction by being status symbols. For example, the associative status of owning a Rolex watch or driving a Mercedes-Benz coupe. The relationship between the user and the product in these examples exemplifies social identity. Clothes are another. It is not just clothes that send out social signals but products such as furniture are often loaded with social significance. In a typical Singaporean office setting, the size of a person’s desk gives an indication of the person’s status and position in the company (Low and Tan, 1996). Even the materials used in an object like the office chair can have a bearing on the person’s office status. Leather in this situation is higher status than fabric, as well as the height of the backrest. The typist chair has a low backrest whilst the managing director backrest goes way past his head when seated. In many other instances, products have the negative effect of being a social nuisance. For example, products that makes a lot of noise in a social environment. One such product is the ringing tone of hand phones in movie theatres as well as during a seminar or talk. Others could be the noise of petrol driven lawn mowers or a pneumatic jack hammer on the street worksite.

5.3 Cultural Experience (Ce)

Culture deals with the ideas, beliefs and customs that are shared and accepted by people in a society (Hofstede, 1991). Culture, by definition, is about transmitting values and traditions from one generation or member to the next and seen as a factor that is dynamic rather than a static set of values, norms and practices. Emotional responses to products can be linked to product aesthetics and that it is dependent, in part on people's cultural values and in part, on their natural human instincts Hatch (1997). In the case of colors, for example, the color red is usually associated with danger (Nemcsics, 1993). This may explain its usage in products that are associated with safety equipments and services like fire-engines, fire hydrants, warning lights etc. Tough and tender cultures. Tough cultures are those cultures where people are likely to be more concerned about performance aspects of the vehicle whilst tender cultures were more likely to choose on the basis of non- performance aspect criteria but more on emotional issues (Mooij, 1998). The form of some of these all terrain 4 WD vehicles as 'tough and muscular' and they look like they have been 'working out in the gym', which would therefore appeal to a tough culture society.

5.4 Ideological Experience (Ie)

This area deals with people's values. These includes, for example tastes, moral values and personal aspirations (Tiger, 1992). However, in design, ideologies such as the Bauhaus refers to a set of ideas and attitudes that strongly influence the way people behave and think about design. 'Green', environmentally friendly products might be seen as embodying the value of environmental preservation relating to a good level of ideological experiences with these environmentally responsible products. Ideological issues concerning the environment such as bio-degradable materials and 'green' issues are well documented in Mackenzie (1991), Papanek (1995), Billatos (1997), McConnell (1999) and Edwards (2001). Harley-Davidson motorcycles are enjoying a measure of success because of its past reputation and associations with Hell's Angels in American history of rebelliousness and nomadic lifestyle (Hardy, 1998). In tightly controlled, highly regulated Singapore, people are buying them because it is an outlet for their rebellious nature, vicariously through its associations with the rebellious, notorious Hell's Angel associations. It also says that these people are tired of the mundanity in their lives and riding a bike with a rebellious ideology panders to their own rebellious side of their nature, reinforcing a cooler, less conformist attitude.

6. Methodology

An expert, used in the context of this study, is someone whose education, professional training and experience make him or her able to make an informed judgment on issues relative to the product or concept under investigation (Kreuger, 1994). A group of 50 professional Singaporean industrial designers, with more than 4 years working experience, were assembled for the purpose of brainstorming key adjectives that act as descriptors of the various attributes of the 4 experiential concepts (physiological, sociological, cultural and ideological - *Appendix A*). A total of 5 objects (2 luxuries, 2 cheap and 1 designer categories) were also presented to the 50 professional designers (Fig.1). The objects were used as visual elements and were physically available to the professional designers to assist them in the formulating descriptors to the 4 experiential concepts. In discussing these objects, a total of 408 different paired polar descriptor words were discussed or suggested under the various 4 headings. A framework that proposes the experiential concepts of the physiological, sociological, cultural and ideological experience could contribute to an emphatic method to categorize people's affective experience with products. 'Lifestyle boards' consisting of images of selected products were also used to determine the 'known' products from the 'lesser known' ones (Baxter, 1995).

Figure 1. The Five Products

However, before commencement of the actual descriptor brainstorm session, participants were asked to give a brief written personal narrative about their own encounters and experiences with the above products. This was done as a warm-up exercise prior to the descriptor brainstorming session proper as well as a way of developing sensitivity to the qualitative aspects of their own encounters and experiences in similar domains (Dittmar, 1992). It also helps the participants to think 'experientially', rather than just 'professionally' about the objects presented in coming up with adjective descriptors and clustering them relative to the 4 experiential categories.

These adjectives are usually related and derived from aspects of the object's formal properties as prescribed by Green and Jordan (2000), for example its form, color, sound, graphics, interaction etc.

Snider and Osgood's (1957) as well as Osgood's (1967), Semantic Differential Technique and Nagamachi's (1999), Kansei Semantic Deferential (SD) Evaluation methods were used as a framework to design the questionnaire and a 5-point scale was used to quantify these subjective information for statistical analysis. Snider et. al (1957) and Nagamachi's (1999) technique were chosen as a scaling technique because it has proven effective in measuring people's attitude towards a product. It can also elicit the kind of experiential associations people have with the objects, relevant in this study.

In his framework of Kansei Engineering, Nagamachi's (1999) case studies used semantic differential techniques effectively to relate adjective words to project specific emotions such as 'speed feeling' or 'tight feeling' in the design of cars, specifically the Mazda MX 5 Miata. Although the experiential terms used in his methods are appropriate, they are too narrowly defined because they are usually only project specific. This study aims to categorize experiential concepts on a much broader platform to cover a range of people's experiences with a range of different designed products.

Adjective descriptors are used to describe formal properties of the product within the four experiential concepts. Similar methods used in obtaining descriptors can be found in Chapanis (1959) and Pepermans and Corlett (1983), where they discuss the use of psycho-physical methods in ergonomics research in which observers make judgments about the sensations they experience, for example, comfort.

These descriptors that are brainstormed and agreed by the professional designers are then clustered accordingly into the four experiential categories into a questionnaire, administered to a sample group of 50 design students randomly selected from a Singaporean tertiary education institution, representative of the main different ethnic groups in Singapore. This sort of sample focus group methodology is now frequently used for design research purposes because it is an economical means of eliciting a broad range of consumer responses on products. Evidence of this can be found in, for example Krueger (1994), The Glasgow School of Art study for furniture design (Macdonald, 1996), The Royal College of Arts's users forums (Coleman, 1997), Strickler (1997), and McDonagh-Phillip & Denton (1999).

7. Data reduction and statistical analyses

There are 5 design products that will be graded for the 4 experiential categories. Each of the 4 experiential categories consists of 10 descriptors, which were graded on a 5 point semantic differentiate scale, with grade 1 reflecting the least agreement and 5 being the most agreement.

The total score of the 10 descriptors for each experiential concept is recorded for each subject's rating relative to each of the 5 products surveyed.

The ratings of the experiential concepts use discrete ordinal data. However, the total score for all ratings of each experiential category is used for hypothesis testing which is a continuous variable with a normal distribution. Therefore, parametric statistical analyses were used. Associations between the 4 experiential factors were determined by the post-hoc regression analysis and by scatter plots.

8. Results

8.1 Influence of experiential concepts on products

Results for the survey done are shown in figure 2. The mean score of the four design factors for all 5 items evaluated by the students, n=50 subjects.

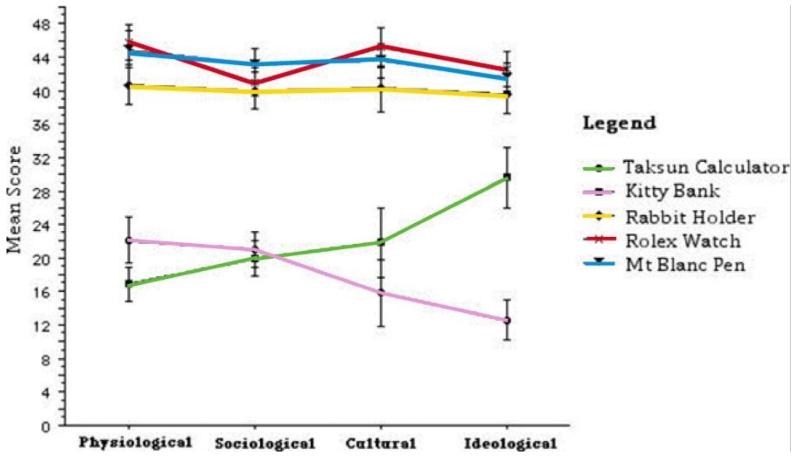

Figure. 2 Mean scores of 5 selected products across the 4 experiential concepts

Overall the 2 products that scored highest were the Rolex watch and Mt Blanc pen. These 2 products were also significantly different compared to the other 3 products ($p<0.0001$). The Rolex watch scored the highest for 3 of the 4 experiential concept, except for the sociological experience category where Mont Blanc pen, scored highest ($p<0.0001$). Error bars represent 1 standard deviation from the mean score. Lines were joined for design factors to demonstrate trends between each product tested

- Rolex watch scored highest for all experiential concepts except for the Sociological experience (figure 2).
- Rolex watch and Mt Blanc pen both scored higher than the other 3 products.
- Hello Kitty savings bank scored lowest for 2 of the 4 experiential concepts (Physiological and Sociological) but quite high for Ideological experience category.
- Taksun calculator scored lowest for ideological and cultural experiential category ($p<0.001$).

9. Associations between the four experiential concepts

Table 1: Overall associations between experiential concepts, rho squared (r^2) and p values, and correlation characteristic between experiential categories

Associations	r^2	p value	correlation
P and S	0.93	0.0001	positive linear
P and C	0.85	0.0001	positive linear
P and I	0.61	0.0001	positive linear
S and C	0.88	0.0001	positive linear
S and I	0.69	0.0001	positive linear
C and I	0.82	0.0001	positive linear

The Pearson Correlation coefficient or r^2 between the overall data from all 4 experiential concepts ranged from 0.61 to 0.93 (Table1). All the 4 experiential concepts have a positive linear correlation, which is statistically significant ($p<0.0001$, refer to Table 1). Therefore all the experiential concepts are related to each other in a way that provides a design aspect or perspective to the design product or object. In addition, all residual plots showed that the linearity and constant variance assumption is valid.

10. Discussions

How subjective experiential concepts of the Physiological, Sociological, Cultural and Ideological experiences influence objective sensorial elements in product design? What is it that makes one product more enjoyable or reflects a person's lifestyle better than another? Why do people find some experiences exciting and affirming whilst others are the opposite? How much do the physiological, sociological, cultural and ideological values and experiences influence our perceptions?

This study has shown that the subjective experiential concepts of the physiological (Pe), sociological (Se), cultural (Ce) and ideological (Ie) trends of each product do influence the quality of the user experience.

The outcome of this survey has rejected the null hypotheses and supported the proposal that when a product has taken into consideration the four experiential concepts of the physiological, sociological, cultural, ideological and manifested them in the form of appropriate formal product qualities as described by Vihma (1995) and Green and Jordan (2000) i.e. form, color, materials, graphics, sound and interaction, the product would score high in the experiential scale and was successful too.

The five products that were chosen for this study were based on their relative success or unsuccessfulness in the marketplace. The success and failure of consumer products as we all know is ultimately decided in the market place (Bonner & Potter 2002).

The Rolex watch and the Mont Blanc pen are very successful consumer products in Singapore (DP Information Network Ranking Services, 2000), whilst the Alessi 'Magic Bunny' toothpick holder has also done well in the marketplace as the agent, X-Tra Design Private Limited, Singapore, has only started the business two years ago.

All three products scored well and had statistically significant and different mean scores from the other 2 products, with the Rolex watch scoring highest for 3 of the 4 design factors.

11. Conclusions

This study was conducted to investigate experiential approaches and how these experiential concepts of the physiological, sociological, cultural and ideological experiences influence specific formal properties of products in industrial design. Results from this study have shown that these four experiential concepts do influence formal product properties. And in turn, the relationship between the four experiential concepts and the product properties influence the quality of the user's affective experiences with products. Correlation tests results also showed support for the questionnaire characteristics to be both independently discreet in describing each design item and yet related in a manner that describes the overall design aspect of the design product.

The results of the survey also showed that when a product has taken into consideration, the four experiential concepts and manifest them in appropriate formal product properties as described by Vihma (1995), Wenger (1998), Kuethe and Reinmoeller (1999), Jordan (1999) and Green et.al. (2000), the product scores high in the experiential scale. From the objective mean scores plotted against the four experiential concepts proposed, significant differences were found between each product which supports the hypothesis that a successful product will score well in all four experiential concepts.

Therefore, indications are that a well designed, holistically considered product would have taken into consideration critical contributing factors such as the physiological, sociological, cultural and ideological elements of people's affective experiences with products.

$$\textit{Holistic Product (Hp)} = Pe + Se + Ce + Ie$$

If the four experiential concepts Physiological Experience (*Pe)+* + Social Experience (*Se)* + Cultural Experience (*Ce)* + Ideological Experience *(Ie*) are well represented in a product, then the chances of success in that product will be high, as is seen in the test results of highly successful products from Rolex, Mont Blanc and Alessi. The 'Hello Kitty' savings bank scored high in the ideological and cultural experience because of the ideological iconic status of the cute Japanese cat's strong associative influences within a community of interest i.e. teenagers, but low in the other two experiential categories because of poor physiological and sociological experiences with the product.

This could also suggest that as designers, we can manipulate specific product experiences to imbue products with biases in terms of these experiential concepts. For example, if we had to make sure of a high ideological content in the products that we were designing.

Manipulation of these formal product properties with an understanding of people's affective experiences within a framework as I have proposed will not only serve to include the intrinsic richness in this area of people's subjective emotive experiences but be able to measure effectively these subjective experiential variables in ways that are useful to the area of product design.

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Innovation

Creativity in Car Design: the Behaviour at the Edges
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Glasgow, UK, 18th-20th September 2012

CREATIVITY IN CAR DESIGN – THE BEHAVIOUR AT THE EDGES

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Abstract: The paper is developed from a longer evaluation of the history of car design. This larger evaluation used statistical processes for investigating the direction of history. Rather than looking at the way that design thinking and paradigms have become established in car design, the paper takes a sideways look at the variations and quirky cars that have been built, categorising them. The paper ends with a brief look at how and why novelty might become innovation and hence alter the course of the product history. This is where the novelty demonstrates significant advantages for the customer and manufacturer.

Keywords: *automotive design, product history, innovation studies*

1. Introduction

Cars have been around us since the latter part of the 19th Century. This paper is a sideways offshoot from a more rational and extensive study into the development of design paradigms in car history. It looks at oddball and off-the-wall thinking in car history and firstly, revels in the variety and secondly, asks more serious questions of how the eccentric might become an accepted innovation.

1.1 Being creative doesn't sell cars

People do not love new ideas, particularly when they might be asked to part with money to purchase novelty. They usually purchase a product to fulfil a need or desire. Products have to work reliably and effectively. Novelty doesn't necessarily do that: novel aspects of products need to be tested carefully to ensure they work and they fulfil the expectations. Since Henry Ford's Model T became successful (around 1910), most people wished to buy personal transport rather than, specifically, a car. If best selling cars are investigated, these are seldom at the forefront of change, however determined. However, change in car design does take place – otherwise we would all be driving Ford Model Ts a hundred years after they were first introduced.

1.2 Definition of the car

The Oxford Dictionary of English (Pearsal & Hanks, 2003) defines a car as *a road vehicle, typically with four wheels, powered by an internal-combustion engine and able to carry a small number of* *people*. One might add that it is designed to carry people, not luggage or goods, and it is typically owned privately.

It would be worthwhile to investigate the edges of that definition. Firstly, is a car a road vehicle? Yes, generally true, but a significant number are either designed as off-road vehicles or for race tracks or other non-road courses. Secondly, some have non-typical numbers of wheels – fewer and greater than four. Some cars do not have internal-combustion engines and yet are still cars.

2. How to investigate creativity in car design

The method used to investigate car history was to analyse examples of cars from 1878 onwards for layout and form (Dowlen & Shackleton, 2003). Nineteen categorical factors were analysed for layout and twenty seven for form using a Categorical Principal Components analysis (Leiden University). Layout variables tend to be categorical in nature, and are related to the position and arrangement of the engine and transmissions, suspension type and body construction. Some form variables are categorical, such as the kind of lighting and front and rear wing forms, but others were obtained by measurement and converted to categorical for analysis. Some were naturally ordered, others ordered by inspecting dates and arranging them into chronological order. This resulted in a number of components for each analysis: the first two components include about 80% of the variation and are therefore the most useful. These four components can be treated as variables and plotted against year of manufacture to allow a line to be plotted along the approximate mean of the data (Figure 1).

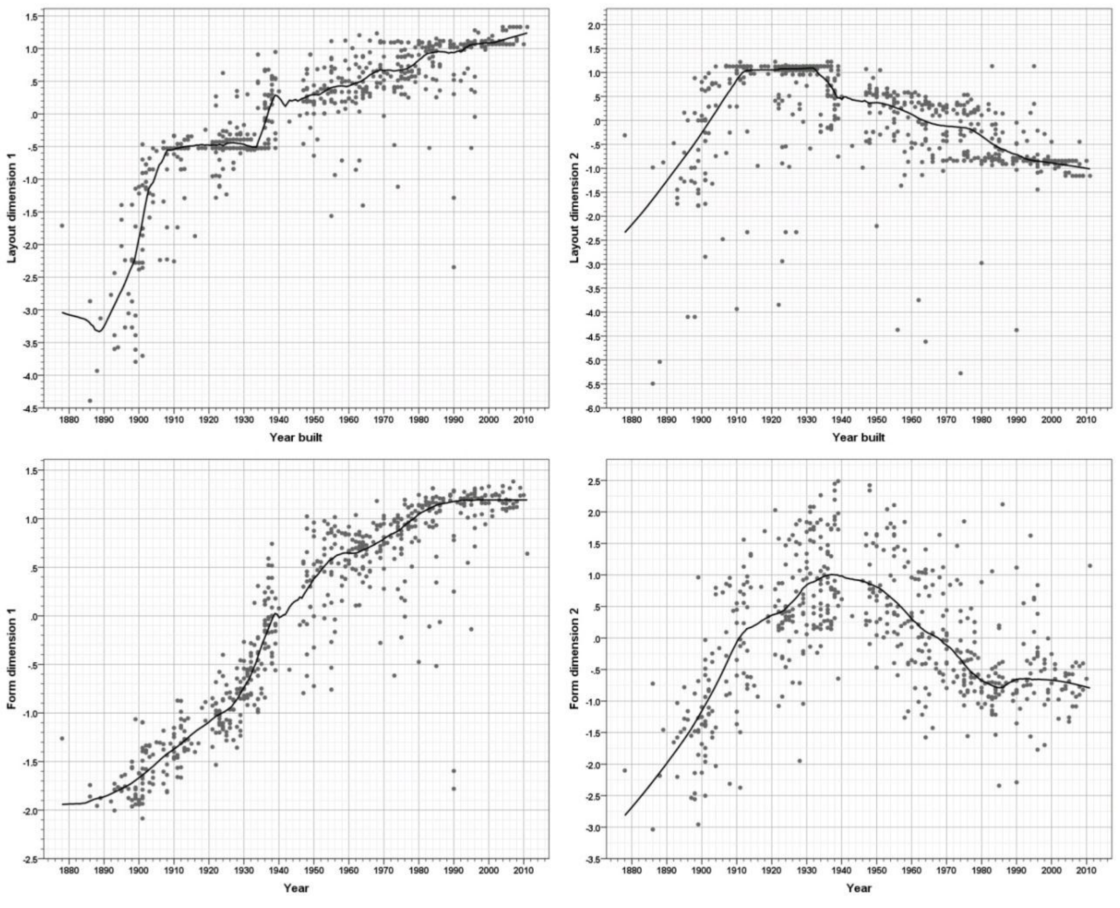

Figure 1. Categorical Principal Component plots for first (left) and second (right) components for layout (upper) and form (lower) analyses: components plotted against date.

The investigation of creativity and innovation in car history is the converse of this. Rather than being a coherent statistical investigation that identifies representative cars and seeks to indentify the direction of change from this, this investigation deliberately looks statistical outliers and categorises them. The initial investigation selected cars simply because it was easy to find information. This resulted in a mixed bag with little coherent reason for selection, on the basis that any car provided useful information. The initial sample included many weird and wonderful examples of creativity, some of which were outside the scope of the car definition such as a non-manufactured design and a disembodied chassis. In the process of obtaining a representative analysis, these find their way to the edges of the statistics and are disregarded. This paper takes these examples and seeks to investigate them in more detail.

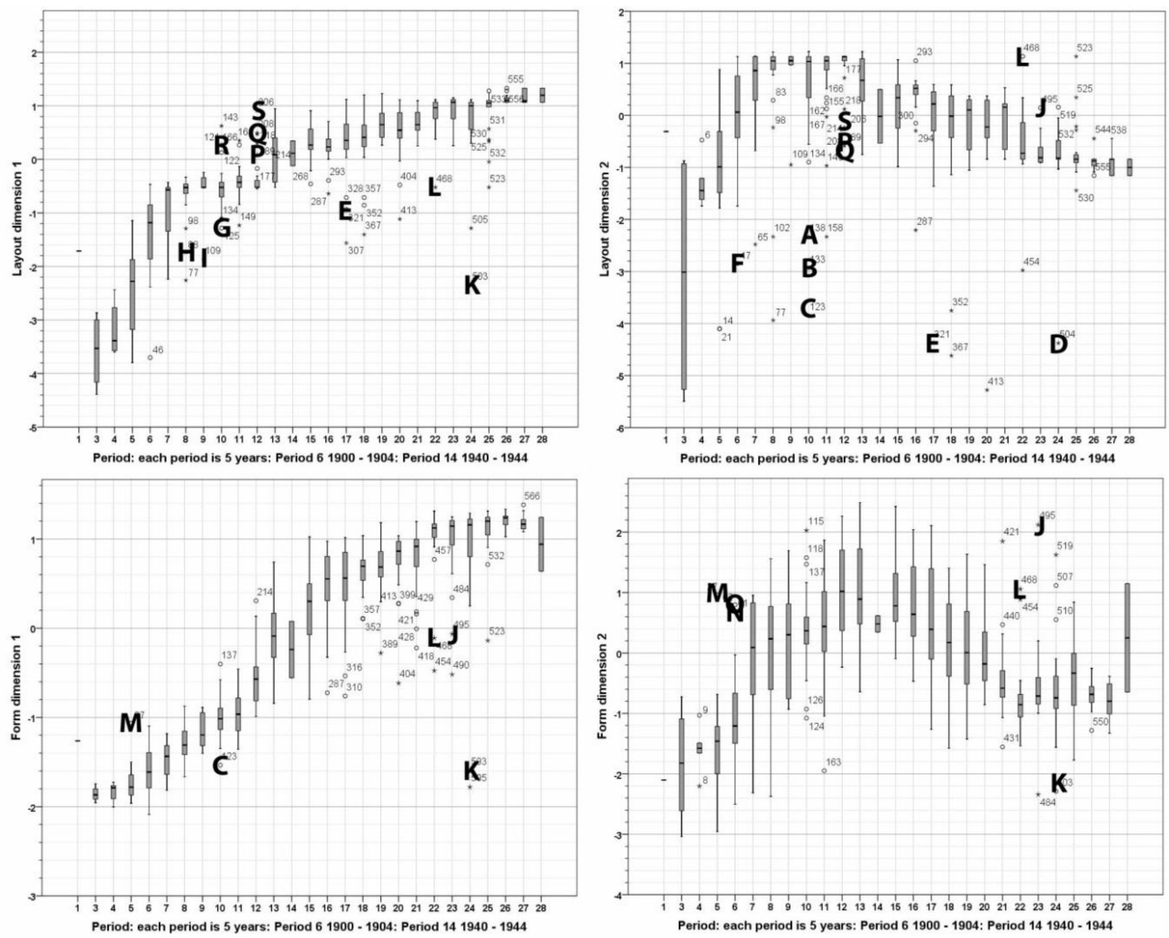

Figure 2. Categorical Principal Component box plots for first (left) and second (right) components for layout (upper) and form (lower) analyses: components plotted against period, with each period being of five years. The points labelled with letters refer to Figures 3 to 7.

Figure 1 shows plots from the main analyses: numerical values of variables do not mean much: the form of the graphs is more important and indicates changes and rates of change of the parameters. Each car is represented by a point on the graphs. There are 575 cars in this analysis. Box plots (Figure 2) investigate the outer edges of the four graphs. These identify the outliers and extreme values. Some are outliers for one variable: others for more than one. The meaning of being an outsider may be that the car leads the way: it may be it is behind the times, or it may simply have a different approach from the mainstream. The interpretation depends on how the variable is moving at that time.

Outliers were categorised using an affinity diagram approach. This produced several categories, with some cars in more than one category or linking two categories. Inspection was more useful than plotting layout and form diagrams and using a clustering analysis. Box plots are date-dependent and what is an outlier at one date may not be an outlier for another.

3. Creative cars

3.1 Eras of car design

Few cars from early eras are deemed extreme. This is because there is a large spread of values for the variables at this point: car designers were not sure how to proceed or what determined a 'car'. By the early years of the 20th century this had been resolved and most cars formed a tightly defined 'paradigm' – described by Sedgwick as a *shibboleth* (Georgano, Sedgwick, & Ason Holm, 2001) and by Utterback as a *Dominant Design* (Utterback, 1996). Eccentricities are easier to identify after that. From the early twentieth century up until the mid 1930s there is a period of consolidation, with movement at the edges. This results in designers trying out ideas and seeing how the market takes them, before the shift of the late 1930s where a new direction had been decided. After the Second World War this direction hardened and there were few attempts to change the layout until the 1970s – when there was a dichotomy of directions, producing a bimodal distribution that masks forward thinkers.

3.2 Categories of creative cars

The affinity diagram approach indicated three main categories of outliers and cars with extreme values. The difference between categories lies in how they relate to the mean line of the variables. These three categories can be described as a) those outside the mean for all dates after the first paradigm was formed: b) those that would not have been outliers if they had been earlier and c) those that would not have been outliers if they had been later.

Cars in the first of the categories tend to be at odds with the 'car' definition. This splits further into groups. Firstly, cars having the wrong number of wheels or wheels in the wrong places. These three-wheelers are below the mean line of the upper right diagram of Figure 2. Examples of five three-wheeled cars are shown in Figure 3. The sixth car is the 1901 Sunbeam-Mabley – with four wheels in diamond formation. The three-wheeled examples include a Morgan, with the single wheel at the rear, a Messerschmitt, with the same arrangement but thirty years later, a Phänomobil with the single wheel at the front – incidentally, driven with the engine on top – and two cars with one wheel on one side and two on the other: a 1922 Scott Sociable and the 1990 Monash University twin-boomed solar car.

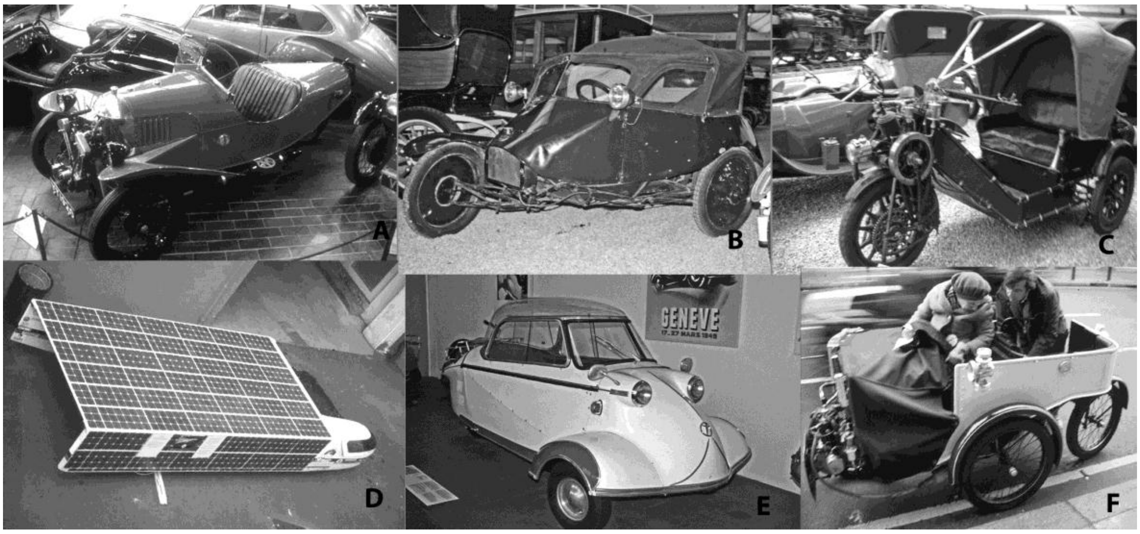

Figure 3. Odd arrangements of wheels. 1924 Morgan (A), 1922 Scott Sociable (B), 1922 Phänomobil (C): lower row, L to R: 1990 Monash solar car (D), 1956 Messerschmitt (E), 1901 Sunbeam-Mabley (F)

Cars in a second group in this category do not have internal combustion engines, such as the Monash solar car above. These are slightly below the mean line in the upper left diagram of Figure 2. In early days internal combustion engines were not the obvious choice, so early electric or steam cars are not extreme and are not outliers. Only a few manufacturers failed to change and steam and electric cars become oddities. These manufacturers are not moving with the rest of the industry, rather than deliberate pushing boundaries.

Cars in this category may have other eccentric features as well. In Figure 3 the Phänomobil and the Sunbeam-Mabley are tiller-steered with no steering wheel: the Detroit Electric also has a tiller and the Messerschmitt handlebars. The Detroit Electric and Sunbeam Mabley also seat the driver at the rear, and the Messerschmitt driver is in the centre.

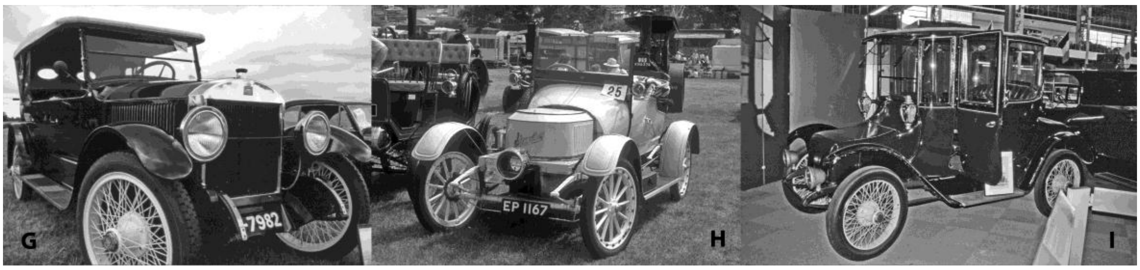

Figure 4. Steam and electricity: 1922 Stanley (G), 1911 Stanley (H) and 1916 Detroit Electric (I)

3.3 Replicas

The second category of outliers is cars that would not have been outliers if they were earlier. Some of these are deliberately so and are historical replicas. Their design process constitutes deliberate flouting of the status quo of car design: disagreeing with the state of the art when they were built. This category splits up into those which are precise copies of specific cars, and those which are intended to copy the flavour of an era. Figure 5 shows three of these cars.

Figure 5: 1986 Kougar (J), 1990 Locomobile replica (K), 1989 Bugatti Royale Replica (L)

Each of these three replica cars takes a different approach and the different dates they are copying mean that they are in different positions on the charts in Figure 2. The Kougar on the left does not copy anything, but picks up the character of an early 1950s open-wheeled sports car. There is no attempt to make the wheels fit the 1950s date – these are from the 1980s. The car on the right is a straight copy of the 1932 Bugatti Royale, using some original parts. In the middle, the Locomobile replica seeks to look and work like the 1900 Locomobile steam car – it has a steam engine – but has enough recent parts (such as front brakes) to make it legal. In all three cases, this aspect of wanting something different has been the spur towards the re-creation. Both the layout and form of these date not from when they were made, but from the date they are copying.

3.4 Innovators

More constructive is a study of the third category of cars: those that are the opposite of this: those that would have been outliers if they had been later. Examples of them can be seen in different periods.

In the early years of the twentieth century three cars stand out as being outliers above the mean in the lower right diagram of Figure 2. They are seen in Figure 6. One is Jenatzy's La Jamais Contente. This car was an electrically powered record car. In terms of its layout, it is not trend setting, but in terms of form it is more integrated (dimension 1) and longer and lower (dimension 2) than other cars. It is cigar-shaped and although trend-setting for form it is outside the mainstream direction. The other two show the direction better, and are a 1904 Mercedes and the 1904 Peerless Green Dragon. These were precursors of a change in (form) design, where cars became longer and lower, with long bonnets at the front with a relatively small passenger area behind. This change was made possible by the (layout) development of the pressed-steel channel-section chassis.

Figure 6: 1899 La Jamais Contente (M), 1904 Mercedes (N), 1904 Peerless Green Dragon (O)

The second major period with a number of innovative cars is in the early 1930s, before significant changes took place in the later 1930s. These cars demonstrate developments in layout, and are seen as outliers above the line in the upper left diagram of Figure 2, and just below it in the upper right one. During this period most cars had longitudinal engines in the front, rear wheel drive, rigid front and rear axles and separate pressed-steel chassis. But some designers were pushing boundaries. These may have had independent suspensions; rear engines, transverse engines, or monocoque chassis.

Cars having rear-mounted engines have never really been regarded as mainstream, although there have been quite a few cars with this feature, such as Volkswagen, Skoda, the much later Smart, and a significant number of sports cars.

Figure 7 shows some examples of cars of the 1920s and 1930s with these features. This shows four different directions that cars might have developed. At the top left is the 1931 DKW F1. Its front wheel drive, transverse engine, independent front suspension and unusual structure push it above the mean, but its two-cylinder two-stroke engine pushes it back down a little. It was a German development of the small car, built for the masses in an economical manner and down to a price. Whether the designer was considering it as progressive is not clear. The Wikipedia website (not always the most reliable) simply states that the company was 'progressive' (Wikipedia). Sedgwick (Georgano, Sedgwick, & Ason Holm, 2001) suggests DKW led the use of front-wheel drive in the 1930s and that it was no longer considered a heresy by that time, which suggests the car's design was outside normally-accepted codes of practice. Although it is not the first recorded use of a transverse engine and front-wheel drive (this honour seems to have gone to an 1895 Graf, one of which is in the Technical Museum in Vienna (Hantschk & Schaukel, 1988)), it seems to have been the first time this was used in a mass-produced car. Although DKW and its offshoots such as the Trabant continued with this layout, the next serious example of this arrangement was the 1959 BMC Mini. The second example, top right, is a rear-engined Mercedes-Benz. In the early 1930s, several manufacturers played with the idea that the 'proper' place for an engine was at the rear and that the driveline between front and rear was misplaced and illogical. Most of this development came from middle Europe, Germany and Czechoslovakia, with examples of the layout from Benz, Rumpler, Hänomag, Mercedes-Benz, Auto Union, Tatra and Volkswagen: of these, the Benz and Auto Union were racing cars and the Rumpler never made it into serious production. Most of these also adopted independent suspension all round, which is probably a more important development. The layout flowered from the mid-1930s. Though it probably had its roots in the German rationality of the Bauhaus, the logicality to placing the engine at the rear did not confer significant advantages over a front-engined arrangement – but in the 1930s it was considered progressive, and managed to flout the accepted codes of practice. The 1934 Citroën (lower right) introduced a combination of front-wheel drive, independent front suspension and unitary body-chassis construction. The lower left example dates from somewhat earlier, and is a 1925 (designed somewhat earlier) Lancia Lambda. This used sliding-pillar independent front suspension and a unitary-construction body-chassis unit. It is now regarded as one of the most sought-after cars of the 1920s, described in *Classic and Sportscar* magazine as the first production monocoque car; innovative and with excellent handling (McKay, 2012).

Figure 7: 1931 DKW F1 (P), 1934 Mercedes-Benz 130H (Q), 1925 Lancia Lambda (R), 1934 Citroën 7A (S)

Another group of innovators on the edge of the box plots is a group of cars from the 1990s and early years of the current century. These are diesel-engined cars, a little in advance of the general market acceptance. This is slightly surprising as the first diesel engined production cars were probably built by Mercedes-Benz as long ago as the 1936 (Lengert, Dreher, & Heidbrink, 2006); it has taken from then to the current century for diesel cars to achieve acceptance in the market.

4. The anatomy of an innovation

None of these developments in car design have the character of the disruptive innovations described by Christensen (Christensen, 1997) and illustrated by the development of the Turbojet (Constant, 1980) as they do not require significantly different manufacturing technologies to be implemented.

What turns something that is merely outside accepted wisdom into an innovation? And why did technologies such as monocoque body-chassis construction, independent front suspension and front-wheel drive became successful innovations whilst the middle European approach with a rear engine did not? And why did it, in some cases, take so long from the earliest use of a particular arrangement to its being accepted as an innovation?

The difference seems to be that developments become innovations after clear advantages are demonstrated that are then translated into an improved product for the customer. In the case of the use of independent front suspensions compared to the use of independent rear suspensions the advantages are to do with the car's roll behaviour, where independence allows a step-change in the moment arm resisting the roll moment compared with a non-independent axle. This allows the independently-suspended car to have a softer suspension than a rigid-axled car could have for the same roll stiffness. This improvement in ride quality sold the arrangement to the General Motors management in the early 1930s, and was deemed to be a noticeable advantage for customers. Independence also confers a significant improvement in handling behaviour by reducing oversteering on the limit (resulting in an infinite response to a steering input) and avoids wheel-shimmy. The use of independent front suspensions also allows the car's engine to be moved further forward between the front wheels, giving more space for passengers and luggage. This movement changes the direction of the second form dimension in the lower right diagram in Figure 1. The improvements arising from monocoque structures may be mainly to do with the manufacturing advantages, in that the combination of a mass-produced body with a mass-produced chassis into a single entity is a logical approach that reduces the number of components. In terms of the customer perception, the improvement is likely to come from the improved use of interior space, the improvement of the form of the car into an integrated whole, and more stiffness for the same weight.

5. Conclusion

The title for the paper originally came from a discussion where someone stated that the interesting things all happen at the edges. This paper takes a look at what these interesting things might be in car history. It is also perhaps a sideways look at the use of statistical analyses: that of analysing the deviant rather than the norm, devising a process of using the outliers to the norm to do so and then gathering the data using an affinity diagram to identify categories and groupings. This may provide an insight into the way in which developments and ideas turn into either dead ends or innovations.

It also indicates that the statistical or quasi-statistical might lead to possible insights that require other processes to investigate them, and ties the analytical analysis process to that of more conventional historical discussion to explain and make further sense of the findings.

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CULTURAL DRIVERS IN PRODUCT DEVELOPMENT: AN HISTORICAL CASE STUDY

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Abstract: This paper explores the role of cultural factors in product development. While a significant amount of research has outlined the economic and business conditions that make for appropriate innovation strategies, the effects of cultural factors such as institutional arrangements, resource endowments, proprietary functions and social values are less well understood and harder to quantify. A historical example is used to identify types of cultural factors and illustrate how they can interact and affect product development. In this case, the research reviews the steam plough and its use by the Duke of Sutherland for land reclamation in the late 19th century. Despite being vastly expensive and in this case of limited effectiveness, a unique set of cultural factors meant that huge sums of money were invested in the design, development and implementation of these devices. It was ultimately unsuccessful, with many crofters returning to more primitive methods with better results.

Keywords: *product development, cultural factors, steam plough, case study.*

1. Introduction

Since the Cox Report was published in 2005 (Cox, 2005), there has been an increasing demand for industry to be more innovative in the development of new products and services, with James Dyson's vision for an Ingenious Britain (Dyson, 2010) and the Technology Strategy Board's vision for accelerated economic growth by 'stimulating and supporting business-led innovation' (Technology Strategy Board, 2011) among the latest high-profile examples. These concepts remain focussed on business and economic measures as indicators of conditions and performance of innovation. While they can provide an understanding of financial issues driving product development, they do not reveal many of the other cultural factors that can play a part in taking a new product to the market. These are harder to quantify, encompass a wide range of issues and interact in complex ways.

A number of frameworks for cultural analysis have been proposed, including sociological approaches that identify nationalist dimensions such as individualism, masculinity, power and uncertainty (Hofstede & Hofstede, 2004; House, Hanges, Javidan, Dorfman, & Gupta, 2004), and anthropological approaches based on observations of context, space and time (Hall & Gay, 1996). On the effect of culture on design and innovation, there are a range of factors that have been identified as important, ranging from labour costs to religion to values (Diamond, 1999; Mokyr, 1990). This research uses a particularly rich historical example – the use of steam ploughing in the reclamation in the Scottish Highlands 1869-1884 – to review how these factors work in a practical sense, and how they should be considered as key drivers in any product development process.

2. Culture in product design

New Product Development (NPD) has evolved into a prescriptive set of steps such as marketing, specification, concept design, detail design, manufacture and retail (Pugh, 1991). The evolution of ideas and products, however, is not an exact science, and despite the increasing clamour for 'innovation' across industry there is still disagreement over how ideas emerge and succeed in the development process. The Schumpeterian model (Akrich et al., 2002a) of the hero inventor who is single-handedly responsible for the success of new products has been widely refuted (Diamond, 1999; Mokyr, 1990; Williams, 1987). Major scientific and technological breakthroughs such as the development nuclear power and space travel are inevitably the result of large scale collaborations. These require a multitude collective agreements, or 'socio-technical negotiations' across a individuals and groups to achieve realisation of the goal (Akrich et al., 2002b). Indeed, the past has a tendency to highlight the importance of individuals when there were many other factors at play, and on closer examination many cases '...demonstrate that new technologies are seldom, if ever, developed by a single firm alone in the vacuum of an institutionalized environment' (Andrew H. Van de Ven, 1993). For example, in the development of the telephone Edison was working in light of 20 years of development, beginning with Meucci's communication devices of the early 1850s. He had a team of assistants and engineers as part of his development team, and even when he was awarded the relevant patents for the telephone in 1876, he was for several years in dispute with Gray, who has been undertaking parallel research. This is not to detract from the undoubted talent and leadership of Edison and others – only to illustrate that no development is without a range of contextual factors and that all but the most basic products involve some level of collaboration. Development therefore has a cultural dimension which can play an important role in motivation and acceptance through the process.

3. Origins of culture

The word culture originally – in the 15th century – meant 'a tilling of the land', and was derived from Latin cultura 'a cultivating, agriculture'. This is appropriate given that it was when humans moved from a hunter-gather to agricultural mode of living that permanent, continuous communities were formed. It was at this point that harmonious co-habitation, laws and traditions were established to allow larger numbers of people to live and work together. From early 19th century, culture was used to describe 'artistic and social pursuits, expression, and tastes valued by a society or class'. While support of creative arts and an appreciation of their enriching qualities are important in a civilised society, it can have negative connotations for those who feel alienated from the abstract or stylised presentation of certain forms, such as conceptual art or opera. Furthermore, during the colonising period of various Western empires, confidence in the superiority of these aspects of culture was used as justification for the destruction or assimilation of many indigenous communities. Later in the 19th century, however, the definition of culture was widened to include the 'activities, ideas and traditions of a group of people'. This more accurately reflects the wide range of behaviours that are developed, valued, and reinforced by different cultural groups. There are certain qualities of the human psyche that are universal in nature. These are the fundamental ability to feel love, anger, fear, joy, sadness etc. as well as a need to socialise, exercise, play etc. What a group does with these basic drives is partly determined by their shared cultural values and reinforced over time. Finally, personality is a unique set of characteristics not shared with any other human being (Hofstede & Hofstede, 2004). This work illustrates the effects of cultural context while considering the role of individuals in the face of these.

3.1. The case of the steam plough

An historical example has been used to better understand the role that cultural factors can play on the development and introduction of new products. Agriculture has been a primary concern of human development and an area where much early design and innovation has taken place (Haining & Tyler, 1985). Beginning with the use of an appropriately shaped piece of wood to groove the soil as early as 5000BC, the plough has been a key product in productive working of the land. By 3500BC, an ancient Egyptian seal documents the use of a plough with handles added and men pulling the implement. Innovations such as the use of coulter, mould boards, and wheels subsequently emerged. It is interesting to note the vast range of configurations developed based on local conditions – the Museum of English Rural Life at the University of Reading holds hundreds of examples of plough design, each adapted for the particular characteristics of the land on which it was to be used. As ploughs became larger and heavier, animals were utilised to provide the independent, portable source of power required for the ploughing of fields. Oxes were bred specifically for this purpose, although they were generally harshly treated, with the ploughing rope commonly attached to their horns and even their tails. The distinctive factor affecting the plough was that it required an independent, portable form of power. The ox was bred to pull the plough, later to be supplanted by the heavy draught horse. These animals were harshly treated, with the ploughing rope attached to the beast's horn and even its tail. Their role was pivotal in the development of agriculture, and definition of land area in acres is indeed derived from the work that an ox could do in a day.

The introduction of steam ploughing in the 19th century was a radical departure from what had gone before. The development of steam power was initially motivated by the need to pump water from mines. Laterally, its transport, marine and industrial applications were critical to its development – its use in ploughing is somewhat nominal and it was not until the emergence of the internal combustion engine that the use of animals ceased. The steam engine was the key invention industrial revolution and steam ploughing an instructive example of Victorian optimism. It was used increasingly from 1855 onwards, and in 1869, the 3rd Duke of Sutherland began the largest land reclamation works in British history on his estates in the north of Scotland (Tindley, 2009); part of this project was fuelled by the Duke's enthusiasm for the latest steam technology, in particular the steam plough, being developed at this time by John Fowler's and Co. of Leeds (Lane, 1980). In partnership with Fowler's, itself a personal business based on improvements in steam machinery, the Duke adapted the eight steam plough sets he purchased from them to the specific difficulties of the Sutherland terrain and landscape.

The use of steam ploughing was never viable in these harsh geographic conditions. The stony ground required a huge amount of preparatory work before ploughing could even begin, and the engines were too cumbersome and heavy for the hilly, boggy terrain. A huge number of workers, mainly local workers, were employed to assist in the work. Problems with engaging them can be attributed to their pragmatic and skeptical view of the work – many continued to use more primitive methods independently with better results. Despite vast expense and limited effectiveness, huge sums of money were invested over a considerable period in the design, development and implementation of the Sutherland plough (Roberts, 1880). While the results were impressive, in hindsight it was always doomed to failure. The application of a rapidly emerging technology, the political and economic tumult of the Industrial Revolution, the range of stakeholders involved, and the Duke's singular personality make this a rich example to unpick the many social, personal and environmental issues that form part of a cultural landscape, and can impinge on motivation for product innovation.

Figure 1. Steam ploughing by Loch Shin, copied from a painting by Rev. J M Joass in the 1870s

3.2. Steam ploughing in Sutherland

Steam ploughing typically consists of two traction engines located on either side of the field, and connected with a steel cable. A ploughing implement is dragged between the engines, with each pulling in turn. The plough can typically pivot around a central axis to allow it to work in two directions. Rocks and stones are then removed and often used to help form drains, boundary dykes and roads as appropriate. The ground would then be broken up, with lime spread prior to crops being sown.

In the case of the Sutherland reclamations there were significant environmental challenges: the interior consisted mostly of mountains, moors and bogs. In addition to this, the land was extremely rocky. Several adaptations were made to the standard plough design to meet these challenges (Lane, 1980). An extremely robust plough was required, so a single, large turn-furrow was used to cut through the soil rather than the four or five normally employed. In addition, very broad rollers were used to prevent the plough burying itself in soft ground. This configuration was found to perform well in ground where there were no obstructions, but the majority of land was riddled with rocks and boulders of varying sizes. These caused considerable damage to the share (the cutting head of the plough) on impact. To address this, a revolving coulter was developed. This was a steel disc placed in front of the share, cutting the soil to a depth of two inches below. When meeting a large stone, it would lift the plough over it. A further improvement was ‘the Duke’s Toothpick’. This was a large iron hook that trailed behind the rear of the plough and lifted any rocks the coulter was unable to move. Extremely large boulders would cause the engine to be backed up and the Toothpick lifted over, with dynamite or manpower used for removal. The ploughs were drawn at a slow speed, with engines operating at double their nominal power to deal with these considerable challenges. There was a trade-off to be made with power and weight, however, as larger, more powerful engines had a tendency to sink in bogs and cause delay.

There were also a number of ancillary developments around the reclamations. A sledge for stones allowed up to five tons to be drawn using the steam engines. This was designed to tip the stones out at the end of its run, and in addition to its convenience the dragging across the surface proved beneficial to the broken land, the rubbing action disintegrating it. With sheep grazing on the surrounding land, it was desirable to fence each field off entirely as the ploughing was taking place. To address this, a folding fence was developed that used steel wire with adjustable stays that could be quickly assembled. To make these sufficient for cattle and horses, coils of wires with ‘spikes... twisted at intervals into them’ were developed – now familiar as barbed wire. Finally, in order to break down the peat after ploughing, a ‘Discer’ was invented. While all previous machines tended to get choked by the fibres of peat or turf after it had been loosened, the Discer was able to disintegrate enough of the ploughed field to allow seeding without disturbing the inverted turf. It consisted of a frame with series of discs mounted at an angle to the line of draft, cutting to a depth of two to five inches.

Steam ploughing in Sutherland, although ultimately doomed to failure, therefore consisted of a series of innovations. There were a range of people who were involved in the process including: the Duke of Sutherland, financier of the scheme and owner of the land; Fowler's and Co., steam plough manufacturer; John Greig, employee of Fowler's and based in Sutherland; John McLellan, a Sutherland farm manager who became deeply involved in the works; and the crofters and small tenants who worked on a temporary basis. Each of the parties involved had their own motivations, values and skill sets. As well as being distinct groups, the cultural dynamic of these groups is critical in understanding the motivation for the steam plough's on-going development.

4. Framework for analysis

A number of texts have reviewed human evolution and the range of factors involved in innovation in broad terms (Diamond, 1999; Mokyr, 1990). In a more modern context, tools such as PEST (Political, Economic, Social and Technical) analysis have been used to frame the macro-environment that forms operate in. These can be used when developing strategy or undertaking market research. Social constructivists have developed a number of approaches to understanding technological development. Social Construction of Technology (SCOT) is a theory that argues humans shape the development of technology (Pinch & Bijker, 1984). Actor-Network Theory is a subset of SCOT, and places material things and concepts in a single network map that captures all factors in the development process. In a more empirical approach, Van de Ven (Andrew H. Van de Ven, 1993; Andrew H. Van de Ven & Garud, 1993) has undertaken longitudinal studies that evaluated documents generated in the product development process to understand some of the social aspects that impact directly on innovation.

While Van de Ven's work is primarily focussed on the structures and formations of communities, it has provided a basis for a set of criteria that also take account of the cultural values and beliefs of the different groups involved. This consists of four main cultural factors: *institutional arrangements* are concerned with the rules and norms of the society in which individuals and organisations function; *resource endowments* relate to the financial and economic resources pertinent to development; *social values* pertain to the character, beliefs and morals of the parties involved; and *proprietary functions* incorporate the particular industrial, educational and geographic context of the work. These criteria are set out in Table 1, along with the examples relevant to the Sutherland study. These are reviewed in more detail below.

Table 1. Cultural factors relating to the use of the steam plough, after Van de Ven (1993)

Cultural factor	Institutional arrangements	Resource endowments	Proprietary functions	Social values
Criteria	• Political structures • Governance and regulations • Technology standards	• Financing and insurance arrangements • Market creation and consumer demand • Labour pool	• Scientific/ technological research • Educational systems	• Openness to technological change • Religion and belief systems • Social groupings and moral codes

Examples	• The British Establishment and the Duke's rejection of political office/ traditional roles • The perceived role of landowners and how investment in technology and land supported this • Patents developed by Fowler, the Duke, Greig and their worth	• The Agricultural and Industrial Revolutions, High Farming, 1850s, 1860s and its effect on agricultural product innovation • The Great Depression, 1879 – 1905 and subsequent challenges faced by Fowler's • The Duke's financial position and eventual abandonment of the reclamations given the poor returns	• Evolution of steam power and its application to different industrial contexts • Technical expertise and the limitations of the apprentice/ entrepreneurial model of Great Britain	• Victorian passion for technology and mechanical development • Role of the individual in Judeo-Christian religion and variations in faith across the collective • The perceived resistance of the Sutherland tenants to the work required in steam ploughing

4.1. Institutional arrangements

Motivation for the reclamation of Sutherland is rooted in political factors. The title of Duke of Sutherland was bestowed upon the 2nd Marquess of Stafford in 1833 by William IV. The Dukes of Sutherland were one of the richest landowning families in the United Kingdom and as bastions of the aristocracy were expected to take an active role in political life. The 3rd Duke, George Granville William Sutherland Leveson-Gower (1828 –1892) was, however a rather idiosyncratic character. He had no interest in public speaking or in politics, instead growing up fascinated by fire engines, railways and industrial enterprises of all kinds. The steam plough first came to his attention through demonstrations on the banks of the Nile in Egypt, where Britain's Imperial interests were still active. It occurred to him that this emerging technology could be harnessed for the challenges of his own land.

As the reclamation work continued, a series of patents were awarded to those involved. Intellectual property rights in Britain were the most sophisticated in the world, and provided a significant financial incentive to those named on them. The emphasis on the generation of intellectual property in the UK has been attributed as a key factor in its ascent during the Industrial Revolution. The development of the steam plough and solving of technical challenges by people across the collective is instructive. Fowler's had little hesitation in committing significant resource to the development of a new plough suitable for the demands of the Sutherland reclamations. The fact that a range of people involved in the project that did not have an engineering background, such as the Duke, his secretary and estate manager, suggests a 'can do' attitude towards the work and machinery required.

4.2. Resource endowments

Critical to the instigation and persistence of the Sutherland reclamations was the Duke's vast wealth. He had an annual income of £120k, the equivalent of £20m today. Despite being one of the richest men in the UK, the money he invested in the Sutherland reclamations was enormous, totalling £254k from 1871 to his death in 1892 (Spence, 1960). In the face of continuing technical and environmental challenges, he continued to pour money into a project that was vastly over budget. By 1880 it was apparent that the scheme was likely to make a significant loss. Despite this, the Duke continued to invest for a further four years before work came to a halt. Without this massive capital investment, the Sutherland reclamations would never have been possible. While this had serious implications for the Duke's successors, the freedom afforded by this generous budget allowed Fowler's and Greig to explore technical options and overcome problems that may have been otherwise insurmountable.

The Sutherland reclamations took place at the height of the Industrial Revolution. During this period, new technologies were constantly emerging, mechanising and automating industries which had changed little over hundreds of years. The 'High Farming' movement of the second half of the 19^{th}C was typical of this - innovations in fertilisers, foodstuffs, drainage and machinery revolutionised the production of food. This provided rich harvests and made it a prosperous period for the agriculture industry. The inducement then, to reclaim large tracts of previously wild land for productive agricultural use was attractive to the Duke and the financial rewards substantial. Despite the obvious geological challenges, the moderate success of such enterprises elsewhere in the country and the continuing evolution of technology would have made the proposition all the more attractive. Although the Duke was incredibly wealthy, he could not escape the economic climate. A factor in the eventual cessation of work may have been the Great Depression (1879-1905), when the sums being invested were no longer viable no matter how enthusiastic the Duke remained for the scheme.

4.3. Proprietary functions

The technical expertise of those involved in the project was a product of Great Britain's entrepreneurial industrial economy. Fowler's was a company experienced in iterative improvement of proven technologies. The Duke was a headstrong enthusiast with significant financial resources. In terms of taking a technology and making it work, the attitude and skills of this profile is ideal. As machinery and technology became more and more sophisticated, and the application of scientific principles necessary to understand and evolve complex designs, the more formal education system of countries like Germany began to prevail. Longer years of structured technical training allowed their engineers to plan long-term development projects that would in the coming years deliver economic success in areas such as the automotive and aeronautical industry. The Sutherland plough was an example of reactive designing, where changes were made as necessary based on the problems of undertaking the work. This iterative process relied on the resilience and ingenuity of Fowler's to ensure the work continued, but did not serve to identify and address broader strategic issues such as the development of the internal combustion engine and its implications for steam power.

4.4. Social values

There were three principle social groups in the collective involved in the Sutherland reclamations: the Duke, financier of the project and representative of the landed gentry; Fowler's and Co., who worked closely with the Duke in design and development of the Sutherland plough and seconded employees to aid with development; and the Sutherland tenants who were a traditional crofting community forced to undertake the labour associated with the work. Each of these groups had distinct vested interests and values that affected their approach to the work and to collaboration.

Victorian 'values' are often characterised as puritanical, with a strict moral and ethical code applied to all aspects of life. This does not seem to have been the case with the Duke, who was known to be of a 'carefree, independent nature' (Sutherland, 1957). Indeed, after the death of his first wife, there was considerable scandal when he remarried within three months – the 'proper' mourning period was considered to be a year. It was also said that he popularised the use of cigarettes in Great Britain rather than the customary cigars after walking down Bond Street in London smoking one (Sutherland, 1957). He did, however, have a deep passion of technology which is another characteristic of the

Victorian Era. If the history of human invention is considered, the explosion of new machines and devices through the Industrial Revolution is startling. It is little wonder that faith in new technologies and developments was so strong. When the Duke's seeming lack of inhibition is coupled with the passion for technology of the time, it provides a strong motive force for the work.

The crofting community were perceived as being particularly resistant to the reclamation works. There could be as many as 100 working in a field at a time, a surprisingly large number to operate two engines and a plough. They were regarded as surly, uncooperative and obtuse in their attitude and engagement with the work. From the perspective of the Duke and the establishment, the tenants were being provided with respectable jobs that would improve their lot. As a group who had tended the land with structures, tools and techniques developed over hundreds of years, the sudden changes imposed through the operation of unfamiliar technologies must have been disconcerting. This tension was evident all through the years of reclamation work, despite all the technical and environmental problems that made the reclamations so difficult, it was reported at the time that 'the chief mistake has been that sufficient supervision was not provided' (Roberts, 1880).

5. Conclusions

While the Sutherland steam plough included a range of innovative design features and the reclamation process was doggedly persistent over a number of years, it was ultimately unsuccessful. Even though the design improvements allowed the ploughing at times to operate impressively, huge numbers of men and crippling on-going investments were necessary to support the work. When it became apparent that the fields which had been ploughed were only moderately fertile and in some cases rapidly returned to their natural state, the work was eventually stopped. That is not to say that the Sutherland plough itself is not without merit: it is an imposing product, full of unique and highly specialised design features that make it distinctive in the era of steam ploughing.

In hindsight, it seems obvious that the cost, effort, geographical and technological challenges made the steam plough impractical. By reviewing and understanding the cultural motivations of those involved, we can better understand the direction and persistence of a line of development. The institutional, resource, proprietary and social factors all played a role in facilitating work undertaken in the face of such trying circumstances. It is, however, perhaps the social values that are most revealing. At a broad level, the strength of Victorian optimism and the faith in the deployment of steam power meant that the enterprise was undertaken with a good deal of enthusiasm. At an individual level, the Duke's idiosyncratic approach to his aristocratic role as well as his vast financial resources were also critical in facilitating the work. And while there was a great deal of good faith in the relationship between the Duke and Fowler's, with a series of innovations made during their collaboration, there remained a continuing unwillingness of the crofting community to embrace the use of the machinery.

This example illustrates the interplays between the cultural values of different parties in a product development process. These factors remain just as pertinent in modern product development, whether it be large-scale projects such as space exploration or specific products tailored for smaller societies or groups. It is the intention of the researchers to further explore the role of cultural drivers in product development through development of an analytical framework, considering techniques such as actor-network analysis to help quantify the cultural motivators at play, their interrelations, and what their influence may be on a particular development process. This will be developed through the interrogation of further historical case studies with the intention of eventually using it to review contemporary product development processes.

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HOW DESIGN THEORIES SUPPORT CREATIVITY – AN HISTORICAL PERSPECTIVE

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Abstract: In this paper we analyse the relationship between creativity issues and design theory. Even if these two notions apparently correspond to two different academic fields (psychology, cognitive science and management for creativity; engineering science and logic for design theory), they appear as deeply related when it comes to innovation management. Analyzing three historical moments of design theory building (ratio method in 1850s catching up Germany, 20th century systematic design and 1920s Bauhaus theory), we show that there is a dialectical interplay that links creativity and design theory, articulated on the notion of "fixation effect": creativity identifies fixation effects, that become the targets of new design theories; design theories invent models of thought to overcome them - in turn these design theories might also create new fixation effects that will then be designated by creativity studies. This dialectical interplay leads to regularly invent new ways of managing innovation, ie new ways of managing knowledge, processes and organisations for innovating. We use this framework to analyse recent trends in creativity and design theories.

Keywords: *design theory, fixation, history of design theory and creativity*

1. Introduction: similar or opposite? – The paradoxical relationship between creativity and design theory

In this paper we analyse the relationship between creativity issues and design theory. Even if these two notions apparently correspond to two different academic fields (psychology, cognitive science and management for creativity; engineering science and logic for design theory), they appear as deeply related when it comes to innovation management. Still there are two contrasted situations: in engineering design, design theories that support innovation processes, seem to be at their limits when it comes to contemporary creative issues; conversely in industrial design, the innovation process of the industrial designer seems to meet contemporary creativity issues… but the underlying design theory is often hardly explicit, which make collaboration with other actors difficult. Is there an opposition between creativity issues and design theory? Or is there a convergence?

In the classical R&D perspective, innovation management aims at improving product quality and variety, by relying on engineering science, through project management processes based on R&D organizations. It is based on clearly established design theories (systematic design). Actually these engineering design theories claim to be creative. But creativity studies show that some types of innovation are actually out of the scope of classical engineering design: how to change business models, to involve users, to radically change technologies, to create disruptive innovation breaking design rules? Hence the opposition is caused by the *inadequation* between design theory and contemporary creativity issues, the latter underline the limits of the former to address contemporary types of innovation and the need for new organizational forms. Thus calling for *design theory renewal*.

Conversely, industrial design claims to be serendipitious, divergent and rule breaking: creativity issues would be more adequately addressed by industrial designer's method. But this raises another question: what is the (industrial) design theory that enables to address creativity issues?

Hence between design theory and creativity issues there is neither an intrinsic opposition nor a natural convergence. We rather intuit a "dialog" between both. At certain historical moments, this dialog enlights the limits of existing design capabilities confronted to new, emerging innovation issues. This can lead to the emergence of new design theories and new design capabilities. *Hence design theory and creativity issues would be two ways –one critical, the other normative- of dealing with innovation management. Their interplay would lead to invent specific forms of innovation and specific capabilities.*

To investigate the issue of the relationship between creativity issues and design theory, we will use an historical perspective: we revisit three historical moments of design theory building. These are: the ratio method, ie the design theory that will be used in the 19th century German industrial catch-up; systematic design ie the theory that will be used for organizing R&D departments from 1950s onward in the whole world; and 1920s Bauhaus methods and theory, that will be used in a large number of design school in the world. For each moment we study the stimuli, the type of innovation that is expected, and the types of design capabilities, ie the type of innovation organisations, that are inspired by design theory (part 2). We show that there is an interplay that link creativity issues and design theory, articulated on the notion of "fixation effect": creativity identifies fixation effects, that become the targets of new design theories; design theories invent models of thought to overcome them - in turn these new design theories might also create new fixation effects that will then be designated by creativity studies. This dialectical interplay leads to regularly invent new ways of managing innovation, ie new ways of managing knowledge, processes and organisations for innovating.

2. Part 1: an analytical Framework for Learning from the history of Creativity Issues and Design Theories

2.1 The tensions between creativity and design theory at the heart of innovation management?

Engineering design, as defined in the reference manuals for teaching design to engineers all over the world (Roth 1982; Rodenacker 1970; Pahl and Beitz 1977, 2006; Ulrich and Eppinger 2008; Pugh 1991; French 1999), aims at proposing convergent thinking method for developing new product, not relying on chance, based on scientific knowledge and design rules and even facilitating the application of known solutions.

It is striking to see that creativity was often defined in contrast with these features. Whereas engineering design will claim to be based on rational problem solving, decision making and optimization, creativity studies are precisely born from the intuition that there might be other forms of intelligence. A lot of studies on creativity in psychology were launched in the 1950s after the presidential address given by a famous American psychologist, Joy Paul Guilford, who defined creativity as a form of intelligence to be distinguished from the one measured by IQ (Guilford 1950). Whereas engineering design process is organized to be linear and without surprises, the « creative process » is far from a predictable one: it relies on serendipity, on « flashes of insights » (Wallas 1926). Whereas engineering design relies on rules and established solutions, creativity consists in breaking rules and routines (Amabile et al. 1996; Boden 1990) instead of using the existing one.

The tensions between engineering design and creativity match three main debates in innovation management:

- how to deal with knowledge? Studies on R&D organizations underline the importance of relying on knowledge and competences. For instance the notion of Absorptive Capacity characterizes the contribution of Research to the innovation process as the capacity to absorb relevant external knowledge (Cohen and Levinthal 1990; Lane et al. 2006). Conversely studies in creativity have shown how knowledge can be "fixing" (Jansson and Smith 1991; Smith et al. 1993), how knowledge can become a core rigidity instead of being a core capability (Leonard-Barton 1992). Hence knowledge might be a limit and a support of innovation. And compromises are not so easily thought (Weisberg 1999; Basadur and Gelade 2006).
- Is the innovation process diverging or converging? Creativity studies will insist on the necessity to diverge, even if some authors will admit that convergence is also important, often advocating for an initial divergence followed by an unavoidable convergence (Eris 2004; Dym et al. 2005; Cropley 2006). Conversely literature on the innovation process will favour convergent thinking, even if divergence might be also interesting from time to time (eg: diverge in the fuzzy front end (Koen et al. 2001; Reid and De Brentani 2004); or diverge during the processes, in flexible product development (Kelley 2009; MacCormack et al. 2001)). Here also the interplay between creativity and design theory might help us to think out new combinations between divergent and convergent process.
- Is the innovation process based on strong leadership and well-administrated projects or it is more based on autonomous creative teams? Since Osborn's invention of brainstorming at his communication agency BBDO (Osborn 1957), creativity studies in organizations tend to analyse teams creativity (Hargadon and Sutton 1997; Paulus and Brown 2007; Paulus and Yang 2000). Conversely the study of organisation of innovation will insist on the structures, methods and administration of innovation, following, as advocated by O'Connor, a "system approach" to radical innovation (O'Connor 2008). Some authors in the organization of innovation call for a combination of creative teams and non-creative one in ambidextrous organization (Tushman and O'Reilly III 1996), but empirical studies have stressed the limits of such simplifying compromises (Brown and Eisenhardt 1997).

2.2 Beyond compromises: the dialectical interplay between creative issues and design theories?

Interestingly enough the tension between creativity and design theory suggests more than just compromises –compromises in knowledge to balance fixation and un-fixation, compromises between convergence and divergence in innovation processes, compromises between control and autonomy in innovation organization. The intuition comes from two clues:

1. One might think that creativity has no place in design theory. This is far from truth: creativity was an historical issue for the theorists of Systmatic Design, as underlined by Wolfgang

König (König 1999). For instance in the 1850s, the great ancestor of German systematc Ferdinand Redtenbacher proposed a proto-version that intend to make the designer (the technician of that time), “more innovative” (Redtenbacher 1852). The first teacher of an elaborated “systematic”, the Russian professor Peter Klimentitsch von Engelmeyer called his method a “theory of creative work” (Engelmeyer 1895). As analysed by Mathias Heyman (Heymann 2005), in the 1970s there were multiple debates in the German systematic community to clarify how far systematic design was already addressing creativity issue. More recently Udo Lindeman, former president of the Design Society, has shown how classical systematic design took into account the creativity required from design engineers (Lindemann 2011). This means that past design theories have certainly “invented” ways to manage knowledge, processes and organisation for innovation. Hence design theories, event past design theories, might be a good wellspring of knowledge for working on innovation management.

2. In certain fields, like industrial design, design and creativity are not in tensions but, on the contrary, are considered as synonym. If there is some kind of design theory or method in industrial design, then this theory or method might propose some ways of dealing with knowledge, processes and organization for innovation management.

We are led to reinterpret the above-mentioned tensions in a more “historical” perspective. At a certain moment in time, the installed design capacities appeared as too limited – with regards to societal issues, new imaginary,… Creativity precisely identifies “fixations” that limit past design theories and that have to be overcome by new design capacities. Under these critics, new design theories are proposed to “stretch” design capacities to overcome fixations. By so-doing they propose new frameworks that enable new ways of dealing with knowledge, processes and organizations for innovation. And they finally enable new types of innovation outputs. This is our main research hypothesis: *there might be a “dialectic” interplay between creativity issues and design theories, that led to regularly invent new forms of design capabilities (ie new types of innovation management) and new types of innovation outputs*.

2.3 Method: analytical framework to study historical cases

To study this hypothesis, we investigate three historical moments of creation of design theory to analyse whether and how it copes with creativity issues and what the formal proposals tell us about knowledge, process and organization for innovation.

We selected three theories that had historically a great diffusion – ratio method was taught in a large majority of German Technische Hochschule from 1850s to early 20th century, Systematic Design is still at the basis of main courses in engineering design, Bauhaus theories inspired industrial design teaching since its creation in 1920s. We chose two theories in engineering and one in industrial design.

In each case we followed the same analytical framework:

- We characterize the creativity issues that the theory intended to address – the kind of “fixations” to overcome.
- We analyse the principles of the theory (we briefly present some illustrations) and the way it enables to address the creativity issues, to overcome the fixation effects. In particular we underline how it leads to new ways of dealing with knowledge, processes and organization for innovation – ie how it leads to propose new design capabilities.
- We finally analyse the types of innovation that is expected from the theory.

3. Part 2: historical cases of inventions of design theories - German engineering design and Bauhaus industrial design

The analysis of the historical emergence of past design theories reveals an interesting interplay between creativity issues and design theory. Two main propositions emerge from this history:

P1: creativity issues are symptoms of the limits of existing design theories confronted to new innovation issues. They emerge at the borderline of established design practices and evolve over time

In the 1850s creativity issue is the fixation by existing, already designed objects; in the first half of the 20^{th} century creativity issue is the fixation by existing design rules and machine elements, leading to non-relevant reuse of existing knowledge; in 1920s in the Bauhaus, creativity issue was the "clichés" and the limited perception capacity.

P2: design theories emerge to overcome contemporary fixations and extend generative capacities.

In the 1850s, ratio method help to use relevant rule for designing context-sensitive products; in the 1950s, systematic design proposed to design according to pre-ordered languages (functional, conceptual, embodiment, detailed design) to enable divergence and the production of knowledge at the right moment and hence to propose constantly improved products. In 1920s Bauhaus theorists renew theories of forms, colors and materials to enable generative super-imposition.

These design theories also provide interesting ways to deal with the issues of innovation management.

P3: design theories invent new ways to use knowledge for innovation

Each design theory provides sophisticated and original ways to make use of knowledge while overcoming knowledge fixation. Redtenbacher ratio method conterbalances the tendency to use the knowledge on existing objects by creating a "context-sensitive" algorithm that is based on stabilized models of the object and lead to use the right knowledge at the right moment. German systematic manages knowledge creation to avoid that designers steadily reuse obsolete design rules. It is based on wide ranging knowledge maps that help identify the "holes" to focus creativity where it is relevant. Bauhaus theories build enriched models of material, forms, colors, contrasts, to disentangle them and support generative super-imposition.

P4: design theories invent new ways to combine divergent thinking and convergent thinking in innovation processes

Redtenbacher ratio method is highly convergent but keeps divergent at well-identified steps. In German systematic convergence is created by the progressive instanciation of pre-ordered languages of the objects, each new language being also a step for temporary divergence. In Bauhaus theories, the emergence of the "organism" results from the super-impositions of dimensions (forms, material, color,…) and this super-imposition itself is also an opportunity of divergence.

P5: design theories invent new ways of combining autonomous creative teams and control.

Redtenbacher ratio method leads to distinguish the rule-maker and the rule-user (initially the professor and the technician). In German Systematic, a distinction emerges between the project team with a clear target and a clear framework and the engineering department, in charge of controlling knowledge reuse and knowledge production. Bauhaus led to invent a form of "self-assessed" collective creativity, in interaction with an inspiring leadership, based on some constraints ("use industrial processes and design rules") and the designation of expansion areas (new objects).

We summarize these results in the table below.

Table 1. Summary of the main results

Creativity issues	Theory	Knowledge management	Innovation process	Organisation	Type of innovation output
Fixed by existing products	Ratio method (Redtenbacher, 1850s)	Method to use the right rule at the right moment, based on stabilized, synthetic model of the object	Context sensitive algorithm insuring convergence towards a satisfying solution and divergence at critical moments	Work division between rule-maker and rule-user	Adapted, varied products.
Fixed by the reuse of non-relevant design rules	Systematic Design (Hansen et al. 1950s, Pahl & Beitz 1970s)	Knowledge creation at well-identified steps; identify "holes" (residue) to focus creativity where it is relevant	Convergence and divergence by pre-ordered languages to create the object;	Project leader framed by a clear, specified target; engineering department heads controlling the relevant use and creation of rules	Variety, continuous innovation, continuous knowledge production
Fixed by "cliché"	Bauhaus school (Itten, Klee,… 1920s)	Abstract knowledge (on form, material, texture, color,…) to disentangle clichés; generative super-imposition	Convergence and divergence by super-imposition	Self-assessment of a group of creators; inspiring leader designating areas of expansions	New grammar of objects

4. Part 3: Design theory and creativity today? Testing our framework

These propositions can be tested by looking at recent advances in creativity studies and design theories, two fields of research that grew very fast in the last decades. A comprehensive study of the advances is out of the scope of this paper. We simply would like to underline what our proposals lead to look at in literature.

Following proposition P1, our question is: what are the new forms of fixations identified in the literature? Prolonging the seminal works and experiments of Smith et al. (Smith et al. 1993) and (Jansson and Smith 1991) on fixation by recently activated knowledge, recent studies have identified several types of fixations: fixation by the representations of things (Ward 1994), fixation by knowledge too "contaminated by the specific goal and task" (Finke 1990), fixation by the limited capacity to use knowledge very far from the task (difficulty to use metaphor, to connect with different types of knowledge) (Burkhardt and Lubart 2010), fixation by emotions (Zenasni and Lubart 2009), fixation by images and metaphors (Chrysikou and Weisberg 2005), fixation by organisational and social relationship in firms that are not "creativity-experts" (Stewart and Stasser 1995; Sutton and Hargadon 1996). These newly identified forms might be the new challenges for design theories.

Proposition P2 invites us to analyse how recent design theories propose to overcome these new fixation effects and extend generative capacity. Let's just briefly look at three theories or methods: TRIZ, C-K theory and Infused Design. TRIZ (or ASIT) intends to help user overcome fixation caused by relying on usual solutions to a problem; it proposes wide databases (wider than the classical libraries of systematic design) and a smart “browser”, the matrix of contradictions, to find “creative” solution principles to problems (Altshuller 1984; Rasovska et al. 2009; Reich et al. 2010). C-K theory (Hatchuel and Weil 2003; Hatchuel and Weil 2009) supports the revision of object identity by the dual expansion of knowledge and concept. It has been shown that it is relevant to counterbalance fixation effects, in particular for teaching designers (Hatchuel et al. 2011b). Infused Design (Shai and Reich 2004a, b) supports rigorous relationships between different scientific objects (truss, mechanics, cinematic,…) to increase the capacity of designers to make use of very heterogeneous disciplines (Shai et al. 2009). It has been shown that it supports the identification of “holes” in certain disciplines (relative velocity in cinematics has no equivalent in mechanics), leading to the creation of new scientific objects (face force) (Shai et al. 2009). It has also been shown that C-K theory and Infused Design increase generative capacities (Hatchuel et al. 2011a). Hence these design theories tend to address (some of) the fixations listed above,…

Do these theories suggest new ways of dealing with knowledge for innovation processes? (P3). We can just underline here how TRIZ precisely proposes new ways of “browsing” for technologies; C-K theory supports rule-breaking in the knowledge base, expansion of knowledge driven by the imagination, the creation of new definitions of things, as well as “knowledge re-ordering” required for “preservation of meaning” in the new world and new forms of absorptive capacity based on structures of the unknown (Hatchuel and Weil 2007; Le Masson et al. 2011). Infused Design aims at identifying “holes” in knowledge bases and “filling” these holes by using “complementary” knowledge for design (Shai et al. 2009).

Do these theories suggest new ways of dealing with convergence and divergence in innovation processes? (P4). Methods inspired by TRIZ like ASIT maintain a strong convergence, in particular by making a “closed world assumption” that avoid too many explorations and tend to focus on the minimal “break” out of the “closed world” (Moehrle 2005; Reich et al. 2010). Processes derived by C-K theory are characterized by interdependent exploratory design paths, meaning that each new design step can provoke unexpected expansions and these expansions open new, unexpected paths for convergence in the growing tree of paths (Elmquist and Segrestin 2007; Elmquist and Le Masson 2009). Infused Design suggests a distinction between fast convergence by making use rigorous correspondences between multiple disciplinary models and divergence to explore the “holes” revealed by these correspondences.

These theories and methods can also inspire or support new forms of organization for innovation (P5), balancing creation and control. TRIZ method supports the intervention of “creative commandos” called by the classical project organisations to solve “extraordinary” problems unexpectedly emerging during the project process (Engwall and Svensson 2001). C-K theory has helped to characterize new forms of organizations, when firms are shifting from R&D to RID, organizing departments dedicated to innovative design (Le Masson et al. 2010). In these design-oriented organizations (DO2), two levels are clearly distinguished: design spaces, where focused explorations and knowledge acquisition are done, and value management, that designates and launches design spaces, coordinates explorations, manage interdependencies and repetitions, and progressively elaborates a design strategy that simultaneously and synergistically accelerates innovation outputs (convergence) and enables more and more disruptive explorations (Hatchuel et al. 2005). Infused Design leads to new forms of interdisciplinarity, in which rigorous disciplinary correspondences push to be more creative and creative explorations enrich scientific disciplines.

4. Further research

Our study on the historical interplay between creativity and design theory is still exploratory. It shows that 1) design theory is in direct relation with creativity and 2) as a support for overcoming fixations, design theories open ways to think on innovation management. This would require further research, at least on three topics: what are the processes that lead from creativity studies to design theories? What are the processes that lead to establish new design practices based on new design theories? What is the relationship between these new practices and the identification of new fixations?

It leads to a new framework to analyse different forms of innovation management. For each form, our framework consists in:

- identifying creativity issues, ie types of fixation, that have to be addressed
- analyzing design theories addressing these fixations and the related design capabilities, ie the way to deal with knowledge, processes and organization
- clarifying types of performance (and measures) to be reached by this form.

This work paves the way to new forms of research on innovation. The use of design theories could help to propose:

1. new frameworks for comparative studies: a study of different types of fixation and different types of "innovation" over time. The identification of new fixations might call for new design theories whereas new design theories might cause new fixation that will be identified by creativity studies. What are the future fixations of the today emerging design theories?
2. new frameworks for analyzing data: recent studies have precisely use design theories to analyse absorptive capacity in radical innovation situations (Le Masson et al. 2011), front end management in drug design (Elmquist and Segrestin 2007), project failure or success (Elmquist and Le Masson 2009) or exploration and exploitation in innovation (Gobbo and Olsson 2010).
3. new frameworks for generating data: through experimentations (Agogué et al. 2011; Savanovic and Zeiler 2009) or in research-industry partnerships (Gillier et al. 2010)…
4. new framework for reinterpreting historical data, from famous inventors or famous engineering companies

Finally by encouraging the interplay between creativity and design theory, by focusing creativity studies on the limits of existing design theories, by supporting the development of new design theories to overcome fixation effects, research on creativity and design theory would contribute to the invention of new forms of innovation management.

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PERCEPTIONS OF CREATIVITY AMONGST UNIVERSITY DESIGN TUTORS

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Abstract: This paper describes the perceptions and views of creativity amongst a selection of UK-based design tutors. The paper presents the findings of research that has questioned a total of 16 design tutors in architecture and industrial design in a leading UK university that specialises in design education. The researchers adopted a semi-structured interview approach and collected a series of rich insights into how design tutors conceptualise creativity, and how they perceive their role in developing creativity in their students. The findings show perhaps unsurprisingly that design tutors clearly value creativity whilst, at the same time, they find it very difficult to define and conceptualise. They were also unable to articulate how they helped their students develop their own creativity. The findings also reveal that the design tutors would value understanding creativity more in order to improve their teaching.

Keywords: *creativity, perceptions, design tutors, university design education*

1. Introduction

Creativity is a powerful label. In Western societies it epitomises success, the 'modern', and trends for novelty and excitement. Whether linked to individuals, enterprises, cities or regions creativity establishes immediate empathy, and conveys an image of dynamism. Creativity is a positive word in societies constantly aspiring to innovation and 'progress' (European Commission, 2009). Creativity can also be a major driver of economic and social innovation and it is an essential feature of a post-industrial economy. Despite interest in the concept of creativity there are issues in how it is conceptualized. The term has been so overused and applied to so many contexts that it's meaning has become diffuse and misinterpreted. Indeed even within the design disciplines it is an often ill-defined term. It has been estimated that more than 80 definitions exist in literature (Dasgupta, 1994). Most definitions of creativity do however contain two important concepts, value and novelty (Barron, 1988; Runco, 2007; Cropley, 2001). Creativity can be a crucial factor when designing products (Chakrabarti *et al*, 2004; Gero, 1993). It can also facilitate innovation, support problem solving, and enable companies to increase greater market share (Ottosson, 1995). Without creativity in design there is no potential for innovation (Amabile, 1996). Furthermore, the importance of education in developing creativity has been stressed by many (Amabile, 1983; Robinson, 1999; Cox, 2005).

2. Creativity in design

The Cox review of creativity in business within the UK suggests that future designers will require a breadth of knowledge in engineering, technology and business as a means of facilitating the fusion of skills necessary in creating new ways of thinking as well as creating successful new products and services (Cox, 2005; Kelley, 2001). Within most disciplines of design practice be that graphic design, architecture, product design, furniture design or engineering design, creativity is routinely viewed as the most outstanding criterion to achieve (Christiaans and Venselaar, 2005). The term “creativity” is commonly used in the context of four main research areas. That is, in the context of the “creative process”, the “creative product”, the “creative person” and the “creative environment” (Murdock and Puccio, 1993; Basadur *et al*, 2000). Creativity and, in particular, creativity in design has been defined using variations of these four research areas (Boden, 1991; Kim, 1990; Gero and Maher, 1993). Several of these studies offer viewpoints to support creativity as residing solely in the finished product whereas others believe that creative processes undertaken by the creator are a key ingredient in the development of creative products (Gero, 1996). Sarkar and Chakrabarti (2011) propose that all stakeholders, including designers, engineers, managers, entrepreneurs, and others, involved in product development need to be creative. It is widely acknowledged that creativity plays a significant role in many types of business and is especially important in the design and development of new products. Creativity is a crucial factor in the successful design of new products and is a key driver of innovation (Chakrabarti *et al*, 2004). Thus, creativity initiates innovation, it helps in resolving design issues, it can support a company in gaining a larger market share, and ultimately creativity can help designers and manufacturers develop new products better and faster (Ottosson, 1995; Molina *et al*, 1995). The importance of creativity and the many stakeholders outlined above implies creativity is part of a socio-cultural system (Csikszentmihalyi, 1996). Creativity viewed as a socio-cultural system is interesting in the context of design education, where the system is made up of a domain (design), the field (design tutor) and the individual (student). This is discussed in section 4, but for now we discuss creativity in design education.

3. Creativity in university design education

The importance of creativity in the cultural and creative industries and the significant contributions that creativity adds to the UK’s overall GDP cannot be overstated. Universities also make a significant contribution to these industries through their research and the education of their students. Indeed Scharmer and Kaufer (2000) suggest that universities are the birthplaces and hubs for communities of creation. Cropley (2001) argues that education is pivotal; it can be extremely successful in facilitating creativity but equally it often hinders the development of skills, attitudes and motivation necessary for the production of novelty. According to Reid and Petocz (2010), subject areas in higher education demonstrate their interpretations of creativity through their specific disciplines but their understanding of the concept can be quite varied, even within the design subjects. Irrespective of discipline most tutors believe creativity to be important. This view could be challenged however as many critics have argued that most universities have favoured traditional educational methods that promote orthodoxy as a result of favouring linguistic and logic-based disciplines, rather than what Gardner calls ‘intuitive’ intelligences such as creativity (Cropley, 2001; Biggs, 2007).

4. Creativity and the role of the design tutor

Contemporary conceptualisations of creativity view creativity as more of a social act rather than an individual act. One of the first advocates of this approach was Stein (1953) who theorized that creative outcomes should not only be novel, but had to be "accepted by a group" (Stein, 1953: 319). Influenced by the work of Stein, Amabile's seminal work also stressed the social nature of creativity and made explicit reference to the importance of people and their creative skills (Amabile, 1983). Socio-cultural approaches to creativity, explain that creative ideas or products "do not happen inside people's heads, but in the interaction between a person's thoughts and a socio-cultural context" (Csikszentmihalyi, 1996: 23). This approach also stresses the social judgements of the creative act by someone other than the creator. By implication, the university tutor and other individuals who work with the tutor, and influence the tutor's decision-making processes, make up the field for the students' creative outcomes and socially validate and encourage students' creativity. Since it is the field (the tutor) that provides the individual (student) access to the domain, in educational settings, it is the tutor who provides the student access to the creative dimension of the academic subject (Csikszentmihalyi, 1996). The way the subject is taught and the criteria against which the students' learning is evaluated have an impact on developing student creativity. Although Claxton (1998) argues that creativity cannot be trained or taught, he does believe that it can be cultivated or facilitated, and this we argue has implications for design educators. Claxton's view of learning as enculturation is linked to what Csikszentmihalyi (1996) calls a "congenial environment" whereby creativity can flourish. This is also linked to a creative climate (Ekval, 1996). Learning as enculturation, climate and environment can be said to conceptualise creativity from a socio-cultural perspective. This in turn, emphasises the role of the tutor of design within the system, and the need to try and identify the design tutors' epistemological beliefs related to creativity. A tutor's readiness (*i.e.* ability and willingness) to engage in educational practices that facilitate the development of skills necessary for creativity is dependent on the tutor's epistemology, which is defined as the set of beliefs that one has about the nature of knowledge and its acquisition. This set of beliefs has an influence on the cognitive processes of thinking and reasoning (Hofer and Pintrich, 1997; Schommer, 1994), and harbours the tutor's conceptions about learning and teaching. This respectively affect the tutor's perceptions of tutor-student roles in the learning process, as well as the tutor's decision making processes related to preferred ways of educating (Chan and Elliot, 2004). Therefore, the tutor's epistemological beliefs that are related to 'what is creativity' and 'how creativity develops' influence the tutor's choices that are related to pedagogic strategies and practices (Chan and Elliot, 2004; Hashweh, 1996) which consequently impact students' creative potential. Thus, the authors' key aim here is to investigate design tutors' beliefs about creativity and in particular how they facilitate creativity in the university design studio.

5. Perceptions of creativity study

In fostering creativity it is essential to start with understanding what creativity involves and what factors allow for it to happen. Despite the enormous amounts of research to understand better and support creativity in design (Bonnardel, 2000), it is still difficult to locate any common agreement amongst researchers on operational definitions of what it means for a designed product, space, experience, service or system to be 'creative'. Given the importance of creativity in our post-Fordist economy, and the role of tutors' in facilitating creativity as part of a socio-cultural system, this paper explores the viewpoints of 16 design tutors at a leading design university in the UK. The study asks a number of questions in relation to creativity and whether or not tutors believe it is an essential characteristic in design graduates. Exploring the role of the design tutor, we believe, is key to understanding creativity within the context of design education at undergraduate level.

There have been a number of studies that have looked separately at tutors' beliefs and creativity (for example see Fryer, 1996; Diakidoy and Kanari, 1999; Nicholl and McLellan, 2008). The study presented here, however, makes an original contribution to this field as there have been no studies that have explored design tutors' conceptualisations of creativity in design and, in particular, the facilitation of creativity in design education at undergraduate level. Using a semi-structured interview approach, which is a highly useful method for uncovering new insights (Robson, 2002) whilst being an excellent mechanism for identifying general patterns in descriptive studies (Saunders *et al*, 1997) the questions posed to the design tutors probed their beliefs about creativity. This study entailed a number of corresponding objectives, namely:

- How design tutors conceptualise creativity.
- Whether design tutors think they possess creativity themselves and whether it is important that they do.
- Whether design tutors see creativity as important and/or valuable in design education.
- How design tutors view their role in facilitating creativity and how they manage this in a university setting.
- Whether design tutors would like to know more about creativity and improve their teaching for creativity.

Given the stated aims and objectives of the study, a series of questions were posed to 16 design tutors. The questions asked, in order, were as follows:

1. Do you consider yourself to be creative?
2. How do you conceptualise creativity in students, what is it, can it be defined?
3. Do you think creativity is an essential attribute for your students to possess?
4. Do design students join the university as "creative individuals" or do you think it is what you do as a tutor that develops their creativity as a cognitive skill?
5. Do you think your teaching methods promote creativity in your students?
6. Do you think having some knowledge of creativity and how to improve it would be of some interest in improving your teaching?
7. Have you ever read anything regarding creativity and how to improve it as an attribute within your students?
8. If not have you learnt to be creative, and how have you learnt to teach your students?
9. What is more important in HE design education - a. teaching the students an awareness of precedents and the work of past individuals and their vocabulary or b. teaching innovation and creativity?
10. Do you think creativity is valued within your discipline?

In summary, the list of questions above are ordered to tell a story of looking at creativity from an individual perspective to a socio-cultural perspective, where design tutors may have a role as educators and/or practitioners. Thus, how do the design tutors view their role as educators of design?

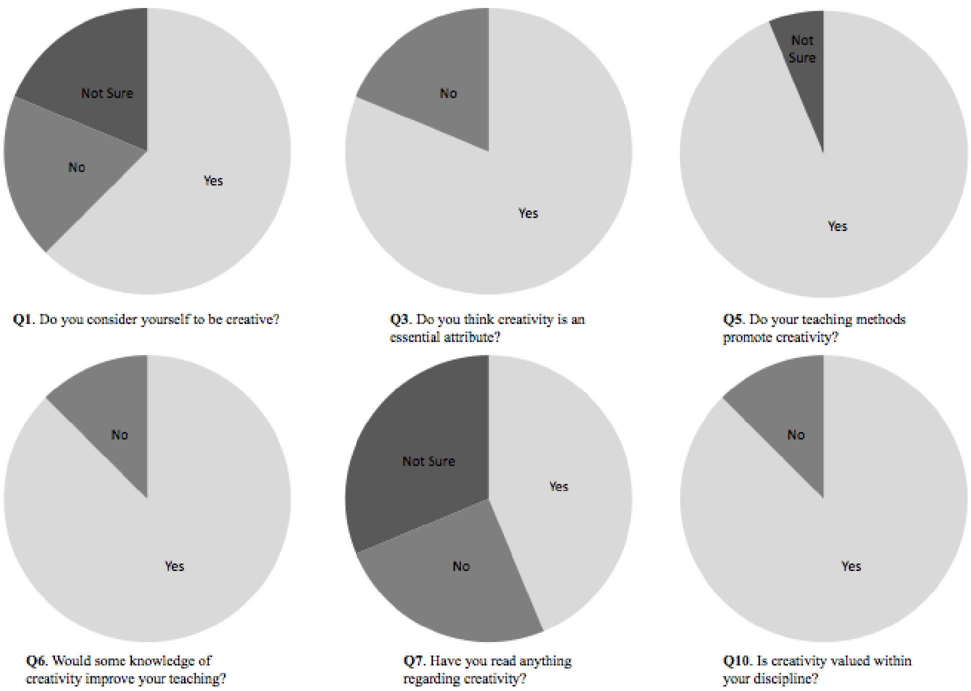
Can the findings from this study be used to help inform and shape the future teaching of design education?

6. Findings

The first question asked each tutor if they considered themselves to be creative. 10 of the 16 design tutors replied with a firm "*Yes*" (Figure 1). The design tutors justified their claims of being creative by stating things like "*...I come from a creative family...*" (Tutor 2), "*Whenever I do one of these management personality tests I am always in the creative category*" (Tutor 3), "*I believe myself to be a creative thinker that can pull disparate ideas together through synthesis and I am good at seeing possibilities*" (Tutor 7), and "*To the average person on the street, I am probably highly creative...*" (Tutor 8). Conversely, a small number of the design tutors were much more circumspect in their responses to this question and replied "*No*" to this question. The reasons they gave included "*No. Enzo Mari in his 'vaffanculo' talk defined creativity as the 'door of hell'*" (Tutor 9), to "*Not as creative as I would like. I seem to inherently restrict myself...*" (Tutor 10), and "*...there appears to be a tangible pressure in society for one to become creative and as such it has become a term used by an increasing unspecified and growing sector of the population. Consequently, I like to refrain from describing myself as creative*" (Tutor 11).

Question 2 asked each tutor how they conceptualise creativity in students, what is it, and can it be defined? Some tutors' answers imply that creativity can indeed be defined and it ranges from "*Imaginative responses to a design brief...*" (Tutor 1) to something that "*...adds value*" (Tutors 2 and 6), "*...is inventive*" (Tutors 3 and 8), and includes "*quirky solutions*" (Tutor 4). A number of tutors, on the other hand, tended to respond in a negative manner and generally suggest that creativity cannot be defined. Their comments ranged from "*Creativity is difficult to define (but we know that already, don't we?). I don't even try"* (Tutor 11) to *"I don't think of creativity as a thing, something that can be isolated and witnessed*" (Tutor 13), and "*I don't believe I can define creativity"* (Tutor 14). Question 3 asked, is creativity is an essential attribute for your students to possess? 13 tutors stated that creativity was an essential or a vital attribute (Figure 1). Once again the responses were variable, "*Absolutely, they won't be able to function on the course without being creative*" (Tutor 1) and "*definitely, it is vital that students have a creative mind to be able to apply skills and knowledge that they are taught in class and put to good use in their projects*" (Tutor 6) whereas other tutors tended to add caveats such as "*...it (creativity) is not the ONLY essential attribute*" (Tutor 11) and "*Yes, but I don't think that creativity is an essential attribute for our students to possess*" (Tutor 13). Three tutors, interestingly, didn't think it was an essential attribute at all.

Question 4 asked each design tutor whether their design students joined the university as "creative individuals" or if it is what they do as a tutor that develops their students' creativity? All the tutors tended to agree that students joined the university as "creative individuals" and that their creative capacity was further enhanced during the duration of their studies at university. For example, Tutor 1 believes students "*…start with some creative skills and we build on them*", Tutor 5 stated "*It is a combination of what we do here as teachers and what the students do…*", whereas Tutors 12 and 16 agreed that "*we are all born creative*", and Tutor 11 suggested that "*…the responsibility is for the tutors to help students develop their creativity*". Question 5 asked the tutors if they thought their teaching methods promoted creativity in their students? In their responses, almost all of the tutors felt that their teaching methods positively promoted creativity in their students (Figure 1). The methods the tutors adopted in the promotion of creativity, however, ranged from "*...challenging the students regularly through tutorials and reviews*" (Tutor 3) to "*...I try to create some sort of story with the students built out of concepts*" (Tutor 4) and "*I tend to simply take students to a situation of unease and discomfort. I think in this way the student learns to challenge his or her own thoughts, observe* *more carefully, and build their confidence…*" (Tutor 8). Several tutors focussed on specific methods and tasks in their responses including "*The type of creative tools that I use with students include mind-mapping, brainstorming and the DeBono's 6 thinking hats* (Tutor 11) and "*…in project work I try to encourage idea generation and exploration rather than pursuit of the safe option*" (Tutor 14).



Q1. Do you consider yourself to be creative?

Q3. Do you think creativity is an essential attribute?

Q5. Do your teaching methods promote creativity?

Q6. Would some knowledge of creativity improve your teaching?

Q7. Have you read anything regarding creativity?

Q10. Is creativity valued within your discipline?

Figure 1. Design Tutors' Responses Summary

The responses to question 6, do you think having some knowledge of creativity and how to improve it would be of some interest in improving your teaching, had almost all of the tutors agreeing that having some knowledge of creativity and how to enhance or improve it would be beneficial in their teaching (Figure 1). Question 7 asked each tutor if they have ever read anything regarding creativity and how to improve it as an attribute within their students? Over half of the tutors had not read anything on creativity or were not sure (Figure 1). "*No, nothing springs to mind…*" stated Tutors 1 and 2. "*No although if I had more time I would as it is important…*" answered Tutor 4, and "*I can't recall reading anything specifically on creativity…*" remarked Tutor 8. Of those that said yes, they referred to the work of authors such as Donald Schön, Arthur Koestler, Bryan Lawson, Norman Potter and Nigel Cross, which tended to be more about the design or creative process. Others stated they had "*…read plenty about creativity…*" (Tutor 13) and "*…the importance of creativity…*" (Tutor 15) but they couldn't list anything in particular. Question 8 asked the tutors how they have learnt to be creative and how they have learnt to teach their students? The responses here were all very similar and they included things like the importance of experience, learning to be creative through doing, learning on the job, understanding what works in certain situations, trial and error, past projects, and by watching more senior colleagues. Question 9 asked the tutors what they felt was more important in university design education – (A) teaching the students an awareness of precedents and the work of past designers, or (B) teaching innovation and creativity? Here, there is little difference in the responses from the tutors. Five tutors stated (A) is most important, five believe (B) is most important, and six think (A) and (B) are equally important.

Question 10 asked the design tutors whether they think creativity is valued within their discipline. Fourteen of the sixteen tutors believe that creativity is valued within their discipline and in their university department. However, there are two tutors who disagreed believing creativity is not valued within their discipline and their department (Figure 1). Their comments included "*In my discipline, creativity is valued less than rigour*" (Tutor 8) and "*...creativity appears to be seen as something to promote and to celebrate by some in my discipline; but it is viewed as a destabilising force by others…*" (Tutor 15).

7. Conclusions and future work

This study has found a number of interesting results related to the perceptions of creativity amongst university design tutors, in particular:

- Design tutors clearly value creativity.
- Design tutors find creativity very difficult to define and conceptualise.
- Design tutors find it difficult to articulate whether they teach for it.
- Design tutors would value understanding creativity more in order to improve their teaching.

In general, the 16 design tutors we interviewed found it difficult to define and conceptualise creativity even amongst those that believe themselves to be creative. Moreover, there were nine different definitions of creativity from the 16 design tutors interviewed including three tutors who believe that creativity cannot be defined. These definitions varied considerably from aesthetic-based descriptions (*i.e.* beauty, elegance) to more politically related definitions such as "challenging conventions" something Csikszentmihalyi (1996) states as being important. Other definitions included "freedom from hegemony", to more value-driven descriptions such as "striving for coherent solutions" and "solving real world problems". The majority of the design tutors we interviewed believe that creativity is an essential or vital attribute for their students to possess. However, several of this majority also stated that creativity is not the only essential attribute. It would be interesting to investigate what other attributes design tutors deemed important and if there was a hierarchy of importance and where creativity featured within such a hierarchy.

The design tutors agreed unanimously that students usually join the university as "creative individuals", and that their creative capacity can be further enhanced over the duration of their studies at university. Thus, tutors acknowledged they had a role within a socio-cultural system (Csikszentmihalyi, 1996). Asked whether they thought their teaching methods promoted creativity in their students provoked a variety of interesting responses. Some suggested "the challenge of the project" promotes creativity and "learning through doing", interestingly, an approach to learning advocated among others by Dewey (1938). Other tutors stated the design project much less but tended to focus on the role of the educator in empowering the students through teaching independence and self-direction. In other words, although tutors viewed their role as important, there was not a consensus and they were not able to articulate fully, the precise nature of their role. Again, this would be interesting to probe in future studies.

A number of the design tutors admitted that, on reflection, they might have deficiencies in their knowledge and approach to creativity. Also, a number the tutors spoke of needing some clarity as to what constitutes creativity (even those who said they have read extensively on the subject). Some of the tutors pointed out that reading about creativity is entirely different to being creative in practice. Again, this is interesting given the previous comments on creativity as solving real life problems, and the wider debates about situated cognition (Brown *et al*, 1989). One or two tutors have read extensively on the subject of creativity, and clearly see the benefit of this to their own and their students' performance. A number of tutors who had read on creativity tended to cite books that were more about the design process. However, the majority of the tutors either could not recall what they had read, or stated that they hadn't read any books on creativity. This might explain why there is such a varied response in the tutors' conceptualisations of creativity. This is a key finding albeit from a relatively small sample.

Another important finding is that the tutors see creativity being formed by the continuous application of knowledge through projects (*i.e.* learning through doing). Designers express their creative abilities through the vehicle of design not through reading. Whether the outputs and processes of the projects demonstrate creativity is another matter, many designers use tried and trusted methods perhaps leading to orthodoxy. Brown *et al* (1989) argues that creativity is reliant on a deep knowledge of the field, and 10 to 15 years is generally recognised as the time taken to be truly creative. Students at university have perhaps only studied design meaningfully for half that time, so investment in knowledge by way of reflection on precedent and the work of other designers is part of this building of knowledge. Several tutors made similar points here including, *creativity is impossible without the acquisition of knowledge and skills and that without a good knowledge base you will end up with wilful nonsense*. This raises the question, how do tutors develop knowledge and skills of the domain, as well as providing opportunities to use this knowledge in creative ways when solving design problems? This is the complex nature of creativity as conceived by Amabile's model (1983).

Interpretations of creativity appear to be dependent on environmental conditions. Most tutors interviewed believe that creativity is valued within their discipline (*i.e.* design) and within their university departments. This is interesting based on the general feeling of pedagogue critics that Higher Education is more aligned to logic-based, linguistic and social science disciplines, where the traditional lecture-based pedagogy prevails, which is relatively straightforward and light in terms of allocation of resources. Many systems within Higher Education lean more towards quantitative rather than qualitative methods. The negative criticism of the education certificates (in their various guises) and the fact that a number of the design tutors dropped out before completion would suggest that these courses are perhaps not considering the specific educational needs and context of the design tutor, other than when the tutor is teaching in a 'traditional' way. In summary, it would appear that many aspects of creativity in design, its definitions and its processes remain shrouded in mystery (Snodgrass and Coyne, 1994). This begs the question, if we don't know what creativity is how can we learn it and develop it in our students, our universities, and in ourselves? Future work planned in this area includes the expansion of the study to conduct a multi-site case study of design tutors throughout the UK and collect upwards of 100 design tutors' responses involved in undergraduate design education. Moreover, in light of the data collected thus far the authors plan to expand the research further to explore a number of the emergent themes articulated in this study.

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CHARACTERIZING ACTIVITIES THAT PROMOTE IDEATION – SURVEY CONSTRUCTION TARGETING REFLICTIVE PRACTICES

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Abstract: Idea generation in engineering design is most often studied within the context of specific tasks, such as brainstorming, mindmapping, TRIZ, etc. Additionally, researchers tend to constrain their search to time and activities within the workday and at the workplace, to understand and improve the process of creating ideas. This work examines creative ideation activities in engineering design from a broader perspective. We aim to 1) identify what accompanying activities designers are engaged in when they get ideas, 2) determine whether the activities occur within or outside of the direct context of 'work', and 3) discern which attributes of these activities makes them conducive to ideation. This paper presents the construction of on online pilot survey and discusses lessons learned before the project engages into the execution stage of a global survey.

Keywords: *ideation, design, creativity*

1. Introduction

Though academically overlooked, it is evident that ideas do not come only when at the office, or when engaged in brainstorming or other traditional design activities. We commonly hear of someone being struck by an idea while in the shower, or while driving to work. Prior research on ideation within this project has found that designers engage in a wide range of different types of activities when they generate or refine ideas, and that they often view off-line activities (outside of the workplace/work time) to be superior to those prescribed by traditional design processes. (Currano, R.M., Steinert, M., & Leifer, L., 2011; Currano, R., Steinert, M., & Leifer, L., 2012; Currano, Rebecca M., Steinert, M., & Leifer, L., 2011, 2012; Meinel & Leifer, 2012) Furthermore, many techniques for idea generation such as brainstorming or brainwriting, which are standard at the workplace, have been tested and found productive only to varying degrees, sometimes with a drop-off over time. (Chidambaram & Bostrom, 1993; Furnham, 2000; Meinel & Leifer, 2012; Sutton & Hargadon, 1996)

Rather than limiting our study to a specific work context, or looking for the 'best' methods for producing creative concepts, we aim to explore the attributes of idea-accompanying activities in general. After extensive multistage qualitative research, we have developed and tested a structured online survey of 22 individuals with varying design experience. The first objective is to learn what activities they are engaging in, when they get ideas. Additionally, we have asked them to rate their five most and five least helpful activities along 13 bipolar attribute scales. In this paper we describe how we developed this survey. We also present the analysis procedure and discuss some descriptive data that came out of the pilot survey. Based on these results, we will create a second, shorter survey, which will be disseminated to a larger audience of engineering design researchers and practitioners. The aim is to generate a sufficiently large data set to run a factor analysis and to establish statistically significant findings, to support more innovative design practices.

1.1. Motivation

Based on prior research, we first hypothesize that some activities are more and some less helpful in the creation of ideas. Second, we propose that these activities are not necessarily constrained to the 'at work' context but increasingly take place outside of the work space or time. Last, we explore the possibility that a set of general attributes exists, which characterize the most and least helpful activities that enable or accompany creative ideation.

2. Pilot Survey Implementation

2.1. Setting up the Survey

To explore these questions quantitatively we developed and launched a structured online survey. The survey questions were derived from two prior studies. In the first prior study, we examined idealog data and found evidence of reflective practice in a variety of activities, such as mindmapping, sketching, and journaling. (Currano, R. M., Steinert, M., & Leifer, L. J., 2011) Within this same study we explored various dimensions for framing reflective practice. These included in-action vs. out-of-action, background vs. foreground, internal vs. external, and remembering vs. gathering.

The second study informing the survey was comprised of a series of in-depth interviews with design students (undergraduate and graduate), professors of design, and design professionals. Participants told us about their design processes, and the reflective practices that they use to get ideas, both within and external to their formal design practice. (Currano, Rebecca M., Steinert, M., & Leifer, L., 2011).

Both of these studies yielded unexpected data on the activities that designers engage in, and the way that they describe these activities. Instead of mentioning primarily work-related activities, participants more often referred to recreational, interim, or social activities like exercising, conversations with friends and family, biking across campus, taking naps, etc. When describing their reflective practices, several participants used words or phrases such as being 'mindless', 'not too mentally taxing', and of letting ideas 'creep into my mind'. These descriptions do not resonate with how we typically think of productive work tasks.

This discrepancy between the activities that designers report as being conducive to ideation and the activities that designers are taught in school and expected to perform in the workplace leads us to ask what the profile of an idea-conducive activity might be.

In this vein we designed a pilot survey, which we disseminated to colleagues in the Hasso Plattner Design Thinking Research program (HPDTRP) at Stanford University's Center for Design Research and at the Hasso Plattner Institute, in Postdam, Germany. Most of the survey respondents were colleagues, or acquaintances, who we knew to be engineers, designers or design researchers and who we could reasonably trust to be diligent in completing the survey.

2.2. Survey Design & Deployment

The pilot survey, designed through the Qualtrix survey tool at Stanford University (Stanford ITS, 2012), was launched in two stages by sending out invitations links via email: a quick first iteration, which three participants completed, and a second, distributed to 28 participants. The key questions remained the same through both iterations, but some open-ended questions, and additional demographic questions were added to the second release, to allow us to look at other variables, such as level of experience, and type of design background.

In step one of the survey, we asked participants to select, from a list of 41 activities, those that they have used in their ideation process for design projects. They could also add in up to three activities that were not on the list. In the second step, they chose up to five of these (selected) activities as most helpful to them for getting new ideas, and up to five as least helpful for getting new ideas. While we required that participants had experience using activities that they selected as most helpful, we recognized that some least helpful activities may never have been used in their design projects, precisely because they are deemed least helpful. In a third step, participants were asked to rate their most and least helpful activities according to 13 attribute pairs on a 5-point Likert scale (see figure 1).

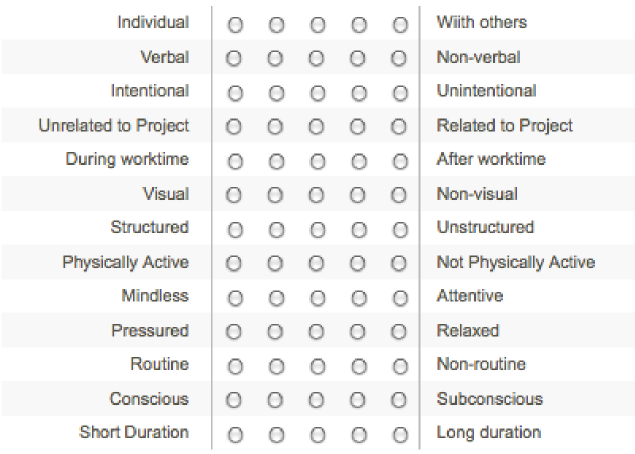

Figure 1. attributes and rating scale for the most and least helpful ideation activities

We also invited participants to expand on their most and least helpful activities in plain text and to comment on what makes these most or least helpful to them. We collected most of the data over a period of 2 weeks in September 2011. Before formally analyzing the data, we checked responses and discarded the datasets of 9 respondents due to incompleteness, straight-line answers, and insufficient completion time (anything below 7 minutes, which we deemed minimum time to thoughtfully complete the survey). In total, 22 participants successfully completed the survey and contributed to the pilot data set.

3 Descriptive Data Analysis

3.1. Activities that Accompany Ideation

3.1.1. All Activities Used

As shown in Figure 2, respondents use a wide variety of activities. In total, all 41 listed activities were identified as having been used for ideation. The number of activities used by each respondent ranged from 14-43, with a median of 24. In addition to this, the activities used were broadly distributed.

Every activity in the original list of 41 was selected by at least 5 respondents, with a range of 5-22 and a median of 14. The data fits a linear trend line with an R^2 value of 0.99, indicating that no single or few activities are used substantially more than others (as e.g., an exponential distribution might suggest).

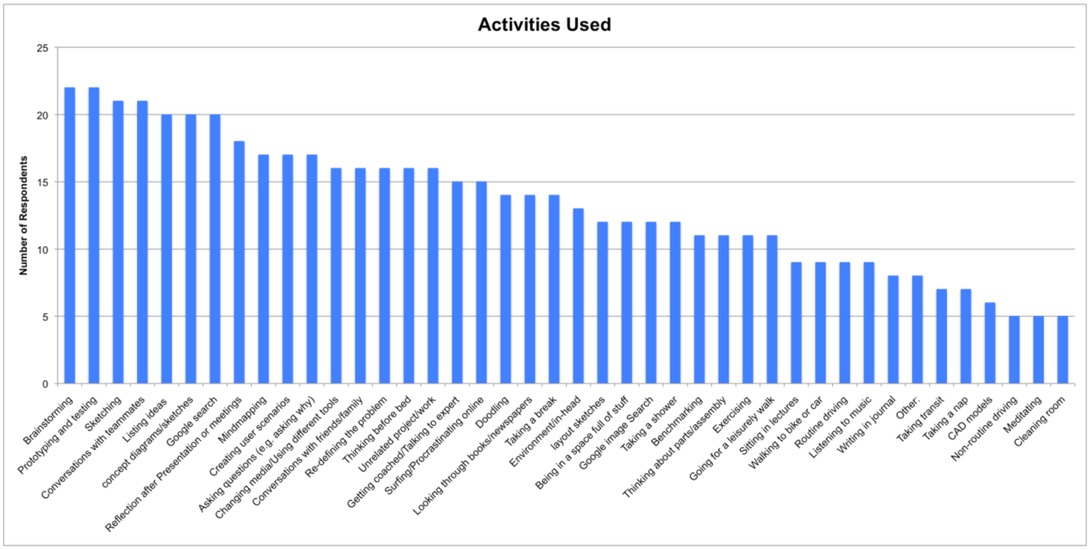

Figure 2. 41 activities and how many participants reported having used each activity in their ideation process for design projects

3.1.2. Most and Least Helpful Activities

Figure 3 shows the most and least helpful activities as reported by survey respondents. The frequency of selection of each category (most and least helpful) is more steeply varied than the frequency of selection of activities used (figure 2). In this case, the most helpful and least helpful selection frequencies do fit exponential trend lines, each with an R^2 value of 0.94, indicating that some are substantially preferred as most helpful and some as least helpful.

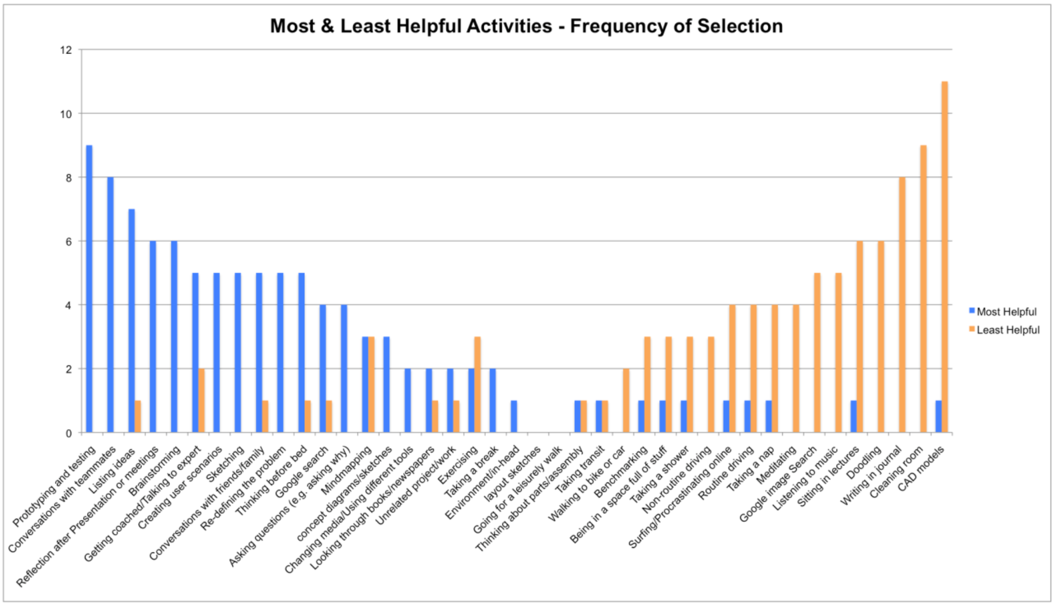

Figure 3. frequency of selection of all activities as either most or least helpful

Each most helpful activity was chosen by a range of 1-9 respondents, with a median of 2. Eleven activities were not chosen by any respondent as most helpful. Each least helpful activity was chosen by a range of 1-11 respondents, with a median of 3. Fourteen activities were not chosen by any respondent as least helpful.

While there is some overlap among the most helpful and least helpful selections, in most cases activities selected as most helpful were either not selected as least helpful, or selected by only one respondent as least helpful (and vice versa). Of the 19, which appear in both of these sets, in only three cases was the same activity selected more than once in both the most helpful and the least helpful sets. These are brainstorming, mindmapping, and exercising. It may be surprising to see that Brainstorming was not one of the top three most helpful activities, given how commonly it is both taught and used in design work. It is, however a method whose strength as an ideation technique has been criticized and debated (Furnham, 2000; Sutton & Hargadon, 1996). It is also interesting that mindmapping was selected equally as many times as most and least helpful, since it too is an established and broadly taught idea generation technique.

3.2. Characterising Attributes of Activities that Accompany Ideation

3.2.1. Attributes of Most Helpful vs. Least Helpful Activities

We call the group of average attribute rankings for each activity an *attribute profile* (two pairs of these are shown in figure 4). To first characterize, and then distinguish, the attributes of activities, we started by examining these profiles for the most helpful and the least helpful activities. Our thinking was that we should see similar rankings for many of the attributes of the most helpful activities, and also similar rankings for the attributes of the least helpful activities, but that these rankings should *differ* between most and least helpful activities. We therefore included the two most frequently selected most helpful activities: 'prototyping and testing' and 'conversations with teammates', and two of the three most frequently selected least helpful activities: 'making CAD models', and 'writing in a journal' (see figure 4).

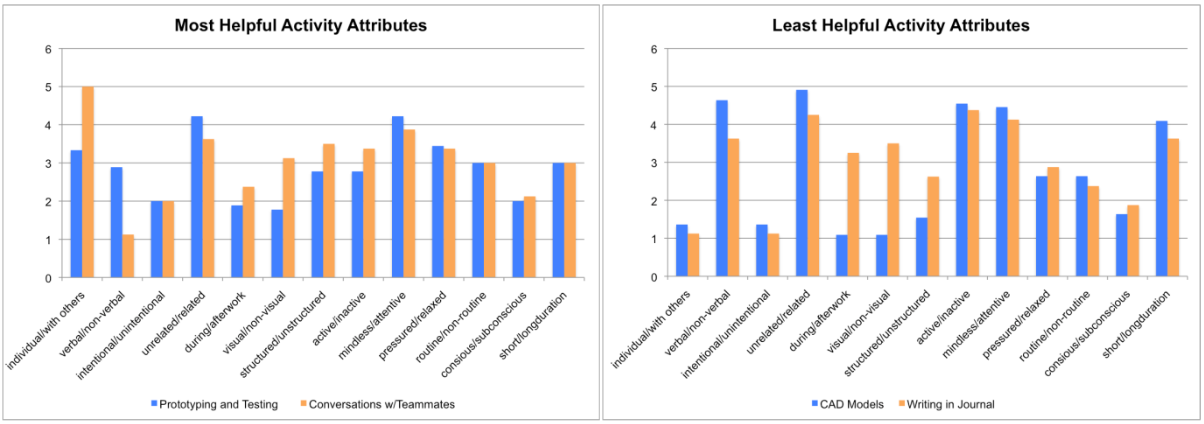

Figure 4. attribute profiles for top most helpful activities (left chart) and attribute profiles for top least helpful activities (right chart)

The chart on the left shows that several of the attribute values for the two most helpful activities are quite similar: specifically, 'mindless/attentive', 'pressured/relaxed', 'routine/non-routine', 'conscious/ sub-conscious', and 'short/long duration'. The chart on the right shows that even more attribute values for the least helpful activities are quite similar: all except 'during/after work', 'visual/non-visual', and 'structured/ unstructured'. For 'writing in journal', these three attributes have middling values, suggesting that participants had no strong leaning; but for 'CAD models', the same three attributes have very low values, indicating that participants mostly work with CAD models during work, in a visual way, structured way.

3.2.2. Attributes of Ambiguous Activities:

We also examined the one activity (mindmapping), which was selected equally in both most *and* least helpful categories (each by 3 respondents). As such, this activity has two attribute profiles (most helpful and least helpful), which we would like to distinguish. From Figure 6, we can see that the values of some attributes (unrelated/related and active/inactive) vary substantially between these two profiles, while the values of others (visual/non-visual and mindless/attentive) are virtually the same.

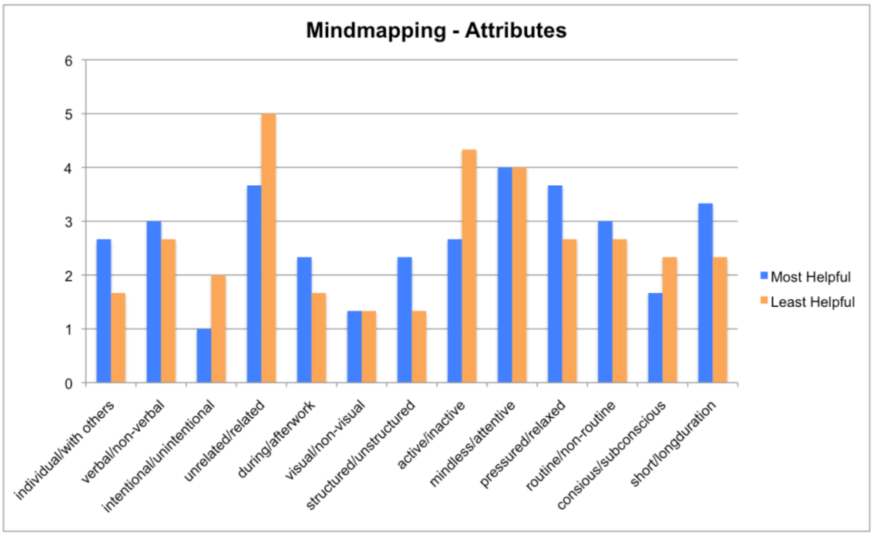

Figure 6. two distinct attribute profiles for mindmapping

3.2.3. Activity Attributes - Averages

Some attribute profiles are strongly contextual, influenced in part by the nature of the activity itself. For example sketching is by nature highly visual and generally non-verbal, while conversations with friends and family are by nature highly verbal, and non-visual. Yet both of these activities were frequently selected as most helpful. Since these attributes do not distinguish between helpfulness of activities, we will remove them from future surveys. Additionally, our sample size is small for any given activity, so we cannot draw very reliable conclusions from comparing attribute profiles of individual activities. For these reasons, we chose to also shift our attention to the profile averages across all most and all least helpful activities.

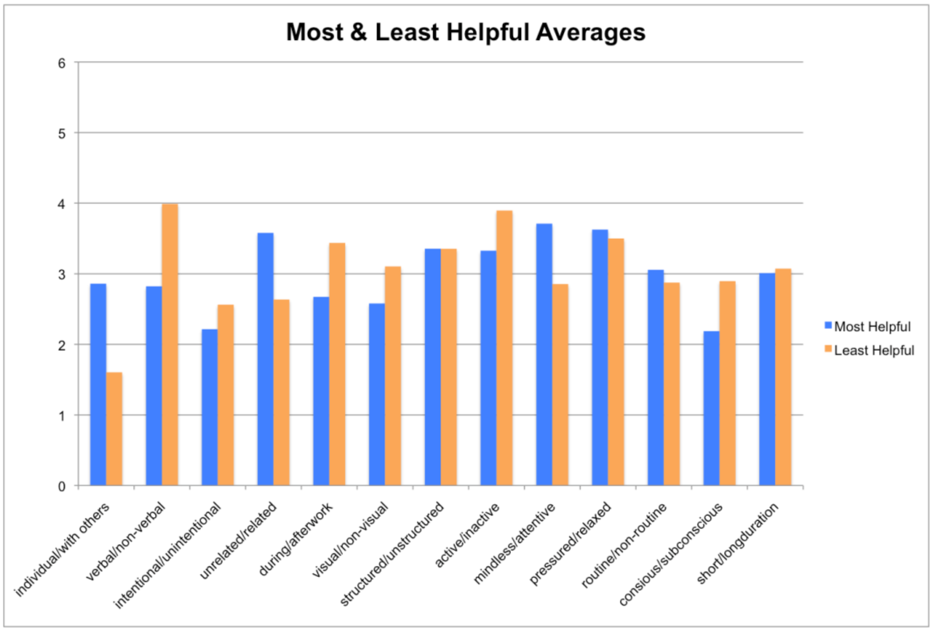

Figure 7. average attribute profiles for all most and least helpful activities

In comparing attribute rankings of least helpful activities to those of most helpful activities, two things stood out. First, that for some attributes, such as individual/with others, verbal/non-verbal, and unrelated/ related the means appear to be different between groups, while for others, such as structured/ unstructured, pressured/relaxed, routine/non-routine, and short/long duration the means appear very similar. The latter insight, that these attribute dimensions do not discriminate between most and least helpful activities, is further confirmed by viewing the data distributions for these attributes (see figure 8).

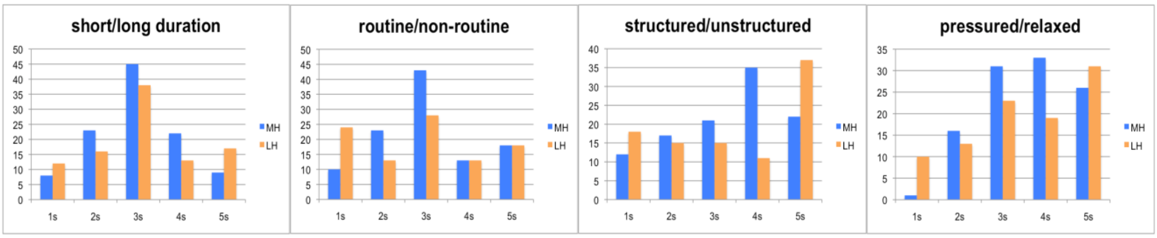

Figure 8. These charts show the data distributions, for particular attribute rankings across all most and least helpful activities. The x-axis indicates ranking options from the Likert scale (1 to 5) and the y-axis shows how many respondents chose each ranking option.

4. Discussion and Conclusions

4.1. Key Findings

From the many charts, graphs, and measures we extracted from our data analysis, a few key findings stood out. First, the survey data revealed a wide variety of activities used by designers to get ideas, which supports the idea of broadening our perspective beyond ideation techniques taught in school and encouraged in the workplace. Some activities as conversations with friends and family, and thinking before bed would not be considered by most people to be productive, work-related activities, yet they were often selected as most helpful for idea-generation by survey respondents. We believe that such activities should be the subject of further study and should be encouraged in addition to more traditional, widely-taught techniques.

Second, we saw an unexpected discrepancy between some activities chosen as most or least helpful in the survey and those cited by interviewees in the prior study. For example, exercising or walking was emphasized by the majority of interviewees as a most helpful activity for getting ideas, while these were more often selected as least helpful by the survey respondents. Other activities, such as conversations with friends and family seemed to appear generally in the same categories in both studies, but more often in the interviews than in the survey data.

Third, we also noted a discrepancy between how participants ranked their most helpful activities in Likert-scale questions and how interviewees in the prior study describe them when answering more qualitative, open-ended questions. (Currano, Rebecca M., Steinert, M., & Leifer, L., 2012). For example, survey respondents ranked most helpful activities as 'attentive' and 'conscious', while interviewees stressed the value of 'mindless' activities or states of attention in activities that helped them get ideas.

We believe this may be due to differences in how question was posed to both groups (as a Likert-scale for the survey, and as a open-ended description in the interviews).

However, misalignment of the data from the preceding qualitative interview study and the current survey may also be influenced by the distinct background of participants, as all of the interviewees from the preceding studies come from the Stanford Design tradition, while the current survey respondents came from two distinct and potentially clustered subgroups, located in different countries, and with different academic backgrounds. The upcoming deployment of the survey will focus onto a global population of engineers and designers from various backgrounds, the common bond being member in an academic and trade association.

4.2 Revising the Survey for Global Distribution

Due to the discrepancy in how respondents' reply to Likert questions and open-ended interview questions, we will prompt respondents first to think about and rank *specific* activities that they have found helpful in generating *specific* ideas, rather than to make broader judgments about types of activities that they find more or less helpful 'in general'. This will increase our confidence in the rankings, by grounding their judgments in real experiences. This decision was influenced by the fact that interviewees described clear and compelling examples of ideas they had, and the context in which they got them, when describing their ideation activities.

As with all structured surveys, the format does not allow for a conversation with the respondent, or for a qualitative probing into the given reasons. We found that the conversations gave interviewees time to think and work out their thoughts aloud. We asked them to visualize and talk through their design process, and to think of their reflective activities in the context of real projects they've worked on. Therefore, we will add more open-ended questions, to encourage respondents to be more descriptive and thoughtful in their answers. These questions allow them to express their thoughts more fluidly and in their own style, which we find they do willingly and abundantly in interviews, despite the increased time involved.

At the same time we have decided to decrease the number of Likert questions, by removing those which relate strongly to the nature of a given activity but which don't distinguish between helpfulness of activities. We will revise other Likert questions, to make them more clear and relevant to the questions at hand, separate bipolar scale rankings into individual rankings, and reword or subsume confusing terms such as 'mindless' under more interpretable categories such as 'subconscious'. And instead of asking respondents to rank five ‘most helpful’ and five ‘least helpful’ activities, we will ask them to rank and describe only two activities, recalling real experiences in which they generated specific ideas.

Lastly, we will distribute the survey over a much larger group to increase our data so that we can run statistical analyses from simple correlations and factor analyses in order to achieve greater validity, reliability and significance in our findings.

4.3 Conclusion

The field of ideation activities by engineers and designers is diverse and difficult to scientifically probe into. However, with this pilot, we have shown that it is possible to address questions such as how to identify 1) what accompanying activities designers are engaged in and when they get ideas, 2) whether the activities occur within or outside of the direct context of ‘work’, and 3) which attributes of these activities makes them conducive to ideation. We hope to roll out the main survey this spring quarter so that we will be able to show some preliminary results with an n>x00 at the conference.

Focusing on the creative potential of activities rather than on established practice can do more than just enhance the creativity of designers at work. It can break down paradigms of what activities and places are considered productive vs. not productive, and help designers to extend their creative potential greatly.

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FEWER CONSTRAINTS MORE CREATIVITY? INSIGHTS FROM AN EDUCATIONAL SCIENCE FICTION PROJECT

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Abstract: This article presents a case study of an experimental product design project in the context of design education. Short stories by Science Fiction writer Philip K. Dick were used as the source of inspiration for designing imaginary products within that narrative. Since the project was free of typical constraints, such as feasibility, cost-efficiency, material and production resources, the students had the possibility to try out extremes and push their limits. We present a description of the project frame, the resulting products, as well as an analysis of the case study. We believe that the work presented in this article demonstrates the impact of creative freedom on creativity and provides some insights for design educators how to trigger a creative leap within the students

Keywords: *creativity, science fiction, design education, Design for Film*

1. Introduction

Space… the final frontier. The voyages of Starship Enterprise have already demonstrated that Science Fiction can indeed have a visionary influence on today's products. Physicist Lawrence Krauss wrote a whole book about the physics of Star Trek (Krauss, 1995), and the X PRIZE Foundation launched a $10 million competition for the design of a medical scanning device based on the Star Trek tricorder (X PRIZE Foundation, 2012). Also other science fiction movies provided some cutting-edge ideas that later turned into actual products, such as the tablet shaped computer in Stanley Kubrick's "2001: A Space Odyssey" from the year 1968 that already showed astonishing similarities with Apple's iPad (Peralta, 2011). So, the question is not only, if existing Science Fiction movies can provide some inspiration for today's products, but rather whether we can generate ideas for innovative products via thinking in Science Fiction contexts? Is it possible that the limitless world of Science Fiction is able to unleash our creativity? When conducting a design project, you usually have a clear vision of what it is about. Either there is a precise briefing, or you are confronted with a clear set of constraints and restrictions (target group, available resources and materials, technological possibilities, budget, etc.). But what if there is no briefing, and there are no such constraints? What if you could do whatever you want? Designing for Science Fiction provides the designer with such a freedom. Everything is possible, there are no limits—neither technological, nor financial, not even physical laws apply here. Is such a designerly freedom the chance for limitless creativity? Or do we actually need some constraints to come up with innovative solutions? This question leads us to our hypothesis, which states that *fewer constraints in a design project may lead to a higher level of creativity*.

In this article we present a case study of a Science Fiction design project, conducted in an educational institution. 14 design students were confronted with different short stories by Science Fiction writer Philip K. Dick, and the task to design a new object within that story that was not defined by the author. Confronted with only a few pages of text, the students had to come up with ideas for the main characters (how do they look like?), the environment, and finally with a new object that was not even described in the original story. The project TRANSFORMERS was conducted over a period of 12 weeks in 2011 at the Bachelors program of Integrated Design (product design, communication design, interface design) at the Anhalt University of Applied Sciences in Dessau/Germany. The project was a 'complementary project', taking place once a week for four hours. Among the 14 participants were four male, ten female, five in 2nd year, 9 in 3rd year. Each one was given a different short story by Science Fiction writer Philip K. Dick. After analysing the content of the narrative, everybody had to come up with sketches of the protagonists and the environment, as envisioned by the student. The original story had to be visualized in a storyboard aligned to a timeline. After that, each student had to invent an object (which was not existing in the original story), which would then modify the story and turn it into an alternative ending. This modified storyline had also to be visualized in a storyboard. Several interim presentations and group discussions provided the possibility to exchange ideas and get feedback. As a creative input there was a guest lecture given by a film and set designer. The results of the project were shown in a public exhibition.

This article starts with a description of the case study methodology, including the used data sources. The third section—the main part of this article—presents the results of the projects as well as an analysis of the data sources. In Section 4 we present a brief summary of our analysis, and we conclude by discussing possible implications for future design and design education.

2. Case study design

The presented case study tries to answer the following research question: How do students cope with relatively limitless design frames? And how does this stimulate or prevent the flow of creativity? Following Yin's Case Study Methodology (Yin, 2009), we based our case study on three data sources: 1) direct observations, 2) semi-structured interviews, and 3) the resulting project outcomes (artefacts).

The observations (1) were conducted by one researcher who was involved in the project as a lecturer and who provided the students with the whole project assignment and frame, and was able to extract first-hand insights through direct observations. After each session (once per week) he took notes about observed group dynamics or noticeable problems of particular students.

The semi-structured interviews (2) were conducted in week 11, prior to the final presentation, with 13 of the 14 students (one missing due to illness; that interview was caught up in week 13 after the final presentation). The interviews consisted of a prepared questionnaire with open and closed questions, which gave us the opportunity to evaluate the results quantitatively and qualitatively. During each interview—which lasted about 10 minutes in average—the researcher could clarify any occurring questions by enquiring details. Subsequently, we clustered the answers and collected those insights that were mentioned most frequently.

The artefacts (3) that resulted from the project were categorized according to their intended function and the respective levels of potential realizability. We distinguished between three categories—poetic objects, potentially realizable objects, and objects for virtual worlds or Science-Fiction movies. This classification was conducted by two researchers (raters), who independently assigned the projects to one of the three categories. The inter-rater agreement was measured with the Cohen's Kappa (Coeffient: 0,76, StdErr: 0,15). According to Fleiss (1981, p. 218) a Cohen's Kappa of 0.75 or more means excellent inter-rater agreement. For the two disagreements, the raters discussed their ratings and then came to an agreement. The two ex-ante disagreements were for the actifacts "Phoebe" (Figure 2, right), classified as poetic after discussion (before rated as poetic and virtual), and for the "Get-Ice-Cubes-Out-Of-The-Air-Racket", classified as virtual (before rated as virtual and real).

Finally, we did a cross-analysis of some of the data-sources, in which we compared the categorized artefacts with the answers from the interviews. This evaluation provided the opportunity to empirically test our hypothesis. The used data sources as well as their analyses are described in more detail in the following section.

3. Analysis

3.1 Observations

Since we were involved in the project as lecturers, we could directly observe the students' behaviour, as well as occurring problems. During the whole project we took notes about our observations and the students' progress.

Observation 1: Problem Solving Attempt. Most students had one initial idea, which would solve the main problem of the story (kill all the aliens or save the entire humankind somehow). They were suggesting an obvious solution ("silver bullet"), which would somehow resolve the problem within the story, but at the same time this would make it boring and destroy the dramaturgy. It was difficult to convince them that the better solution for this project was actually something that would cause problems, to make the story more interesting. We believe that an additional input into film dramaturgy would have helped the students to better understand the scope of the project. The lack of such information led to a major confusion among the students about what to focus on.

Observation 2: Science Fiction Experts. All students were Science Fiction fans, which made the whole process more fun, and everybody had a lot of input to give. On the other hand, most of them came up with ideas that were inspired by existing Science Fiction movies they already knew. It was difficult for them to design totally new worlds.

Observation 3: Ugly Design. Many students enjoyed the possibility to design "ugly" things. Usually designs had to be pretty, but in this case they were able to design really disgusting and yucky objects. Obviously they drew a lot of pleasure from this. The "Brain Worm" (Figure 4, left) is an example of an "ugly" solution.

Observation 4: Undirected Creative Energy. Some of the students developed a fascinating creative energy. They came up with a lot of creative ideas, which however didn't fit into the story or did not served the dramaturgy. This had to be guided by the instructors.

Observation 5: Phases of Creativity. Within the 12 weeks of the project, we observed that the mood of the students changed significantly. While in the beginning everybody seemed to be excited of their respective story and the visualization, the highlight seemed to be the input given by the professional film designer, which gave the students an idea of where this project could lead. However, after that there was a big decline of motivation and creative output, since most of the students were heading towards a too simple solution (see also observation 1). Group discussions and individual consultations with the instructors seemed to help. In week 9 there was a kind of breakthrough for most of them, where they got really excited about their final ideas. In this week they presented the final ideas in an interim presentation and got group feedback. In week 11 there was another minor decline, which was probably due to time pressure towards the end of the term.

3.2 Semi-structured interviews

This section describes a summary of the outcome of the semi-structured interviews, as well as our analysis and interpretation. The first group of questions was about the project itself, such as the level of difficulty the students thought the project had, compared to other projects. We presented them a 5-point Likert scale (1 = very easy, 5 = very difficult), in which the average rating of all interviewees was 2.79 (standard deviation: 1.19, median: 3.00). Figure 1 (left) shows a violin plot of all answers. A violin plot is a combination of a box plot and a density plot. The black bar in the middle of Figure 1 is a box plot, representing the lower quartile, the median (white dot), and the upper quartile. The yellow (grey) part is a kernel density plot that shows the distribution of the answers.

Selected quotes from this group of questions:

> "It didn't feel like work, more like a hobby."
>
> "It was not difficult at all, because it was so much fun."
>
> "It was difficult to find the right material for prototyping the futuristic ideas:"
>
> "It was difficult to judge the results. You don't know what would be appropriate."

The second group of questions concerned the individual level of creativity of the students, such as how creative they felt in this project. Again, we provided a 5-point Likert scale (1 = not creative, 5 = very creative). Here, the average rating of all interviewees was 3.46 (standard deviation: 0.69, median: 3.50) (see Figure 1, right).

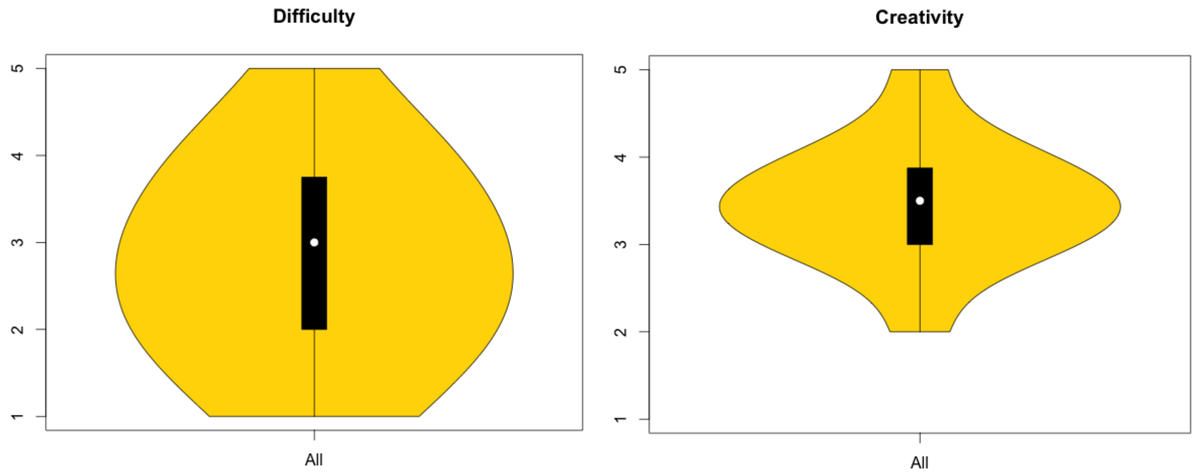

Figure 1. Left: Violin Plot of Difficulty (n=14). Right: Violin Plot of Creativity (n=14)

Also, we asked how they rated their level of creativity in this project, compared to other/previous projects (more creative, same, less creative)? The vast majority of the students (74%) felt more creative than in other projects, only one felt less creative (7%).

Selected quotes from these questions:

> "I felt far more creative than in other projects."

> "The endless possibilities triggered my creativity."

> "In the beginning it was difficult to turn off my internal censor how that might be realizable. But after that I could loosen up."

> "It was difficult to decide which idea to take, because I had so many."

The third group of questions related to the freedom within this project, specifically how the students experienced the lack of precise constraints or the possibility to design unrealistic, ugly or useless objects. From the 14 interviewees, 9 found the freedom positive and inspiring, two said it was difficult, and 2 said it was difficult in the beginning but later it was inspiring.

Selected quotes from this group of questions:

> "More constraints would have made it easier, but also more boring. I liked the challenge."

> "It was the perfect balance of freedom and constraints."

> "I would have preferred even fewer constraints and more freedom."

Finally, we asked some general questions about how they liked the project in general, what they did not like, or what was missing. The most insightful answers were about the multi-disciplinary approach of the project (there were sketching and illustration involved, as well as prototyping), and that the medium of the design was open (product, graphic, interface). On the other hand there were some complaints about the complexity of some of the stories.

Selected quotes from this group of questions:

> "I liked to manipulate the story, and that we had to design within that story."

> "I liked to design under 'pseudo-scientific' conditions. It didn't have to make any sense."

> "I didn't like the struggling at the beginning until I got my final concept."

> "My story was more difficult than most of the others' stories."

> "I had problems to understand the stories of the other students in their interim presentations."

3.3 Results (artifacts)

There was a great variety of different materials, styles, scales, and product functions within the resulting designs. Futuristic cosmetics or medications, therapy tools for depressed Aliens, Steampunk-style nano robots, ugly slimy worms, living and breathing lamps, ridiculous household devices (such as a futuristic sponge, a living trash can, or a tool to capture air humidity and turn it into ice cubes), and even dangerous viruses or DNA time capsules. Some of these things make sense and might be realized in the future, others are more like persiflage of our own living culture. The following section presents a description and analysis of the results.

We distinguish between three categories of resulting artefacts: 1) poetic or philosophical objects, 2) almost realistic objects, which suggest cutting edge concepts that would actually make sense in just a few more years or even today, and 3) objects that mainly make sense in the virtual world of a game or a Science Fiction movie. We describe the resulting objects according to these categories in the following section.

1) Poetic artefacts: Among the poetic objects were the brain massager that helps to overcome aggression (Figure 2, right), “Hasplexus”, the hate-consuming virus that feeds itself upon the hate within humankind and finally mutates and turns evil (Figure 2, left), and “Phoebe”, the breathing lamp that inhales air and exhales light, which gets frightened by an intruder and turns dark with shock (not shown).

Figure 2. Two examples classified as poetic. Left: The “Hasplexus” Virus, feeds itself upon the hate within humankind (scale 100,000 : 1). Right: “Phoebe” the living lamp.

2) Potentially realistic artefacts: Among the almost realistic objects were the nano-robot that purifies the body from inside (Figure 3, right), another microscopic robot that fixes damaged cells within the body (not shown), the DNArk, which preserve human genetic information in case the earth gets destroyed (Figure 3, left), the nano sponge that helps cleaning up stains (not shown), CalmCat 300—the digital pet (not shown), a futuristic communications device in the shape of a bracelet (not shown), and an intelligent robot that executes mine-working in contaminated areas (not shown).

Figure 3. Two examples classified as realistic. Left: The “DNArk”: a sort of time capsule with human DNA probes to rebuild the destroyed earth. Right: The “Purification Nanit”: cosmetics of the future—a nano robot that cleans up your body from inside (scale 100,000 : 1).

3) Artefacts for virtual worlds, games and Science-Fiction movies: Among the virtual objects that fit best into a virtual game or a Science Fiction movie were the brain worm to entertain you while you are in deep space hibernation (Figure 4, left), the carnivorous plant, which serves as a trash can for food leftovers (Figure 4, right), the “Get-Ice-Cubes-Out-Of-The-Air-Racket” to turn air-moisture into ice cubes (not shown), and the therapy device for depressive aliens (not shown).

Figure 4. Two examples classified as virtual: Left: the “Brain Worm” for deep space hibernation. Right: The “Carnivorous Plant”: For disposal of food leftovers.

3.4 Cross-analysis of artefacts and interviews

Subsequently, we compared the answers from the interviews with the respective project outcome for each student. We wanted to test our aforementioned hypothesis that fewer constraints lead to more creativity. For that purpose, we compared the realistic results with the results that were classified as virtual or poetic (since the latter obviously had to cope with fewer constraints than the realistic results).

Figure 5 (left) shows the violin plot between the artefact category (1. poetic/virtual or 2. realistic) and the level of creativity the respective students indicated in the interviews. The plot shows that the mean of the creativity of poetic/virtual artefacts is higher than the creativity of realistic artefacts (poetic/virtual: 3.86 vs. realistic: 3.07). The difference is significant ($t = 2.52$, $df = 11.7$, $p = 0.027$).

Figure 5 (right) shows the violin plot between the category and the level of difficulty the students declared they had with the project. The mean of the difficulty of poetic/virtual artefacts is lower than the difficulty of realistic artefacts (poetic/virtual: 2.43 vs. realistic: 3.14). However, the difference is not significant ($t = -1.14$, $df = 11.7$, p-value $= 0.28$).

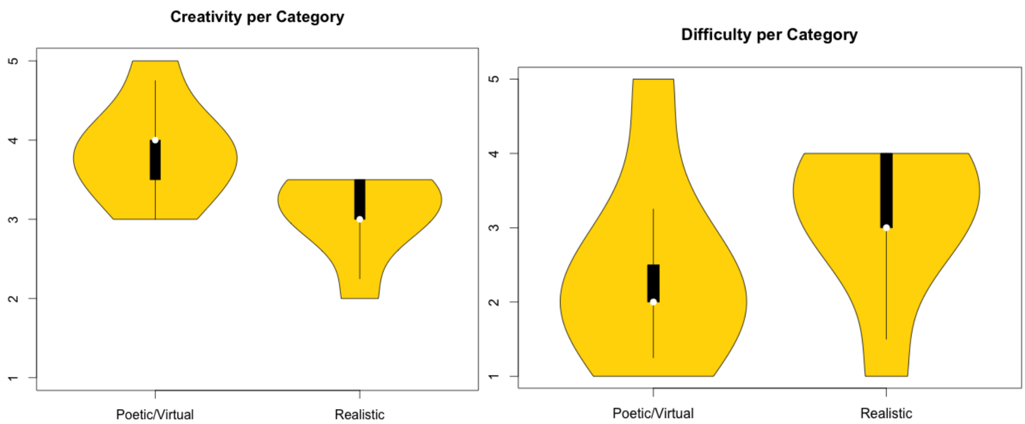

Figure 5. Left: Violin Plot of Creativity per Category “Poetic/Virtual” and “Realistic” (n=14). Right: Violin Plot of Difficulty per Category “Poetic/Virtual” and “Realistic” (n=14).

This leads us to the following conclusion: The more the students were able to ignore realistic design constraints (feasibility, logic, physical laws, etc.), the more creative energy they were able to generate, according to their self-evaluation. This supports our initial hypothesis that a limitless design frame in educational project work is able to foster creativity within students.

4. Summary and discussion

This article presents a case study of a Science Fiction design project in an educational context. Our initial hypothesis claimed that a limitless design frame with lots of freedom might be able to trigger creativity. We used three data sources to evaluate our hypothesis: direct observations during the project, semi-structured interviews with the participants, and the actual results of the projects (artefacts). This section provides a brief summary of our findings and the respective analyses. From the actual results of the project—the artefacts—we distinguished between three types of artefacts: poetic objects, potentially realizable objects, and objects for virtual worlds or Science-Fiction movies. From the observations and semi-structured interviews we could extract six key insights that seemed to have a positive influence on creativity, in the context of this Science Fiction project.

The following aspects had a positive influence on the creative output:

1) Few constraints, freedom, anything goes

2) Mix of different media (illustrative, sculpting, writing)

3) Possibility to design something weird and ugly (doesn't have to make sense)

4) Personal interest in the Science Fiction topic

5) Group discussions and external input (such as guest lectures)

6) Last but not least the story itself, which provided an inspiring playground

At the same time we could identify several aspects that seemed to restrain the creative flow. The following aspects had a negative influence on the creative output:

1) The lack of dramaturgic understanding

2) The challenge to realize "unreal" objects (finding the right materials for modelmaking)

3) The internal impulse to check the ideas for feasibility

Our main insight was, however, that those students, who decided to design an almost realistic object that might be realizable in the near future, felt significantly less creative than those students, who designed something really futuristic or poetic. Also, the students with the more realistic approaches indicated that they found the whole project more difficult than those, who designed fantastic and unrealistic products. You could also say, that those who focused on the "Science" part within this Science-Fiction context developed less creative energy than those who focused on the "Fiction" part.

Of course, the analysed case with 14 students provides only a narrow perspective on the impact of creativity. Also, we did not analyse the reason why some students decided to design more realistic objects, while others were able to get rid of the constraints. This may have been caused by the different stories each student received, which may have provided some constraints in itself. But this does not change the outcome of the analysis, that those who designed more realistic objects felt less creative than the other two groups. However, another limitation of our finding is, that they rely on a self-reported measurement of creativity. Future research should evaluate the creative output independently.

We derive the following recommendations for educators, who want to trigger a creative leap within their students: Encourage wild ideas and allow experimentation with ugly or unrealistic concepts in order to trigger creativity. It will always be possible to reduce those wild ideas down to a more realistic setting, later on. Also, provide students with a playground—an inspiring context with “safety nets” (where everything is allowed and can be tested), where they can push their limits. The challenge will probably be to find a means to switch off the internal quality control of the students. This problem may be addressed in further research.

The question remains, whether such a fictitious project setting makes any sense at all, since the results were either too cutting-edge for today’s technologies, or even completely unrealistic. Of course, we cannot know by now, if the ideas in this design education project will turn out real within the next years or decades. Maybe there will be a vegetable device that eats our food leftovers, or a nano-robot that purifies our skin, or maybe this will remain just Science Fiction. However, we believe that this article indeed demonstrates the positive influence of such limitless projects on our creativity. Moreover, there is definitely a market for such wild design concepts in the areas of film or game design. It is a fact, that more and more things in our world become virtual—for example there are about 80 times more virtual farmers, playing the online game “FarmVille”, than there are real farmers in the US (Cohen, 2011). This demonstrates the huge potential for designing fictitious products for film, games or other virtual worlds. We believe that the work presented in this article demonstrates the potential of a loose design frame with a lack of constraints to unleash creative energy.

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CREATIVITY IN CRAFT LED DESIGN: THE TOOLS ARE THE RULES

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Abstract: The co-evolution of new forms with specified tools characterises craft led design. Formal views of design and creativity may be characterised by the manipulation of the rules of a knowledge domain. This paper proposes that tools are one form of rules, and the selection, modification and invention of tools corresponds to the definition, transformation and creation of spaces for exploration in accordance with Boden's framework of creativity and other accepted creativity literature. Evidence from interviews with designer-makers who work directly with tools demonstrates this phenomenon. Finally the discussion proposes that knowledge from the results of this study could enhance the creativity of designers working in craft-led design by providing an explicit rationalisation of a particular design process of which they may have been previously unaware.

Keywords: *craft, rules, tools, transformation, emergence, synthesis, prototyping*

1. Introduction

Designers employ various kinds of tools to inspire, prototype and fabricate designs for products. These range from traditional hand tools to computer software to complex manufacturing systems. Many designers also adapt or make their tools.

It follows that tools may often play a part in creative design outcomes and the aim of this research was to explore the role of tools in creative moments in the design process. To do this it seemed appropriate to examine design situations where tool use is a dominant feature of the design process; termed for the purposes of this investigation as 'craft-led design'.

The industrial revolution transformed the way everyday objects came into being, despite this, craft has continued to play a pivotal role in the discipline of design. It has featured in the ideology of the Arts and Crafts movement, in the manifesto of the Bauhaus, and continued in the sensibilities of the designer-craftsmen of the 1950s, finally right up to the current working practices of many contemporary designers (Adamson, 2009). Today there is a breed of designer who makes working prototypes and/or all of their products for the market. These designers bring together conceptual ideas alongside their knowledge of physical making with tools, materials and techniques, and their existence is not surprising given the studio and workshop based nature of most design education.

To try and discover explicitly how the use of physical tools in such design situations corresponded with frameworks in established creativity literature a series of interviews with designer-makers was undertaken. The aim was to find evidence how of tools were involved in creative discoveries in the design processes. The final section of this paper opens a discussion on the implications of these findings for designer makers and how theoretical knowledge of the role of their tools in the design process may support creativity. This investigation was done to support a larger research project concerning creativity and generative design software tools for use with digital fabrication, a discussion of how the findings relate to this area is included.

2. Literature review

A brief review of frequently referenced literature on the subject of craft, focusing on tools, is presented to give the reader a grounding in the subject. Supporting literature about design creativity is dispersed in the main sections of the paper to corroborate the ways tools were used to creative ends by the interviewed designers.

2.1. Tools and craft

There are many complex ideas and connotations associated with the word 'craft' in the general domain stemming from how it has been appropriated in different contexts. These range from the epistemological, to the theoretical and even the political (Greenhalgh, 1997). But what is craft? Craft researcher Glen Adamson (2009) describes craft as '*a way of doing things….an amalgamation of interrelated core principles*', specifically craft is supplemental to art and design, secondly it is entrenched in material experience and thirdly it is skilled.

One well-known attempt at a formal definition of craft is David Pye's thesis on 'workmanship' (Pye, 1968). He defines making along two dimensions, first as the 'workmanship of risk' where the end result is down to the skill and dexterity of the maker, and second as the 'workmanship of certainty' carried out by machines. The implication is that direct and flexible control over one's tools is a feature of craftsmanship, which in turn tends to give the opportunity for freer and more diverse aesthetic outcomes.

Peter Dormer is another author on the subject of craft. In his book The Culture of Craft (Dormer, 1997) he echoes some of Pye's concerns in suggesting that one of the differences between craft and design is the 'personal knowhow' of craft in contrast with the 'distributed knowledge' of industrial design. Again the issue of direct control over tools is raised. In a similar argument to Pye, Dormer articulates that his main concern about technology is that ubiquitous tools, such as standardised machines and software, produce ubiquitous objects.

An earlier essay (Dormer, 1994) on craft knowledge, heavily influence by philosopher Michael Polanyi's work on personal knowledge, is an in-depth study of skill in craft. Dormer personally investigated the process of becoming learning a 'plastic art' – through pragmatic, structured, learning of 'recipes' or rules from a master in order to accumulate the tacit knowledge or feel for an activity. Dormer reported the signs of skilled craftsmanship as the seemingly effortless use and manipulation of domain conventions for expressive effect.

More recently researchers such as Rust (2004) and Wood (et al., 2009) have addressed the importance of tacit knowledge also with reference to Polanyi, particularly centring around ways of explicating the tacit knowledge of skilled practitioners which can provide valuable insights.

Finally, McCullough (1998) proposed that the way we work with digital technologies is analogous to craft practice, with the computer and its software being a toolbox. The difference being that the tools operate on symbolic systems rather than material structures. However, he noted that important aspects of craft such as dexterity, skill, dynamic feedback and an aptitude for aesthetics all play a large part in digital media.

3. Methods

This paper has arisen from research currently being carried out by the first author into the development of digital generative design tools in conjunction with 3D printing. As part of this an attempt has been made to find information about the role of tools in designers' practice by undertaking interviews with designer- makers who use tools and materials as their main source of inspiration. These were semi structured interviews carried out in the designers' studios with the intention of finding out about their design processes with particular emphasis on tools and a chronological discussion through the steps of one or more design projects. The first author is a designer herself in a similar domain and has known the designers' interviewed and their work for several years as part of a peer group. This gave a deeper understanding of the designers' work and also established familiarity and trust between interviewee and interviewer, resulting in very close case studies of the designers' working practices.

The first interviewee was a ceramics tableware designer, Ian McIntyre, who designs by making his own full ceramic prototypes for production and some of his finished products in his studio. From experience of internships the designer explained that many tableware designers work by making foam models and computer aided design drawings despite the difficulties in translating such representations into clay. He prefers to work directly with the manufacturing tools and materials of industry to design and terms this '*design through making*'.

The second interviewee was jewellery designer Eleanor Bolton, who works with textiles. Her current body of work has come from developing her own craft technique of hand stitching soft cotton rope into coils to create large scale, tactile neckpieces and bangles.

Thirdly silverware designer Kathryn Hinton was interviewed who has two bodies of work in progress. The first body of work is designed through sketching and then produced with traditional silversmithing techniques such as hammering and forging. Recently as part of a research project she has developed her own haptic digital tool, a hammer with internal motion sensors that plugs into a computer via a USB port and works in conjunction with computer modelling software, these designs are then realised with various digital fabrication tools.

Evidence from the interviews has been analysed to attempt to find similarities in cognitive processes of those working in closely with tools to produce objects. This in turn has been corresponded with Boden's (2003) typologies of creative ideas and other creativity literature.

4. The domain

Domains are an essential aspect of creativity. Csikszentmihalyi's (2006) definition of creativity is '*when a person, using the symbols of a given domain such as music, engineering, business, or mathematics, has a new idea or sees a new pattern.*' Similarly the world of craft contains various sub domains, each described as a 'medium' - a range of tools and materials (McCullough, 1998). Dormer (1994) provides a neat dovetail with Csikszentmihalyi's summation by stating that craft activity 'follows rules, conventions and patterns', in craft these are physical techniques and tools as well as conceptual or symbolic conventions.

Boden's first specification of creativity is what she calls 'exploring conceptual spaces'; searching within formalised sets of rules. She considers this search as taking place in the mind, describing it as a metaphorical map of terrain to be explored. Examples of widely known 'conceptual spaces' are haiku poetry or jazz music, where certain stylistic rules are followed to create works, but also define a problem to be solved.

The designer-makers interviewed were very concerned with their position in domains; particularly how their work would be perceived by peers and public and often throughout the interviews the conversation would come back to the nuances of the domains they were working in, perhaps partly as the interviewer is also very conscious of the same domains. This careful positioning seemed to be important for the initial direction of any design activities, the aim seemed to be to adhere to certain expectations of a community yet at the same time situate a niche position within that. The ceramics tableware designer had previously made what he called '*experimental products*' but had then decided he wanted to be the designer of everyday, functional tableware. He wanted to make sure he addressed details such as capacities, ergonomics and practicalities such as the size of microwaves, however the niche part of his position was a desire to help bolster the ailing British ceramic manufacturing industry, making use of the skills available within it. These domain decisions influenced the ceramics designer's choice of tool, the jigger-jolly machine, '*it was the closest thing we had that mirrored real life production… things are still produced on those machines in industry*'. The use of this tool also allowed him to '*design a range of products that nipped into a little gap in the market that otherwise would be incredibly hard to get into*' as he could initially produce the products himself to get them into the market while still having the possibility of having them produced in a factory once some confidence in his designs was gained.

The jewellery designer also stated that she had wanted to change the domain position of her work as '*I found that what I was previously doing, there was a lot of people combining found objects… I felt like I am not adding to this in anyway*' Her reaction was a desire to make less '*conceptually laden*' work that was more fashion led with an emphasis on aesthetics and tactility and reduction in the number of different processes used on one piece of work. To do this she moved towards textile materials, tools and techniques.

In both these cases the tools the designers selected were a crucial part of the domains selected by the designers. They not only embodied larger ideals about their design work but also became part of their personal domain to be explored for creative ends.

5. Constraints, rules and tools

Under-constrained design problems, such as those usually found in craft-led design, are approached by designers in a significantly different ways from over-constrained problems, such as those found in engineering design. Stacey and Eckert, (2010) compare processes and describe a process of dealing with under-constrained design problems, using evidence from interviews with knitwear designers. This process first finds implicit constraints in a design brief, which is then followed by a tactic of self-imposing explicit constraints to frame the design problem.

The descriptions of the designer-makers interviewed in this study corresponded with these theoretical ideas. Beyond the broader domain positioning discussed in the previous section the designers seemed to go through a process of further restriction within their design process, each restriction with the intention of moving closer to a solution; in the cases of the designer-makers most of these were related to the selection of tools. The jewellery designer restricted herself to a particular set of materials and tools and then finally to one making technique she had then developed: '*it was literally* *just, right here's a ball of yarn, here's a needle and here's the rope and I wasn't allowed to use anything else'*

This procedure of building or formulating a 'space' appears regularly in design theory, such as Schön's (1992) 'design worlds' and as the co-evolution of problem and solution (Dorst & Cross, 2001). Also Boden (2003) talks of creativity as exploring, transforming or constructing a new conceptual space. The way this is achieved ranges from bending or tweaking accepted rules, to complete remapping, when surprising, even shocking, new ideas are formed. In the case of the designer makers the tools are often the 'rules' that defined their personalised conceptual spaces, guiding and focussing attention and actions.

5.1. Tools and design synthesis

One of the widely known ways that creativity occurs in the synthesis phase of design is through analogy (Boden, 2003, Cross, 2000 & Gero, 1996). Designers also use metaphorical comparisons in order to view the situation differently in the hope of achieving a paradigm shift in viewpoint and consequently an original idea.

In the case of the designer-makers this analogical shift took place through tools and was most demonstrably apparent in the conversation with the silversmith when discussing the haptic digital hammer she had envisioned, made and used to create vessels and jewellery. When describing the new tool she used several 'like' comparisons with other tools, '*like a hammer….like a (Nintendo) Wii…like a Wacom pad'* Analogies which had led towards the creative idea of a digital silversmithing hammer, achieved by mapping the workings of known digital interface tools that that are driven by hand movement to make the bridge between the analogue hammer and the digital hammer.

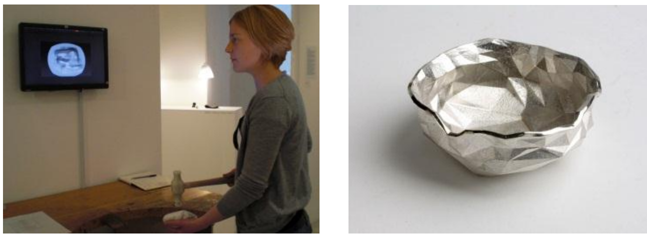

Figure 2. Digital hammer in use, rapid prototyped and cast silver bowl.

Another way of producing creative insights is 'concept blending' where a new concept is produced by combining two base concepts, the 'blend' inherits structural aspects of each (Nagai et al. 2009). Again this took place through tools and techniques, in particular in the work of the jewellery designer at the start of her idea generation process. The initial concept she started with was one of chains, an archetype of jewellery design, the other concept was that of stitching with a needle. The 'blended' concept is a coiling technique where the cotton rope is stitched onto itself to create a soft tube. She describes it thus: '*I can create something that looks like a chain but it's just one continuous piece, so that was the idea to make these sort of loops and then stitch them together*' Creative ideas can come about through using analogy and concept synthesizing of the actual tools the designer is using applying them in new combinations or contexts.

Figure 1. Close up of stitching technique and examples of form variations from altering stitch counts

5.2. Transforming tools

Boden (2003) also describes how creativity occurs by less dramatic domain shifting by transforming rules. A similar concept is named as 'mutation' by Gero (1996). Again this approach was seen in the designer-makers practice. The silversmith interviewed described the common practice of altering tools to suit, '*I guess with traditional tools you adapt them If it's a stake that's not right for your job you file it until it gives you the right shape…… you shape hammers and cut them or take off the sharp edges*', an example of transformation or mutation of rules in the most basic sense. Actively customising or hacking tools corresponds to the creative activity as described by Boden (2003) and Gero (1996), a process deforming rules for new ends.

5.3 Breaking the tools

Boden (2006) also cites deliberate rule breaking as route to creative work, similarly Dormer (1994) describes how once learned rules of craft techniques can be knowingly broken to convey certain meanings in an artefact. Purposeful rule breaking was also very much apparent in the designer-makers' design process. The ceramics tableware designer had done an earlier project where he made plaster standardised plaster moulds each of which he chiselled into to create individualised design features on a cast porcelain vase, see Figure 3.

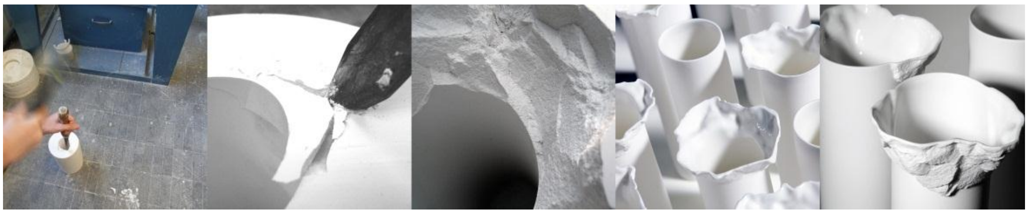

Figure 3. 'Broken Vase': chiselling process and finished objects

This is almost a literal example of creativity found in the breaking of a tools or a rule, by physically breaking a mould to create something new. Describing a later project he stated '*I don't really like to add a step because I feel that makes it a little bit more complicated and not quite as clever. I usually try and remove a step, so putting in less clay to an existing mould*'. This particular breaking of convention was used in a plate design where a pleasing irregular, organic edge to each plate was created by slightly under filling the mould that the clay was pressed into. This had the added benefit of gaining efficiency in the production process by removing the step of trimming excess clay at the edge of the mould. These examples highlight that creative rule breaking can occur not only in a very literal way with tools but also with the conventions associated with their use, present the opportunity for fresh concepts for the designers.

5.4. Emergence from tool use

Sets of rules, once coupled together often exhibit emergent properties that may previously not been recognised or intended. Emergence can be serendipitous to the design process; new information can provide the bridge between the gradually co-evolved problem and solution; spurring a creative leap (Dorst & Cross, 2001).

Most of the creative ideas generated by the designer who were interviewed were the result of emergent properties of the tools they were using. After the jewellery designer 'blended' together her original concepts she discovered an emergent property of the technique she had developed, increasing or decreasing the stiches on successive coils expanded and retracted the overall forms of the jewellery: *'so it just started off that I was making these tubes….then using the idea that like in knitting and crochet you add and drop stitches to create different shapes and forms*'. The silversmith also experienced emergent aesthetics from her tool, the nature of the digital mesh that was 'hammered' into resulted in the facetted aesthetics of the work made with it. These forms were a pleasing contrast to the smooth surface of hand raised silver vessels and belied the partly digital process behind them. The ceramics designer found more conceptual emergent properties through his creative tool use, namely the bonus of several of his products having individualised features, adding perceived value over what would normally be identical manufactured ceramics.

An aspect of making use of such emergent properties is a requirement of the user to anticipate and, critically, to recognise their presence (Schön, 1992). Oxman (2008) goes further than this and suggests that emergence is to some extent guided by designer's domain knowledge. Certainly the ceramics designer was searching for such emergent properties in his experimentation with tools and materials '*the idea was to elevate the quality of the material and elevate the process as well, so it was about finding a quality that only could be produced on the jigger-jolly machine and a quality that could only be produced in clay*'

Gero (1996) defines emergence as an implicit property which can be made explicit, interestingly echoing the concept of tacit knowledge, something considered to be a cornerstone of craft and tool use, gained through practice with tools (Dormer, 1994). Rust's (2004) interpretation of Michael Polanyi's work on 'personal knowledge' is that leaps of 'illumination' occur from having a deep implicit understanding of something, gained from the direst use and prototyping of artefacts.

However too much skill or expertise can also be to the detriment of creativity, the tableware designer stated that despite the in-depth knowledge of ceramics he now holds '*a lot of my original projects were successful because I didn't know the rules… it's a double edged sword because now I know the material too well so I rule out all of the experimentation that could possibly yield new ideas…which is why the next project I do probably needs to be outside of ceramics, to freshen me up a bit*'. This is an echo of a phenomenon described in creativity literature, designer burnout (Eckert et al., 1999) and the problems of fixation (Wiley, 1998) are associated with lapses in the creativity of expert designers.

Emergence of serendipitous outcomes is not always born of expertise. A particular example of this was the severe error in the design of an expensive mould which left the tableware designer with no choice but to rethink his whole design and process of production, but in turn this yielded one of his most successful products, by casting into the mould in a different way from what was originally intended. This non – guided emergence from a tool, which initially appeared to be a financial disaster, stimulated a reformatting of the designer's whole approach. Although the mistake was made by inexperience of making a tool it is likely the situation was perhaps redeemed by the designer's creative abilities.

6. Implications

6.1. The Tools are the rules

The interviews undertaken sought to look at the use of tools in the design process and how these corresponded with established literature on creativity. The interviews revealed explicitly that tools play an important part in the creative processes of some designers. Tools seem to be embodiments of rules, working alongside more conceptual rules and conventions to transform design problems towards a creative design solution. Analogically viewing tools as rules sits well in frameworks such as Boden's (2006), they appear to perform the same role as more conceptual rules but in a material sense, useful for the designer who is working towards physical objects. The reversal of this is the idea neatly allows the idea of rules being tools for designers, the designers exhibited a tendency to try and constrain themselves in various ways to help formulate a tighter problem space as would be expected in such under-constrained design situations, rules become the tool for such challenges. In particular serendipitous emergence, more often than not guided by the designer's tacit knowledge of their tools, was the key to creative and successful outcomes.

The background hypothesis of this work has also been influenced by shape grammar theory (Stiny, 2011 & Knight, 1995) in which transformative rules concerning shapes and their positional relationships are formalised to describe and generate new shapes. Stiny (2011) has discussed how shape rules are creative; they take, recombine and make use of emergent shapes to create new shapes, a similar process to the tools use discussed throughout this paper.

6.2. Pedagogical implications in craft-led design

An understanding of creative frameworks and the role of tools within them would be of use to designers. The designers interviewed had undertaken these processes in the most part intuitively. Only one seemed explicitly aware of how they had gone through a process of constraining herself, yet formulating unusual combinations of tools and techniques. She had also mentioned that this way was a successful but new way of working for her she had almost stumbled upon recently and had previously done quite different, less successful work that followed a known style rather than being particularly original. From the first authors experience and conversations with other designers with similar educational backgrounds it seems apparent that creativity theory in terms of rules and tools is not something particularly spelled out in under constrained, craft led design education such as jewellery, textiles and ceramics. When asked the designer-makers had very vague definitions concerning rules and tools that they might use, however as the conversations progressed it was revealed there were quite strict about following certain rules and their conventions either from their domains or their of their own choosing. Also of note was when asked what their tools were the designers answered with materials as well as conventional tools, this suggests that materials may also play a similar role in creativity. As has been mentioned the designers were undertaking these processes apparently intuitively or under slightly different cognitive guises, however perhaps knowledge of these theoretical concepts may have helped at times and may help new designer understand ways of fruitfully using tools creatively.

7. Future work

This study has come about as part of a wider research project into the use of computational generative systems, in particular shape grammars, in conjunction with digital fabrication technologies by designers and how creative outcomes can be achieved. The first author has moved from a similar craft-led practice as the designers interviewed to developing and using her own generative software tools and digital fabrication and found an affinity in the ways of working during this transition.

Oxman (2006) states in that a '*new generation of digital design specialists is emerging*' these are designers who are '*digital toolmakers*': designers who have the ability to create and customise digital tools and that the accepted design theory paradigms, which were generally established from research around paper based activities such as those developed by Schön & Wiggins (1992) may need revising (Oxman, 2008). It is the first author's hypothesis for the research project that something may be learned by carefully looking the designer's interaction with traditional and generative tools during design processes.

More interviews with designers using tools both traditional and generative, along with reflection on the first author's design practice is planned to give further insight into the relationship between creativity and tools, particularly generative design tools.

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