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WHAT'S THE BENEFIT OF PROBLEM EXPLORATION?

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1. Introduction

During the design process, designers often engage in activities of information search and problem exploration [Cash et al. 2013]. These activities, which are also recommended in the design literature [Cross 2000; Eide et al. 2011; Pahl & Beitz 1996], might be performed at any stage of the design process and might even be performed multiple times as the project progresses. However, problem exploration is most typically recommended in the initial stages of the project so that the generation, evaluation and communication of design ideas build on a well-developed understanding of the problem being addressed [Howard et al. 2008; Löbach 2001; Snider et al. 2013]. This basic sequence of design tasks is represented in many frameworks or models of the design process, and is often taken to be descriptive of good practice.

Many empirical studies have been conducted to permit a better understanding of the efficacy of the design activities that are associated with the different stages of the design process. Consequently, we know the impacts of implementing methods for idea generation [Hernandez et al. 2010], concept evaluation [Verhaegen et al. 2013] and design communication [Verstijnen et al. 1998]. However, although the design literature often promotes the importance of problem exploration activities, the benefits these activities bring have not previously been investigated in depth. Indeed, it is conceivable that teams omitting this exploratory step could produce equivalent or even superior solutions than those who explore additional information about the problem, [Collado-Ruiz & Ostad-Ahmad-Ghorabi 2010]. Studying how problem exploration methods affect the design process and the resulting design outcomes would allow us to better understand how to teach design methods and to improve design education, and when to employ such methods and to improve design practice.

This paper describes an empirical study on the activities of problem exploration performed as the first step of a problem-driven design process. We report on an initial study that tests whether these activities have a positive effect on the work of novice designers tackling unfamiliar problems. In particular, we tested two hypotheses: H_1 states that following a problem exploration procedure increases the designers' perceived knowledge of the problem; and H_2 states that following a problem exploration procedure enhances the quality of the design concepts subsequently generated. By testing problem exploration within a design process framework, our aim is to perform an initial examination on the effects of a design step that is often recommended but without empirical justification.

2. The design process

Both early and recent research describes the intertwined and iterative nature of the design process, mostly with respect to the complexity of design problems [Dorst & Cross 2001; Kruger & Cross 2006; Rittel & Webber 1973]. However, in this section we will adopt a simpler view of the design process as described by Neill et al. [1998] and Cross [2000], comprising the steps of exploration, generation, evaluation, and communication. Although it is a simplification, this four-step framework of the design process is in line with many others found in literature [see Dubberly 2004; Hybs & Gero 1992]. Adopting such a clear framework helps designers to follow a structured process, which is believed to lead designers more efficiently towards a good solution [Cross 2007] and to allow a deeper exploration of the design spaces. Additionally, a structured process helps in instructing less experienced designers by working as a map to problem solving [Ulrich & Eppinger 2007].

In this paper, we consider the following hierarchical structure of the design process: the process is first divided into stages (i.e. early- or late-stage design); the stages consist of steps (e.g. idea generation); and the steps are performed by applying methods (e.g. brainstorming). The early stage of the design process presented here is more commonly represented in design frameworks that describe creative design, as opposed to routine design [Howard et al. 2008]. Late stage design steps and methods (e.g. manufacturing details and material selection) typically concern issues that are not pertinent to these preliminary steps of creative design [Snider et al., 2013], and therefore are not considered further. Table 1 illustrates different creative process frameworks found in the literature that account for most of the four main steps of early-stage design. Specifically, such frameworks were selected because they all feature a step in which designers should explore the problem, which indicates the relevance of problem exploration to the early-stage design process. It is important to highlight, however, that these frameworks may have other steps that are not in the scope of this work, and so are not presented here.

Table 1. Early-stage (creative) design process frameworks that define steps or methods for problem exploration and also idea generation, evaluation, and communication

	Problem exploration	Generation	Evaluation	Communication
RIBA handbook [1965]	Assimilation	General study / development		Communication
Asimow [1962]	Feasibility study	Feasibility study	Preliminary study	Detailed design
Archer [1968]	Data collection	Synthesis		Communication
Ray [1985]	Exploration of problem	Search for alternative proposals	Test for and judge feasible alternatives	Specify solution
Cooper [1986]	Preliminary investigation	Development	Testing and validation	
Isaksen et al. [1994]	Exploring data	Generating ideas		
Munari [1998]	Data collection	Creativity	Verification	Constructive design
Cross [2000]	Exploration	Generation	Evaluation	Communication
Shneiderman [2000]	Collect	Create		Donate / communicate
Löbach [2001]	Collecting information	Generation	Evaluation	
Kruger [2006]	Gather and assess data	Generate	Evaluate	
Lawson [2006]	Analysis	Synthesis	Evaluation	

2.1 Problem Exploration

Developing a new product often involves far more than defining form and function; it also involves identifying a problem and opportunity, researching the market and analysing competing products, predicting trends, performing user studies, etc. This information collection represents the step of problem exploration, and as a central component of early-stage design, it can be very important in influencing the outcomes of the entire process [Baxter 1999]. Information search is also fundamental for a thorough analysis of the problem space. By exploring the problem space, it is expected that designers will be more capable of framing it [Cross 2007], leading to a better understanding of the task, its needs, and constraints, and therefore to a more successful solution [Fricke 1999].

With respect to the time and effort spent in searching for information, information-driven approaches place far greater emphasis in data gathering, while solution-driven approaches aim to generate solutions and only collect information when necessary, with little time spent on defining the problem [Kruger & Cross 2006]. Still, it is believed that designers alternate between exploring both problem and solution spaces while designing, and that these spaces thus co-evolve [Maher et al. 1996; Dorst & Cross 2001; Wiltchnig et al. 2013]. While co-evolutionary descriptions of design propose that problems and solutions develop in tandem and in a balanced process, this is unlikely to occur when designers do not have enough previous knowledge about the problem. In that case, designers are more likely to exhibit problem-focused behaviour [Cross 2007]. Thus, when designing for an unfamiliar problem (or a problem about which no previous information exists), novice designers are expected to be more problem-focused, which allows them to effectively frame the problem and solve it.

For the educational context of this study, we adopted different exploratory methods in line with design literature in order represent the problem exploration step. The chosen methods can provide students with a broad view and understanding of the problem: they properly encompass crucial design aspects concerning the user, the product, and the context, while incorporating both qualitative and quantitative information. The selected methods were seven:

- Market Research, to identify the commercial objective of a product, new areas of design and business opportunities, as well as potential areas of 'innovation receptiveness';
- Historical analysis, to gather deep information about a product's creation, its evolution over time, historical contexts, and to identify patterns and possible relations with the future;
- Competitor analysis, to compare the product under development with existing ones, based on parameters that are relevant to the project, as well as to identify strategies and opportunities;
- Trend prediction, to investigate and identify evolutionary lines for the class of products relevant to the project, according to visible patterns;
- Reverse engineering, to gain a better understanding of the components of products, their sizes and interrelationship, how mechanisms work, and structural aspects;
- Design ethnography, to investigate the positive and negative relations between users and products, users' daily life, social practices, and behaviours;
- Personas, to organise and represent information about a target audience (e.g. needs, behaviour, values) in the form of individual profiles rather than abstract summary data for a population.

These methods, mainly inspired by the practices of the design firm IDEO [2003], have been adopted for many years on a graduate design course at the Universidade Federal de Pernambuco, Brazil. Whilst staff and students have welcomed the use of these methods and regard them to be successful, there is no empirical evidence to support the claim that adopting exploratory methods actually benefits the design process. It is even possible that there is no impact or even a negative effect. To measure the efficacy of problem exploration methods, we conducted an experiment to assess how these methods impact on designers' perceived knowledge of the problem and on the quality of concepts they created.

3. Experimental Setup

The basic experiment design involved providing teams with a series of design problems and asking them to develop concepts for each problem in turn. The participants were assigned to different experimental conditions, which varied according to the problem exploration step of the design process outlined earlier. The participants' perceived knowledge about the problems was measured through self-report questionnaires and the quality of their concepts was assessed by experts. Although we focus only on the

problem exploration step, to assess the quality of the resulting concepts we also needed participants to generate, evaluate, and communicate their ideas.

3.1 Participants

The experiment involved thirty participants divided into five teams. All participants were second or third year undergraduate industrial design students; therefore, they should be considered as novice designers. The participants' design work in this experiment was separately assessed as coursework and thus constituted part of the final grade.

3.2 Experimental conditions

Over a three-week period, the participants designed solutions for three different problems (one problem per week). Each team had one week (nominally 20 hours) to explore the problem, generate and evaluate ideas, and communicate their final concept for each problem. Each team followed the same framework, with the exception of the first step of the process, which had three different procedures:

- No exploration: using no methods for collecting data, i.e. skipping the problem exploration step completely;
- Unstructured exploration: using any tools of the participants' choosing for collecting data, i.e. searching for information without a defined methodology;
- Structured exploration: using a set of structured and detailed methods for collecting data, i.e. searching for information while following a defined methodology that was instructed to the participants. This included market research, historical analysis, competitor analysis, trend prediction, reverse engineering, design ethnography, and personas.

While we manipulated the step of problem exploration between teams, the steps and methods for idea generation, evaluation and communication were controlled for all teams. To prevent possible learning effects, no teams performed unstructured exploration after performing structured exploration. However, no learning effect bias was expected for teams progressing from the 'structured' or 'unstructured' conditions to the 'no exploration' condition, once teams in this condition were explicitly required not to undergo any exploration. Additionally, even though the participants were assumed to have similar levels of knowledge and expertise with respect to problem-solving activities, it was desirable that every team underwent every experimental condition, so as to avoid bias related to team capability with respect to a given condition. As a result, Teams 2, 3 and 4 each executed projects under each of the three experimental conditions: no exploration, unstructured exploration, and structured exploration (see Table 2). Team 1 represents a control group operating under the 'no exploration' condition for all problems, and Team 5 is a comparison group operating under the 'structured exploration' condition for all problems.

Table 2. Different conditions for each team related to each problem. The cells are colour coded as follows: white for no method applied for exploring the problem; light grey for unstructured methods; dark grey for structured methods (this coding is retained for the next table)

	Problem 1	Problem 2	Problem 3
Team 1	No exploration	No exploration	No exploration
Team 2	No exploration	Unstructured exploration	Structured exploration
Team 3	Unstructured exploration	No exploration	Structured exploration
Team 4	Unstructured exploration	Structured exploration	No exploration
Team 5	Structured exploration	Structured exploration	Structured exploration

3.3 Problem Selection

In order to permit comparison of the teams' design work, the problems under investigation should ideally be the same; thus, offering equal levels of difficulty for all experimental conditions. On the other hand, applying the same problem to all teams for three weeks of development would allow learning effects as participants progressed from one condition to the next. To address this, we selected three design problems about which the participants had no previous information (based on the participants' self-

reporting scores about how little they knew about each problem on an extensive list): (1) an autonomous ironing system, (2) a shaving mechanism for facial hair that works with pre-set templates, and (3) a system to dry people when leaving swimming pools. The identification of these three problems permitted use of similarly unfamiliar – and yet different – design challenges for each one of the three weeks. Although these can be considered typical industrial design problems, they should be considered as relatively simple or 'tame' problems, as opposed to more complex or 'wicked' problems.

3.4 Procedure

The activities for the three weeks required theoretical and practical work, both inside and outside the classroom environment. Prior to executing any activity, all participants were asked to complete a questionnaire to verify their perceived knowledge of the problems (they used a self-reporting scale from zero to ten) so that we had a baseline for later comparison. All teams were then informed about the forthcoming weekly activities. The teams then followed a basic four-step procedure:

- Each team performed the first step according to the experimental condition they were in (see Table 2);
- The second step for idea generation was completed by applying the 6-3-5 brainwriting method by all teams [VanGundy 1988];
- The third step for idea evaluation was completed by applying the Pareto Analysis method by all teams [Juran & Godfrey 1998]; and,
- Each team communicated the selected solution to the problem of the week on two sheets: one containing written specifications, such as measurements, functions, and resources; the other containing sketches and views. It is important to emphasise, however, that the process executed within our experiment did not rigidly follow discrete steps, but could rather involve deviations and iterations within a structured framework.

On the first day of each week, those teams that were to perform structured problem exploration as part of the design work had a thirty-minute lecture on exploration methods. At the end of each week, all teams had carried out their design work, developed a final concept and delivered it to the experimenters. Also at the end of each week, all teams were asked to complete the perceived knowledge questionnaire again, resulting in three additional datasets. In this way, the knowledge the participants had about each problem at the end of each week could be measured throughout the experiment.

3.5 Data Analysis

In order to assess the designers' performance, twenty-one experts evaluated the final concepts. The experts comprised a mixed-profile team of lecturers, practitioners, and researchers, from industrial and engineering design as well as computer engineering fields, having at least 4 years of professional experience in developing products. The experts evaluated the participants' outputs against three parameters that are often reported in the literature to assess design quality: novelty, feasibility, and adaptability [Shah et al. 2003]. To enable the expert evaluators to record their judgments, they were provided with paper-based feedback forms, with a description of each parameter. The parameters (and descriptions) were novelty (what is the level of novelty of the solution?), feasibility (how feasible is the solution with respect to a production context?), and adaptability (is the solution adaptable to variations and changes that the problem context may suffer?). For each parameter, a five-point interval scale was used for assessment. All twenty-one respondents executed the same procedure fifteen times in order to evaluate each of the three concepts for each of the five teams.

4. Results

4.1 Participants' Perceived Knowledge

The participants' self-reported knowledge changed from week to week. Table 3 summarises the variation in the means of all teams along the three-week procedure – the variation was always positive, so that all values represent increases. As in Table 2, white cells correspond to the procedures with no problem exploration, light grey cells correspond to the procedure with unstructured problem exploration,

and dark grey cells correspond to the procedure taken with the support of structured methods for problem exploration. The values in Table 3 represent the gain of information, as perceived by the team members, after finishing each round of search and design activities for each problem.

Table 3. Increases in means for participants’ perceptions of information gain after each week

	Team 1	Team 2	Team 3	Team 4	Team 5
Problem 1 (after first week)	0.5	2.0	4.8	5.4	6.8
Problem 2 (after second week)	1.0	5.1	0.3	7.0	6.3
Problem 3 (after third week)	1.9	6.8	5.5	4.9	5.7

It can be observed that the (white) ‘no exploration’ condition cells in Table 3 usually present lower increases after the design activity than both the (light grey) ‘unstructured’ condition cells) and the (dark grey) ‘structured’ condition cells, and that the ‘structured’ condition cells show the highest increases. Thus, the ‘unstructured’ condition always shows a greater increase on the perceived knowledge when compared to the ‘no exploration’ condition, and the ‘structured’ condition always shows the greatest increases when compared to the other two conditions. These results suggest that for these experimental conditions, the perceived knowledge over each design problem was most affected when the team adopted a structured approach to exploring the problem compared to if they explore the problem in an unstructured fashion or not at all. This supports our first hypothesis (H_1), that following a problem exploration procedure would increase the designers’ perceived knowledge. Figure 1 shows the differences in participants’ perceived knowledge based on their problem exploration procedure. Although there is a substantial overlap between the ‘unstructured exploration’ and ‘structured exploration’ conditions, an independent-samples two-tailed t -test indicated a significant difference between all pairs of conditions ($t=-4.6932, p<.01$ for the ‘no exploration’ and ‘unstructured exploration’ conditions; $t=-6.2355, p<.001$ for the ‘no exploration’ and ‘structured exploration’ conditions; and $t=-4.0379, p<.01$ for the ‘structured exploration’ and ‘unstructured exploration’ conditions). This suggests that allowing exploration of any kind enhances designers’ perception of knowledge (i.e. the reported amount of contextual information available to solve the problem).

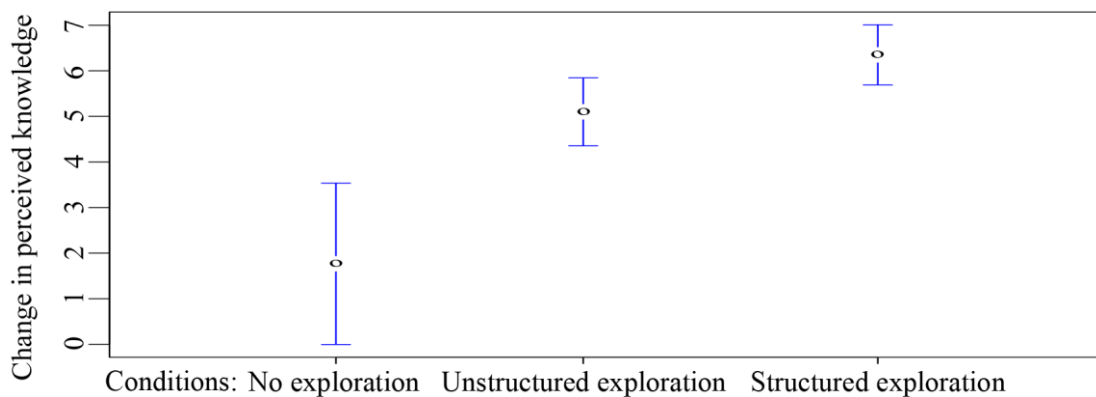


Figure 1. Mean plots of perceived knowledge under different problem exploration conditions (whiskers indicate \pm one standard deviation)

4.2 Concept Scores – Expert Evaluation

The overall quality of the concepts was evaluated according to their novelty, feasibility and adaptability. Scores for team 1 and 5 are initially compared with each other in isolation from the scores for the other teams, as they represent the control and comparison groups in the experiment – the former skipped the problem exploration step and the latter followed the structured exploration procedure every week (see Table 4).

Table 4. Expert evaluation for the concepts: means and standard deviations for teams 1 and 5

Evaluation parameter	Team 1 mean (SD)	Team 5 mean (SD)
Novelty (N)	3.13 (1.05)	3.16 (0.95)
Feasibility (F)	3.06 (1.20)	3.00 (1.08)
Adaptability (A)	3.24 (1.17)	3.08 (1.08)
Overall quality (N+F+A)	9.43 (2.18)	9.24 (2.33)

Our second hypothesis (H_2) predicted that following a problem exploration procedure would enhance the quality of the final concepts designers create. However, the results obtained from comparing the overall quality of the concepts generated by teams 1 and 5 do not support this. An independent-samples two-tailed t -test indicated no significant difference with respect to the overall quality of the solutions from both teams ($t=.474$, $p=.6364$). Performing additional t -tests on each quality parameter (novelty, feasibility, and adaptability) also revealed no significant differences ($p=.8597$, $p=.7556$, and $p=.4315$, respectively).

To further explore the effects of adopting different problem exploration procedures, we analysed the results of teams 2, 3 and 4 with respect to their problem exploration conditions, this time incorporating the ‘unstructured exploration’ condition, in which participants were permitted to freely adopt any exploratory methods to collect information about the problem. The same evaluation parameters were used and the results are shown in Table 5.

Table 5. Expert evaluation for the concepts: means and standard deviations for the three experimental conditions

Evaluation parameter	No exploration mean (SD)	Unstructured exp. mean (SD)	Structured exp. mean (SD)
Novelty (N)	3.33 (1.04)	3.62 (0.97)	3.02 (0.86)
Feasibility (F)	2.88 (1.16)	2.60 (1.09)	3.07 (1.10)
Adaptability (A)	3.03 (1.12)	2.62 (1.24)	3.11 (1.06)
Overall quality (N+F+A)	9.24 (2.25)	8.84 (2.36)	9.21 (2.24)

Additional independent-samples two-tailed t -tests on all parameters compared the results of the three experimental conditions. Irrespective of the team, the ‘no exploration’ condition produced equivalent results to those executed with the structured framework ($p=.7512$). Likewise, the ‘unstructured exploration’ condition presented no significant differences when compared to the ‘no exploration’ ($p=.6221$) or ‘structured exploration’ ($p=.4102$) conditions. However, significant differences were found when comparing the novelty of the concepts in the ‘structured exploration’ condition with those generated in the ‘no exploration’ ($p<.001$) and ‘unstructured exploration’ ($p<.001$) conditions. In both cases, the concepts generated in the ‘structured exploration’ condition were judged as less original, which suggests that following a structured framework hindered participants’ creativity. Along with the analysis of the control and comparison groups (teams 1 and 5, respectively), these results show that, according to the expert evaluation, executing a detailed scheme of methods for problem exploration (‘structured exploration’) resulted in no significant improvement when compared to designing without any methods for exploration (‘no exploration’) or even following an exploration process of their own (‘unstructured exploration’). In other words, the results do not support H_2 .

5. Discussion

Performing problem exploration increased the designers’ perception of how much they knew about the problem (H_1 supported). This may be due either to an increase in designers’ confidence during the process (irrespective of how much they actually know) or, in fact, due to a real difference in the amount of information each team acquired after performing distinct procedures. This increase in perceived knowledge supports the idea that executing a structured set of methods may indeed help designers explore the design space – for our specific scenario, the problem space. Moreover, adopting methods that explore different aspects of the problem space, such as user, product and context aspects, has been shown to result in even stronger perceptions of knowledge about the problem. This finding is in line

with the results shown by the participants' responses in the 'unstructured' condition; it could be that in this condition participants explored only a few perspectives on the problem. However, even though the participants in the 'no exploration' condition performed no information search, these participants also reported small increases in perceived knowledge after designing for each problem. This outcome indicates that even when designers do not perform research of any kind, thinking about the problem and designing for it may also represent an exploratory procedure so that some information gain is expected, which suggests that designing is also learning. Additionally, it is possible that the procedure resulted in a reframed understanding of the problem by the participants, thus interacting with the reported perceived knowledge. However, the general increase in perceived knowledge of the teams in this experiment may not necessarily correspond to better design work. It has previously been shown that participants' in design experiments may perceive their work in ways that are not in line with their performance [Linsey et al. 2010]. Since early-stage design activity is mainly creative rather than analytical, it may be that the structured information acquired through problem exploration does not play an important role during this stage of the design process.

Whether participants did or didn't perform problem exploration, and irrespective of whether that exploration was structured or not, the overall quality of their solutions was unaffected. This non-effect was consistent across all experimental conditions (H_2 not supported). However, novelty levels were greater in both 'no exploration' and 'unstructured exploration' conditions when compared to the 'structured' condition, which suggests that too much effort in exploring the problem space and gathering related information can actually restrict the solution space that designers explore. Similar results have been found when presenting designers with previous solutions as a source of information and stimulation, a phenomenon called design fixation [Jansson & Smith, 1991]. This outcome indicates that the use of design methods should not happen indiscriminately, and that design educators should be aware of that.

When considering the validity and limitations of the study, one should note that the sample used is a major shortcoming of this work. Even though a reasonable number of students took part in the experiment, they were grouped into teams and treated as such, ultimately being assessed according to only one final concept per team. Apart from the control and comparison groups (teams 1 and 5), other teams (teams 2, 3 and 4) were also evaluated, which provided an additional dataset for analysis, but the sample is still small. Although a comprehensive analysis of a larger number of teams would undoubtedly provide a stronger test for our claims, this is outside the scope of this paper, which is presented as an initial effort towards examining the effectiveness of the problem exploration step of a design process. Other experimental features should also be noted: the participants were only given short and simple statements for the three problems (instead of more detailed briefs); the design problems were relatively simple (or tame) and were unknown to the participants (instead of complex (or wicked) design problems with which designers may be familiar); the experiment fitted with a schedule determined by the students' course of study (being longer than many empirical studies on students – often one hour in duration – but shorter than many real design projects – often weeks or months); the design work was assessed by evaluating ideas or early concepts (instead of real products, for which the parameters used in this study could be less relevant).

Another crucial issue that needs to be discussed is whether our results could generalise to more realistic design contexts. All participants in our experiment were second to third year undergraduate industrial design students; i.e. they were novice designers. Due to their low expertise in problem-solving and the lack of prior information about the problems for which they designed, we expected that exploring the problem would play a fundamental role in the design process and improve it. Surprisingly, that was not the case, and perhaps different results would be obtained if experienced designers were tested. Finally, this work dealt with an academic scenario for its experiment; it is desirable that complementary studies be conducted in real-world scenarios. Apart from tests with experienced practitioners in industry, future research might consider applying similar experiments to other steps of the design process.

6. Conclusions

The investigation of the design process and its methods has always been a key subject in design research. Over the years, models of the design process have been conceived, discussed, modified, and adapted in

order to provide both academia and design practice with a better understanding of the idea generation and problem-solving processes. These models satisfy the need for turning the design process into something teachable and learnable, and therefore communicable and understandable [Bürdek 2005]. However, as Bomfim [1995] and many other authors have suggested, while methodology in design is important to support designers when developing products, its adoption does not guarantee success. It is this uncertainty that motivated this initial study reported here.

The main contributions of this work are two-fold. First, it indicates the divergence between designers' perception of their knowledge of the problem (as they judge it) and the quality of the concepts they create (as judged by independent experts). Second, it suggests that the use of problem exploration methods (as defined in this experiment) does not necessarily result in higher quality design work. Although the experts' evaluation may not identify other advantages of using exploration methods with respect to the final concepts, we believe that using these methods can be extremely helpful for the way designers work. Design methodology clarifies ideas during the process by providing a structured framework to support the design of new products and it can work as a map that guides the entire process, which is critical for design education or less experienced designers [Ulrich & Eppinger 2007]; or it can even make individuals feel more productive, as was found in brainstorming studies [Paulus & Yang 2000]. In addition, the documentation of the entire process is valuable when designers present their ideas to others, since it can explain or justify how those ideas were developed [Crilly & Clarkson 2006]. In these respects, problem exploration methods can be valuable for both design education and practice. Ultimately, we understand that using such methods heavily influences the cognitive process in design (e.g. understanding the task, planning, executing, communicating) and it can enhance the way designers think, even if it were not to strongly influence the final product.

As previously stated, this should be considered an initial study into the benefits of following a design process framework and performing its steps and methods. Future research into this topic could use more naturalistic settings, adopting both experimental and observational approaches by using a mix of quantitative and qualitative methods. Early experimental studies already indicate relevant gains when using creative methods for generating alternatives, whilst the evaluation and selection steps still offer a great opportunity for further exploration. We believe that testing these often-recommended steps is essential to the growing of design as a science; if design research promotes the use of design methodology, it must also prove the efficacy of doing so.

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