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Investigation of the priming affect of material, challenge formulation and warm-up phases in soft prototyping sessions

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ABSTRACT

Prototyping is a common method in the Nordic user involving design approach. However little is empirical shown about how priming factors affects out-put of prototyping sessions. In this paper we investigate whether three parameters; material, challenge formulation and warm-up sessions; affect out-put of generated prototypes.
The research question has hence been: *How does the material, challenge formulation and warm-up phases affect the out put of a prototype session?*
We led ten participants through three rounds of individual prototyping-sessions each lasting ten minutes. The participant was given one of three challenges to solve in each round and was allowed to prototype in one out of four materials in each round. After each round the participants presented the prototypes to a running camera.
On average each participant made approximately 3.7 prototypes in each round, which lead to 112 prototypes in total. These prototypes were evaluated regarding number of parts, number of functions, number of functions mentioned in the presentation, size and 2D versus 3D. After each session the participant were asked to fill out a questionnaire concerning their experience with the different materials and challenges.
Through statistical analysis of the mentioned data we were able to conclude that material, challenge formulation and warm-up significantly affected the prototypes ($p<0.05$).
Hence we end suggesting further research areas to address under more controlled experimental set-ups. This is with the aim of gaining deeper understanding on the complicated creative processes going on in the early stages of new product development.

1 Introduction

The Scandinavian approach of design has since the 70s and on involved user involving activities, prototypes and co-creation (Gregory 2003). There is a common accept that prototypes and prototyping are important tools when it comes to exploring, evaluating and communicating new ideas in the process of designing innovative solutions (Spinuzzi 2002). However still little research has been done in order to understand which parameters influences and primes the results of prototyping. As a conclusion to their literature study Colombo et al. (2015) concludes priming to be useful to cause different attitudes, and consequently

behaviours, toward a creativity task. Still most priming research are focusing on associative mental sessions *before* a given task. We wished to explore the lack of understanding of priming effects *while* performing the creativity task. Onarheim (2012) map out seven categories of creativity constraints that can occur in the case of engineering design where creative performance is needed. These constraints touch among others on material choice. Also the framing of the task can be constraining or inspiring depending on the person interpreting the task (Onarheim, Balder; Biskjaer 2012). Additionally other studies indicate that certain warm-up phases before the actual creativity task is performed can influence the out-put in a positive way (Steidle and Werth 2013).
With this knowledge in mind the scope of this study has been:

- *How does the material affect the out put of a prototype session?*
- *How does the formulation of a challenge affect the output of a prototyping sessions?*
- *How does warm-up session affect the output of a prototype session?*

An initial experiment was designed involving 10 participants who were asked to prototype solutions to 3 different challenges while only using one specific material (paper, foam, cardboard or Lego bricks). The material use as well as order of the challenges was randomized so that the combinations were different from participant to participant. That is the test persons in the study could not choose material or challenge themselves, but was told to prototype in only one material to a specific challenge.
After each session we had a group of prototypes, which could be evaluated in terms of: Total number of prototypes; Number of parts of each specific prototype, Level of abstractness and more. This allowed for statistical comparison (ANOVA test) of differences between the three independent variables; material, challenge and prototyping round as well as qualitative observations. In this way our work contribute the community with deeper knowledge on material use, challenge formulation and warm-up aspects when facilitating prototyping sessions.
In section 2 we will present the theoretical foundation of prototyping as well as highlight how previous researchers has evaluated prototyping sessions and which parameters can affect these. This is followed by a description of our research setup and methodology in section 3. Further Section 4 describes the Analysis and Findings of the experiment. Section 5 discusses the results and limitations of our study, which is finally followed by a conclusion.

2 Theoretical Background

2.1 Priming and Creativity Constraints when prototyping

Theory of priming and creativity constraints argues it is reasonable to hypothesise that by hardening or softening the constraints at hand one can affect the level of constrainedness and further the creative performance in a creative sessions (Onarheim 2012; Colombo et al. 2015). The parameters affected could be number of generated ideas or functionalities participants end up with in a prototyping sessions(Friedman et al. 2003; Onarheim 2012). As a conclusion to their literature study Colombo et al. (2015) concludes priming to be useful to cause different attitudes, and consequently behaviours, toward a task. Still most priming research are focusing on associative mental sessions before a given creativity task. We wished to explore the lack of understanding of priming effects while performing the creativity task. But what to focus on? Onarheim (2012) map out seven categories of creativity constraints that can occur in the case of engineering design and affect the work of the engineering designer. These constraints touch among others on material choice. In literature one find several studies on how prototypes of different materials affect the users differently in terms of output of the session (Blackler 2009; Hare et al. 2013; Lim et al. 2006). However few studies have used materials as an active input variable that in it self can affect the output of an active prototyping session and hence is usable for statistical analysis. In fact Wiberg (2014) describe and suggest several research questions covering e.g. how texture can fit specific interactions or whether certain properties of a material fits specific purposes etc. Similar to the material usage the framing of the design task can be constraining or inspiring depending on the person interpreting the task (Onarheim 2012).

Finally a common practice when making experiments in the field of creativity research is to include a pre-warming creative task before the actual creative experiments (Friedman et al. 2003; Steidle and Werth 2013; Yoruk and Runco 2014). This is in-fact based on the knowledge on pre-priming as an effective tool to enhance creative performance (Mednick, Mednick, and Mednick 1964). Hence we felt a need to include this aspect and test whether this warm-up factor could be identified in our study.

2.2 Measuring Prototypes and Divergent Processes

In order to create a comparable research setup we had need of looking into how previous researchers has evaluated prototypes and there out put. Jensen, Balters, and Steinert (2015) summarize how literature previously has evaluated the output of prototypes. This covers both aspects as insights one achieve through the usage of the prototypes, as well as functional dimensions as how many functions a prototype have or the size of a prototype. Also part count has been used as a parameter for evaluation prototypes in product development process. In their study of factors in prototyping Yang (2005) evaluate the time spent on various design activities as well as evaluating the prototypes through part count. In our study the focus has been on a short-term study that did not take part of longer process of product development. Hence we have focussed mainly on physical parameters of the prototypes built by the participants.

Moreover using prototypes as an ideation tool places us in the field of divergent thinking processes as well as their evaluation. Steidle and Werth (2013) utilizes two ways of evaluating the output of a divergent thinking process. They define ideational fluency (diversity of ideas) and quality (expert ratings of each idea). From a neuroscientific perspective Yoruk and Runco (2014) also differs between number vs. quality. Further Plucker, Qian, and Schmalensee (2014) evaluates six quantitative methods for evaluating output of divergent process and further conclude a combination of objective and subjective evaluation methods. Since our study was rather small and short-term we have prioritized to focus on quantitative evaluations of the prototypes combined with subjective feedback in form of a questionnaire.

3 Research Methodology

The research strategy was to facilitate a controlled experiment, where we had the possibility to control the parameters we hypothesised would affect the prototyping session. Hence a very simple and short time set-up was chosen in order to study the immediate functionalities and usage-properties of the respective materials and avoid learning processes related to the different materials.

3.1 Description of the Experimental Set-up

The experiment consisted of three rounds of individual ideation through soft prototyping. Each participant was given a short introduction of the concept of soft prototyping. Afterwards they were assigned 10 minutes to prototype solutions to a challenge while only using one specific material. The materials used in the experiment were either: Ordinary LEGO-blocks

(1), paper (2), cardboard (3) and polystyrene plates (4). The tools provided were Duct tape, normal tape, a glue gun (with glue sticks), scissors and a cutting knife. While prototyping the participants were alone in the room. At the end of each session the participant presented their developed prototypes to the facilitator. Also they would write a title and a number on the prototype to indicate the chronological development of the prototype. After this presentation the prototypes were removed from the room and the participant would be supplied with a new challenge and a new material. This process was repeated three times so that every participant solved three challenges while using three different materials.
In the end of the 3x10minute session the participant filled out a short questionnaire concerning his or her experiences and difficulties with each material and challenge.
Figure 2 illustrates the surroundings and set-up of the prototyping station. A high table was set up so that the participants were standing while working.

Figure 1 Experiment set-up for participants

3.2 Description of the Challenges

In order to experiment with the task formulation given to the participant three challenges were formulated. These increased in level of freedom in relation to information concerning the creativity constraints described by Onarheim (2012). The three challenges were:

#1 Highly defined challenge: *Design an alarm system that alarm people in the workshop in case of an emergency. Often they are using welding masks or hearing protection and wear heavy clothes.* In this challenge the functionality and use case of the product were quiet specified and as such the challenge was constrained.
#2 Medium defined challenge: *Design an Alarm clock.* In this challenge the functionality was given, but the use case as well as the means of achieving that purpose were open to the participant.
#3 Low defined challenge: *Design the future private driving experience.* In this challenge the use case and functionality were defined however when introducing the “future” the challenge suddenly become less constrained and ambiguous. Also the word “driving” was meant to represent a means of transportation, not necessarily in a car.

3.3 Data Collection

The strategy of the experiment was to generate and collect data consisting of quantitative data points suitable for statistical analysis combined with qualitative insights to support the findings. Therefor three overall data collection methods were used:

- Statistical Analysis of three independent variables and 10 depending variables (see Table 1).
- Video recording of the experiment including an oral presentation of the prototypes. This was used for observing the behaviour of the participant as well as counting the

number of functionalities mentioned in the oral presentation of each prototype (variable 7 in Table 1).

- Questionnaire with 9 qualitative questions based on likert-scale and 4 open-ended questions with text based answers.

Table 1. List of the variables collected in this study and how they were measured (*A prototype was evaluated as 3D if one of its dimensions had a thickness bigger than the thickness of the material it was made of.)

Independent Variables	
Categorical	1. Type of Material (1-4)
Categorical	2. No. of Challenge (1-3)
Categorical/Interval	3. No. of Prototyping Round (1-3)
Depending Variables	
Interval	1. Total number of prototypes pr. material pr. participant
Interval	2. Total number of prototypes pr. participant
Interval	3. # of prototypes pr. challenge
Interval	4. # prototypes pr. round
Interval	5. # of parts pr. prototype
Interval	6. # of functions pr. prototype
Interval	7. # of functions mentioned in the presentation pr. prototype
Interval	8. Level of Abstractness (ratio between mentioned prototypes and physically built prototypes)
Interval	9. Size of the prototype (area)
Categorical	10. Size (2D/3D) pr. prototype*

4 Analysis and Findings

In this section we will describe the findings from each data research method - Statistical Analysis; Video Recording and the Questionnaire. The main statistical data analysis has consisted of several ANOVA tests that allow us to identify statistically significant differences between the independent variable and the depending variables. A chi-square test was used to compare the frequency and distribution of the categorical independent variables. Further the analysis consisted of carefully reading through the answers of the questionnaire as well as observing the behaviour of the participants when prototyping on the video recordings.
In the following section we describe the findings regarding 1. Material Aspects; 2. Challenge formulation and 3. Warm-up factors.

4.1 Findings regarding Material Aspects

Table 2 Results from ANOVA test in STATA (* indicates $p < 0.05$ and ^ indicates $p < 0.10$)

Independent Variable	**Depending Variable**	**F**	**P**	**R^2**	**Significant difference between:**
Material	5. # of Parts	13.31	0.000*	0.2699	Lego and the other Materials
Material	6. # of functions	6.25	0.0006*	0.1478	Lego and the other Materials
Material	7. # of functions mentioned	6.07	0.0007*	0.1443	Lego and the other Materials
Material	8. Level of Abstractness	0.78	0.5067	0.0213	
Material	9. Size	5.85	0.0010*	0.1398	Lego and the other Materials
Material w/o Lego	5. # of Parts	1.78	0.1751	0.0443	
Material w/o Lego	6. # of functions	2.09	0.1307	0.0515	
Material w/o Lego	7. # of functions mentioned	0.21	0.8143	0.0053	

Material w/o Lego	8. Level of Abstractness	3.87	0.0250*	0.0925	Cardboard and Foam
Material w/o Lego	9. Size	1.37	0.2615	0.0342	

A chi-square test showed no significant difference between the total numbers of prototypes built in of each material. That is no material was found to make participants built significantly more prototypes than in the other materials. Yet we found from the statistical analysis that the average of independent variables no. 5-9 between the four materials were significantly different (Table 2). This was in particular when comparing the average of Lego with the three other materials. Since we found Lego to be radically different from the three other materials we decided also to make an analysis without including Lego. Here the results showed that only level of abstractness was influenced significantly when comparing the average level of abstractness between foam and cardboard. Moreover when evaluating the prototypes after the experiment we found that some prototypes covered the same idea, but were made from different materials (figure 3). This indicates that the factor of previous knowledge has a big effect on how people interpret a challenge and further come up with the ideas for a solution. This background knowledge might play a bigger role than the influence of each material.

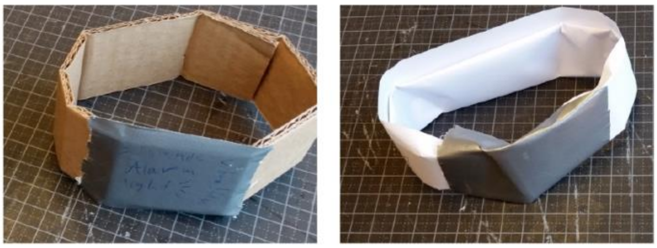

Figure 2 Examples of two prototypes made from different materials of two different participants yet representing the same idea of a waist band with an alarm function solving challenge two (Alarm system for a worker in the workshop).

This finding is supported by the comments in the questionnaire concerning the experience with the different materials. These were mainly related to the physical properties of the material. These properties were mentioned to limit or support the participants' ability to physicalize ideas. For instance prototyping with paper was described as easy yet hard when the participant wanted to create bigger and voluminous prototypes. On the contrary foam was seen as a good way to create shapes and forms. Similar cardboard was described as easy to build with and easy to construct 3D forms from. Also advantages as stiffness and thickness were mentioned compared to the other materials.

The participants were split in their opinions on effectiveness of using Lego to built prototypes. On the one hand the Lego bricks was described as constraining since the predefined blocks and objects did not allow for creating the exact idea in the mind of the participant. Also participants mentioned that they spend too much time browsing through the box of Lego in order to be inspired or find the exact block they were looking for. They felt the Lego bricks were defining the prototype rather than the opposite. As a solution one participant just started to duct tape the blocks together to get the shape he was looking for (figure 4). Other participants disagreed and felt they could build anything with Lego and that kept them from being stopped in the building process. Still these participants explained that they had considerable prior experience with Lego from their childhood. A final observation when investigating the topic of material was whether the tools supported the materials. E.g. the blade of the cutter knife several times mentioned as too short for cutting in foam which let to frustration of the participants.

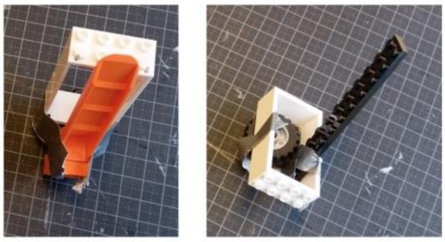

Figure 3 Examples of prototypes of Lego, which was put together with duct tape

4.2 Findings regarding Challenge Formulation

Table 3 Results from ANOVA test in STATA (^ indicates $p < 0.10$)

Independent Variable	Depending Variable	F	P	R^2	Significant difference between:
Challenge	5. # of Parts	0.16	0.8559	0.0029	
Challenge	6. # of functions	2.48	0.0884	0.0435	Challenge 1 and 2; and 1 and 3
Challenge	7. # of functions mentioned	2.55	0.0828^	0.0447	Between challenge 1 and 2
Challenge	8. Level of Abstractness	0.47	0.6261	0.0091	
Challenge	9. Size	1.81	0.1693	0.0321	

A chi-square test showed no significant difference between the number of prototypes answering each challenge. However the statistical analysis shows that the number of functionalities of the prototypes answering challenge 1 was significantly higher than the two other challenges. In table 3 it is illustrated how there was significant difference between the average number of functions and average number of functions mentioned in the presentations between challenge 1 and 2 ($p < 0.10$). The highest constrained challenge resulted in a higher number of functionalities than the two others.
In the questionnaire the participant rated the attractiveness of the different challenges different and found the high and medium constrained challenges the most pleasant to work with. However one participant stressed that the combination of challenge and material was what made the real challenge when it came to ideating:

"At first I was very happy to get Lego, because then I just needed to combine existing block, but then I got the assignment of making the future car and it turned out challenging to make soft, organic forms out of the bricks." Answer from the questionnaire

4.3 Findings regarding Warm-up Aspects

On the topic of warm-up aspects we investigated whether the chronological order of the prototypes made in each individual round had an effect on parameters as no. of functions, size etc. That is if the prototypes built in the beginning of a session was less advanced than the once build in the end. Also we investigated whether the order of the prototyping rounds affected the out-put of the prototyping round.
The result of the statistical analysis can be found in table 5 and 6.

Table 4 Results from ANOVA test in STATA (* indicates $p < 0.05$ and ^ indicates $p < 0.10$)

Independent Variable	Depending Variable	F	P	R^2	Significant difference between:
Prototyping Round	5. # of Parts	1.44	0.2408	0.0258	
Prototyping Round	6. # of functions	4.42	0.0142*	0.0750	Round 1 and 3
Prototyping Round	7. # of functions	4.54	0.0128*	0.0769	Round 1 and 3

	mentioned				
Prototyping Round	8. Level of Abstractness	0.91	0.4040	0.0176	
Prototyping Round	9. Size	0.89	0.4149	0.0160	
No. of Idea	5. # of Parts	0.71	0.6447	0.0470	
No. of Idea	6. # of functions	0.39	0.8822	0.0266	
No. of Idea	7. # of functions mentioned	0.27	0.9503	0.0184	
No. of Idea	8. Level of Abstractness	0.74	0.6173	0.0498	
No. of Idea	9. Size	0.75	0.6093	0.0499	

Table 5 Results from OLS analysis in Stata between prototyping round and 4 different interval variables (* indicates $p<0.05$)

Independent Variable	**Depending Variable**	**Coefficient**	**t**	**P > t**	**R-squared**
Prototyping Round	5. # of Parts	0.62	0.79	0.430	0.0057
Prototyping Round	6. # of functions	6.91	2.78	0.006*	0.0657
Prototyping Round	7. # of functions mentioned	6.97	2.83	0.006*	0.0677
Prototyping Round	8. Level of Abstractness	- 0.25	-1.07	0.286	0.0110
Prototyping Round	9. Size	38.04	01.09	0.277	0.0107

In both table 5 and 6 one sees that the chronological number of the idea did not to affect the characteristics of prototype. In fact in the video observations we saw that the ideas seemed to inspire the next in terms of concept. E.g. a participant first made a prototype representing an alarm clock in with puzzle bricks fitting into specific holes, next a puzzle tower and finally a colour code puzzle alarm clock (figure 5). With the terminology of Yoruk and Runco (2014) the ideational fluency was affected, but not the variety of ideas.

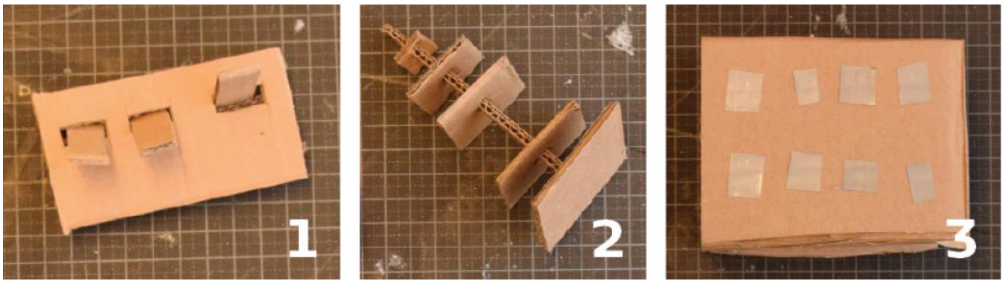

Figure 4 Three prototypes built in the indicated chronological order. No. 1: A 3D puzzle alarm clock. No. 2: A 3D alarm clock puzzle where the pieces have to be put in size order. No 3: A 3D alarm clock with lighted buttons, which the user has to press in a certain order.

A chi-square test showed no significant difference between the total number of prototypes built in each round. Instead the statistical evaluation showed that the average of functions built as well as mentioned in the oral presentation was significantly different. The number of functions and number of functioned mentioned in the oral presentation increased throughout the round number. That is in prototyping round three the participants would create prototypes with more functions and more mentioned functions. This indicates and supports the theory of a sort of warm-up effect while prototyping.

5 Discussion

Because of the size of this initial study design involving only ten people the general conclusions of the study are limited. However the learning from the experiment serve as inspiration to future studies touching upon how to conduct research in and conduction of soft prototyping sessions.

In term of material choice we saw that the material in it self does only in few cases actually inspire and lead to an idea. In relation to theory of priming the material parameter was not observed to unconsciously prime participants, but actually more obvious characteristics of the material affected the participants. This dealt with whether the properties of the materials supported the mental idea flow of the participants. This calls for considered choice of materials when prototyping in certain markets or problems. There is no perfect material for prototyping, but as a facilitator one must secure a variety of materials that support different functions and details such as mechanical details (rotation, bending) or shape building properties. It should be the mental idea flow deciding on material choice rather than material affecting the ideas.

Opposite to the material parameter the parameter of challenge formulations was found prime people to get ideas of different functional details. Further the study indicates that the formulation of challenges also have an impact of participants' motivation towards a certain challenge. Still we saw examples that the combination of challenge and material could be the true constraint in some cases. Hence we suggest for future studies to include multifactor analysis in order to see whether certain material and challenge formulations match better than others. This corresponds and extend the suggestion of Wiberg (2014) to not only investigate how certain materials fit different purposes, but also how certain materials fits different contexts.

Regarding the warm-up session we identified a significant effect in the statistical analysis. This concerned the level of functions physically built as well as mentioned in the oral presentation of the prototypes. This effect might have influenced the other findings of the statistical analysis and must be considered actively in future research set-ups. Moreover it would be interesting to investigate long term aspects of the prototyping session - that is for how long the warm-up affect last. This touches upon organizational learning rather than actual creativity constraints.

6 Conclusion

In this paper we address the need for knowledge on priming effects when deliberately experimenting with the creativity constraints; material, challenge formulation and warm-up factors in soft prototyping sessions. We addressed the following research questions:

- *How does the material affect the out put of a prototype session?*
- *How does the formulation of a challenge affect the output of a prototyping sessions?*
- *How does warm-up session affect the output of a prototype session?*

An initial study was made involving 10 participants who individually ideated on solving three challenges with prototypes built of three different materials. The challenges varied from high to low degree of freedom and the materials were either paper, cardboard, foam or Lego bricks. Through this study we found that the properties of the four different materials affected the participants understanding of whether the material supported their ideas or if the material dictating their ideas. This especially covered mechanical properties such as texture and flexibility of the material. Hence we conclude that a good prototyping material should be a selection of materials and tools supporting as many mechanical varieties as possible. This will hopefully support the mental idea flow of the participants.

Regarding the challenge formulation this study showed that participants when solving the challenge with the lowest degree of freedom came up with the most functionalities both built and mentioned in an oral presentation. Moreover participants tended to prefer the challenge with low or medium degree of freedom to the challenge with high degree of freedom.

We cannot conclude that future facilitators should go for low or medium degree of freedom challenges, but stress that the formulation of the challenge can influence both *the output of* *ideas* and *the motivation* towards a certain task. Finally the warm-up effect of conducting several rounds of prototyping significantly differed in the average design of functionality of the prototype. Hence we suggest to include this parameter in future studies since this factor can affect the two other parameters. In this way we have begun the investigation of how different parameters can affect soft prototyping sessions, but stress the need and motivation for further discussing research approaches in this field.

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