INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
6 & 7 SEPTEMBER 2018, DYSON SCHOOL OF DESIGN ENGINEERING, IMPERIAL COLLEGE, LONDON, UNITED KINGDOM

STRATEGIES TO REDEFINE THE PROBLEM EXPLORATION SPACE FOR DESIGN INNOVATION

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ABSTRACT
Designers are used to solving problems that are given to them, leading them to focus on creating feasible solutions rather than exploring novel perspectives on the presented problems. Creative innovations in problem understanding may lead directly to more innovation solutions. Although problem exploration has been identified as a key process in design thinking, how designers restructure and reframe the problem is not fully examined. The present work aimed to understand how designers intentionally explore variants of problems on the way to solutions. Through an empirical study industrial design students, we documented a high degree of variation in the problem perspectives among the design students working on the same problem. Analysis of qualitative changes in problem perspectives revealed systematic patterns. The results showed a causal relationship between the number of strategies used in reframing the problem and the quality of the solution generated. Evidence for the utility of problem exploration strategies in the problem defining stage is examined and suggestions for their use in design pedagogy are provided.

Keywords: Design education, problem exploration, design strategies, design tool

1 INTRODUCTION

Design education often focuses on developing solutions rather than a facilitation for broader explorations of the problem that may lead to consideration of a more diverse set of potential solutions. The process of problem exploration allows the designer to discover the essential properties of the problem, along with the creation of an appropriate solution. When faced with complex problems with many potential directions to take, asking different questions to explore the problems than the ones presented may lead to innovation [5]. True innovation requires looking beyond the problem as presented in order to “discover” the true problem, a process called problem exploration. Problem exploration includes restructuring problems as it defines the set of possible solutions and is crucial to search for innovative solutions.

As the design work progresses from the initial presented problem through ideation and development, and on to the prototype stage, desired features and constraints are modified, leading to a redefined problem. Past research shows that design experts simultaneously, and iteratively, ‘explore’ a problem while searching for solutions [8]. More rich and varied problem descriptions occur with greater levels of expertise [2], with superior depth and detail, more interconnections, and more actions. Paton and Dorst [16] describe the ability to “frame a problematic situation in new and interesting ways” as one of the key characteristics of design thinking. This ability is also seen as a longer-term predictive for reputation and financial success [11].

Further, empirical studies have documented that problem statements change as the design process progresses, termed as co-evolution [6-8]. This oscillation between the solution and problem suggests a process where a stated problem is subject to restructuring as solutions are considered, leading to simultaneous and iterative explorations by the designers while searching for possible solutions. Although there are many studies examining the evolution of the solutions space, there are fewer studies examining how designers explore stated problems to have a full analysis of the problem space. While the importance of problem exploration has been evident in the literature, there is a lack of empirical evidence on problem exploration [18]. To address this gap in the evidence about how designers successfully explore problem, through an empirical study, we documented design students’ problem explorations as they created new opportunities for their solutions. This empirical study provides evidence about how designers intentionally alter the stated problem in the course of generation novel solutions. Rather than beginning with a search for solutions to a given problem, we propose an initial search to find the problem [18].

2 PROBLEM EXPLORATION STRATEGIES

We propose that problem exploration is a vital contributor to the creation of innovative solutions. Some design texts and popular books offer techniques however they don't provide empirical evidence. One approach offered by MacCrimmon and Taylor [14] identified complexity as being a limitation in problem formulation and provided four decision strategies: 1) determining problem boundaries, or examining the assumptions; 2) examining changes, or focusing on any alterations changes in the problem description; 3) factoring into sub-problems, such as using methods including morphological analysis [12] and attribute listing [17]; and 4) focusing on the controllable components, or selective focusing [19]. Fogler and LeBlanc [9] proposed strategies for defining "the real problem" underlying a given engineering problem. The "5 Whys" [4] technique, used by the Toyota Motor Corporation, repeatedly asks "Why?" question in order to explore the cause and effect relationships underlying a problem. Abstraction laddering [1] is also used to better understand the problem space based on the data gathered from stakeholders. It focuses on asking a series of 'how' and 'why' questions to describe the design problem at increasing or decreasing levels of abstraction. Parnes' [15] restatement method varies how the problem is stated using prompts, such as 'vary the stress pattern by placing emphasis on different words and phrases in the problem', and finally, the Kepner-Tregoe [13] pushes the designers to distinguish what the problem 'is' and 'is not'. All of these techniques propose to trigger questions that may assist designers in further defining the presented problem; however they are lacking the empirical evidence of their use in creating innovative solutions.

3 EXPERIMENTAL APPROACH

This study seeks to understand how cognitive strategies promote exploration of the problem space while the design students' were working towards the goal of innovative outcomes. Based on our prior work on problem exploration strategies [21-23], we hypothesised that design students use such strategies although they may not be deliberately conscious or elaborate about this process. Do these changes in problems occur naturally in the design process? Can problem exploration strategies be identified in students' design problem definitions? How does the use of strategies differ among the design students?

3.1 Participants

Fifty-four junior industrial design students (43 males and 11 females) taking the same project-based course focusing on systematic design methodology at a large Midwestern university participated in the study. This 6-credit course is the third required studio course in the industrial design curriculum after completing the core programme in the first year. The students are not considered as novices as they had an entire year of industrial design education before their junior year. Although, they were not exposed to problem framing as a concept before their junior year.

3.2 Data Collection and Analysis

This study was conducted in a classroom setting. As part of their ongoing project, students were given a broad design problem based on an international houseware competition. Students then were given two weeks to gather user insights on potential problems to target and create their own problem statements which varied from designing new organisers to ergonomic razors. They were then asked to generate up to five concepts addressing the issues stated in their own problem definitions. Then, in a new task, we asked them to go back and define the problem they had addressed within each of their solutions: "For each of the solutions you generated, write a problem statement that would allow other students to come with the same solution". This was challenging for the students but allowed them to identify their own view of the important differences between their original stated problem and their innovated problem they solved. This session took about 20 minutes which seemed to be sufficient as most students were done writing the corresponding problem statements, to their design solutions. The data reported in this paper compares the original problem statement students submitted while they were generating the design solutions and the four innovated problem statements they generated based on the concepts they developed.

The original problem statement and the innovated design problems based on the solutions created were analysed by two coders trained in industrial design. Using an inductive thematic analysis [3], we were able to identify the commonly used patterns design students used in diversifying their problem framings, to generate new and innovative solutions. After the original problems and reframed problem statements were analysed, their respective concept sketches were examined to understand how the innovated problem framing impacted the outcome.

4 RESULTS

Fifty-four participants generated an average of 4.03 unique problem statements resulting in 218 innovated design problems. These revealed multiple cognitive strategies used to structure the stated problem in alternative ways. Across these statements, sixteen strategies found to be commonly used by the design students as they were reframing their problems to find the most promising solution. All 218 problem statements showed evidence of multiple exploration strategies. For example, participant 39 (P39) focused on *define user interaction characteristics* as a strategy which led him propose a solution with one handle that does multiple jobs: on/off/pour. P51, on the other hand, focused on multiple strategies including *define efficiency characteristics, define context, and insert a limitation*. He emphasised efficiency through organisation, context through describing the counter top as the location for use, and the limitation through saving space (Figure 1). When the solutions are compared, the student that used more strategies to define the problem had a more complex and developed concept, with potentially bigger impact for the user. This suggests that more detailed strategies used in the problem statements results in more innovative solutions.

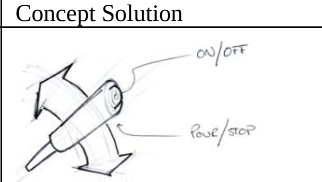
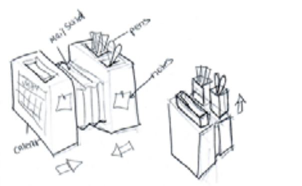
Participant	Problem Statement	Concept Solution	Concept Description
P39	Make an easy access coffee maker.		Design a coffee maker: Handle implements both on and off and pouring tap
P51	Organise office supplies like pencils and scissors, emphasise and organise key notes to self and family members and store and sort mail, all while saving counter top space in a family home.		Design home organisation: When the pieces push together, the pencil supplies compartments pop up to allow

Figure 1. Problem-Solution example demonstrating two participants' data on the frequency of problem exploration strategies used

Table 1 shows the list of the sixteen strategies observed in this dataset, their frequency, supported with an example demonstrating potential applications for a backpack design.

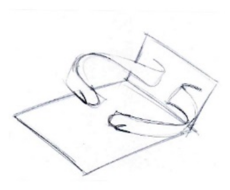
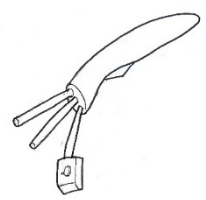
Table 1. List of sixteen strategies observed

#	Strategies observed	# of times observed	Example application in the problem statement
1	Define the product/service	148	backpack
2	Define the primary function	87	to house photography equipment
3	Define the context	84	in rainy regions
4	Product specification	73	has a rugged shell
5	Define attributive characteristics of the product/service	54	outdoors
6	Define user interaction characteristics	42	access camera gear easily
7	Define the user	40	young adults who enjoy hiking
8	Define efficiency characteristics	39	easy to carry
9	Describe an unwanted situation	32	isn't bulky
10	Describe a potential use scenario	29	when hiking in a downpour
11	Describe the user sentiment state (think, progress, motivate)	21	enforces safety of the equipment
12	Define mobility characteristics	17	portable
13	Define perceived materialistic attributes	15	lightweight, breathable
14	Define emotional characteristics	14	hassle-free
15	Define spatial characteristics	10	space saving
16	Insert a limitation	6	only houses necessary equipment

The most commonly observed strategy among the 218 problem statements was *Define the product/service* (68%), followed by *Define the primary function* (40%). This is expected as the design students tend to label what the product would be, such as, manual razor, or an office accessory, with a focus on the primary functions, such as trimming, or organising. The three least observed strategies were *Define emotional characteristics* (6%), *Define spatial characteristics* (5%), and *Insert a limitation* (3%). Overall, this table serves as a guideline to showcase designers' priorities to explore the problem space. After observing the strategy ranking in order from most to least prominent, it is apparent that the strategies increase in specificity and detail as the usage amount decreases. This also acts as a hierarchy as the strategies needed to be expressed first were the most commonly stated.

In order to understand how one single strategy is applied to different original problem statements, we chose two participants' data, as they applied *Define perceived materialistic attributes* to their original problem statement in order to shift their problem-solution exploration (Table 2). How the problem exploration strategy impacted the innovated problem is highlighted with gray. This material-focused strategy is used by the designers to understand and integrate what the material could look and feel like. For example, P17 perceived 'better performance' as 'durable', making an assumption that if the appliance was durable, it'd increase its performance. P7 used this strategy in a way to bring comfort and flexibility to the user.

Table 2. Example of 'Define perceived materialistic attributes' strategy observed across two different problem statements

Participant ID	Original Problem Statement	Innovated Problem Statement	Concept Solution	Solution Description
P17	How to improve small kitchen appliances for college students that have little to no cooking experience and results in overall better performance?	Create a smart, durable kitchen appliance that stresses simplicity and elimination of food waste.		Adjustable arm scan the cup to get a measurement of liquid
P7	How might we design a disposable razor that gives users the freedom to choose the length at which they cut their facial hair?	Design a manual razor that allows the user to adjust the length to which they cut their hair, and provides the comfort and flexibility provided by other manual razors.		To increase flexibility in trimming, the head can be attached to one of the three different necks.

In order to explore how the uses of different strategies lead to different problem statements, we traced the evolution of problem statements generated by a single design student. Each statement, created by Participant 13, utilised a unique set of strategies that led him explore new solutions with diverse characteristics and features. The participant used home organisation, specifically storage, as the main category for developing problem statements. For the analysis (Table 3), each statement was broken down into short phrases and then labelled with its respective strategy. For each statement, there was also a concept that resulted from the reframed problem. Because the statements were diverse and broad enough, the concepts differentiated from each other, dramatically, supporting the prior findings on the relationship between problem-solution spaces, how a new problem could lead to exploring a new solution [6].

Table 3. Innovated problem statements generated by P13, and the observed strategies corresponding to the characteristics of these statements

	Innovated problem statement	Strategies observed
1	Create a portable, segmented, and rotatable wardrobe piece	Define mobility characteristics; Define flexibility of use; Change the context of use
2	Simplify the process of hanging clothes	Define the process of use; Change the context of use
3	Create a modular and collapsible way of segmented storage spaces	Define mobility characteristics; Define spatial characteristics;
4	Reduce clutter and rummaging with many pairs of footwear	Describe an unwanted situation; Define the product in context

Figure 2 shows the varied concept solutions generated by P13, focusing on various innovated problem definitions. For example, the concept for problem one was a portable organiser similar to a backpack, whereas the concept generated from problem three was a flat-pack, cube organiser. Since problem one focused on mobility characteristics and perceived materialistic attributes, the participant created a sturdy backpack form to account for these strategies. For problem three, the participant focused on spatial and user-interaction characteristics to generate a solution for modular and collapsibility criteria. Because P13 used a variety of differentiating strategies for each concept, they visually and conceptually resulted in very novel and different ideas.

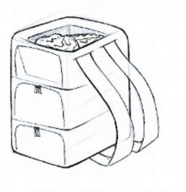
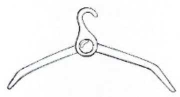
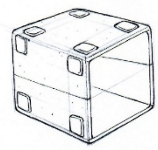
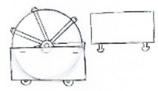
Concept 1	Concept 2	Concept 3	Concept 4
			
Instead of being stuck in a wardrobe, this concept could be used for hiking. As a result, the top can be turned into a container for holding interesting things found along the way.	The arms use less material so they're smoother.	Other than magnets, this concept is made out of a durable, recyclable material… maybe some sort of high density cardboard or mat board?	The packaging container for the shoe wheel is split into two halves; the bottom half has cut outs for the wheels and can be used to store more things.

Figure 2. Concepts generated by P13, based on the innovated problem statements in Table 3

5 DISCUSSION

The empirical study discussed here provides varied evidence for the use of cognitive strategies to explore design problems. The empirical evidence of multiple designs generated for a stated problem revealed systematic patterns of problem revisions resulting in rather diverse design solutions. The phenomenon, called problem finding [10], problem framing [20] and co-evolution [6] is readily apparent in the data collected for this study. The results showcased that there is evidence of systematic use of strategies in exploring the problem space. Designers do this as they create new solutions or iterate on their prior solutions. These strategies varied in frequency of incidents observed, as well as the level of specificity. For example, *Define the product/service* was observed 148 times whereas *Insert a limitation* was only seen 6 times. Although the difference among the quantities is rather noticeable, some of these strategies are more advanced, meaning they require more elaboration and intentional thinking regarding how the problem could vary to target different aspects of the problem space. These 'more advanced' strategies are not required to build the essential structure of the problem statement; however they seem to diversify the solutions in unique ways.

Another finding observed is the relationship between the number of strategies used and the quality of the solution generated. The number of strategies observed in each problem statement varied between two and five. Compared to the solutions generated with five strategies applied, concepts with two strategies are very similar to the prior solutions the student created. This tells us that the more diverse strategies explored, the richer the problem statement becomes and the more unique the solutions are. Although this is a hypothesis based on a small sample size and an exploratory study, the patterns seem to show evidence of these outcomes.

There are limitations of the evidence described here about problem exploration process. In particular, This empirical study examined only 218 problem statements generated by fifty-four design students, the study only focuses on before (the stated problem) and after (the innovated problem), and does not capture student designers' thought processes. This study was also limited by the constraints of the time, and task definition, which may not reflect typical working conditions for designers. Additionally, problem definition and framing may occur more often in a team environment. Nonetheless, even this small set of data showed evidence of strategies existing in problem exploration and framing.

6 CONCLUSIONS

This paper presents evidence that design problems are and can be restructured to reveal alternative views of the problem, and the varied and innovative solutions that result. A variety of problem exploration strategies have been identified along with empirical evidence about their spontaneous use by students. Understanding and enhancing design education through the inclusion of problem finding, formulation and reframing are critical. Exposure to a list of strategies that could expand design students' thinking on problem exploration and framing would benefit concept generation, success of the design process, and ultimately the innovation that may be brought into the market. These findings suggest it may be helpful to encourage design students to adopt strategies for problem exploration to help them discover alternative perspectives about the problem and when and how to apply them. This study suggests that utilising a diverse range of strategies in formulating new problem statements can lead to a countless new concepts. This research provides the rudimentary building blocks of observed strategies with design students.

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