DRS 2012 Bangkok
Chulalongkorn University
Bangkok, Thailand, 1–4 July 2012

Heuristic Use in Different Types of Design Tasks

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Abstract
This paper explores the use of Design Heuristics as cognitive strategies in idea generation, and how designers' preferences in heuristic use may change between redesign and novel design problems. In previous work, we found evidence for specific Design Heuristics that support the exploration of the design space, leading to the generation of varied and creative solutions (Yilmaz & Seifert, 2009; Yilmaz, Seifert, & Gonzalez, 2010). This paper presents a new empirical study analyzing the protocols of six professional industrial designers, and the sequences of sketches generated in two differing design tasks. The results show evidence of frequent Design Heuristic use, and their involvement in generating diverse, creative, and practical concepts. Further, the study reveals some differences between designers' behavior in the two types of design problems.

Keywords: design heuristics, ideation, creativity

Introduction

It has become widely accepted that business survival and prosperity is strongly linked to the ability to innovate (Prahalad & Ramaswamy, 2003; Soosay & Hyland, 2004). The increased market demands for new and creative products, and the elevated levels of competition, require the ideation phase of the design process to be shorter and more effective than ever. Innovative outcomes are often traced to success in the concept generation phase, where multiple creative ideas can be developed, and diverse concepts can be evaluated and pursued (Brophy, 2001; Liu, Bligh, & Chakrabarti, 2003). The potential for innovative design outcomes increases as more, and more varied, ideas are produced. Thus creative tools are required to aid designers in producing more 'creative' and 'diverse' ideas in shorter periods of time. While a variety of techniques exist, there is limited research about how they affect the design outcomes. In addition, there is very little evidence about their utility in different design tasks.

Most design tasks include a mixture of problems to solve. For example, a design task might call for a new consumer product that will toast, spread butter, and serve a slice of bread on a plate. Since this is a new product, there will be a lot of conceptual design work upfront. However, it will also be necessary to configure the various parts, convert conceptual ideas into design elements, analyze heat conduction for toasting, (which will require parametric design), select a heating element, and select various fasteners to hold the components together. Furthermore, it may also be possible to redesign an existing product to fit to the needs of this new design task. Styling for the individual components and the overall look of the product is also required. Each of these subtasks can be considered a different type of design problem.

Throughout design research, categorizing the different tasks within the design domain has proven to be useful for both analysis and the construction of tools, methods, and techniques. Numerous researchers from engineering design field have identified different design outputs (Gero, 2001; Pahl & Beitz, 1996; Ullman, 1992). For example, Pahl and Beitz (1996) detailed three primary classes of design:

- Original Design: An original solution principle for a system with the same, a similar or a new task.
- Adaptive Design: Adapting a known solution principle to satisfy a new or changed task.
- Variant Design: Varying the certain aspects of the system, leaving the function and solution principle unchanged.

Design outputs can be defined based upon the initial problem or activity perspective (Ullman, 1992). This suggests that the designers begin their work with a notion that the eventual product will be either innovative, adaptive, or to order, and thus, perform the appropriate activity to accomplish these tasks. While these different design types appear to vary in their levels of creativity, they do not explicitly distinguish what is a creative or novel design from what is a routine or redesign. That is, a "variant design" could also be considered among the most innovative.

"Routine (redesign) design," according Gero (2001), is defined as having the necessary knowledge available for the design problem. In addition, routine design operates within a context that constrains the available ranges of the values for the variables through good design practice. Non-routine (novel) design, on the other hand, brings unexpected values to the design process and the artifacts designed because the problem specifics are not limiting which allow designers to explore the criteria further. Ottosson (2001) stated that for a product to be considered “new,” it must have 60% new or redesigned technical parts, and from a marketing point of view, be considered new to the market.

Strategies for generation of new ideas have been proposed; however, these tools are not empirically driven, nor have they been tested for their impact on the success of ideation in differing design tasks. For example, while brainstorming (Osborn, 1957) includes guidelines such as, “suggest many ideas,” “do not evaluate ideas,” and “build off of others’ ideas,” it does not provide specifics for developing ideas. SCAMPER (Eberle, 1995) offers more specific information about how to transform ideas, but its set of general guidelines (e.g., "combine") can be difficult to apply to specific design problems. TRIZ (Altshuller, 1984) provides guidelines based on successful patents; however, its more specific strategies address refinements in mechanisms and design tradeoffs that occur later in the design process.

Design Heuristics

Some potential designs are easy to consider because they involve simple combinations of known features, or involve already-known elements. However, a designer may never consider some possible solutions because they do not come easily to mind. This may be because the designer becomes "fixated" in a particular perspective (Jansson & Smith, 1991), or because he considers the solution is good enough. Design Heuristics (Yilmaz, et al., 2010) have proven to be useful strategies to help explore the "space" of potential designs, similar to Newell and Simon's (1972) "problem space." Each heuristic takes the form of a transformation of an existing design concept, such as "changing the orientation” of a design element. As a result, possible design concepts are considered that may not have been generated without them. The key to innovative solutions is to apply different heuristics and combinations of heuristics, resulting in greater coverage of the design space (Yilmaz, et al., 2010).

This paper extends the Design Heuristic approach by considering the inclusion of problem constraints. How is the use of Design Heuristics affected by the level of constraints provided within a design task? Would a novel design problem result in more use of design heuristics than the redesign of a familiar product? Redesign and novel design problems differ because a redesign begins with an existing product, which presumably leads to a degree of initial fixation. A novel design problem, for a product that does not yet exist, would seem to allow free reign to consider the design space.

For both types of problems, the hypothesis for this study was that the application of Design Heuristics would enhance the diversity, quality, and creativity of potential designs generated during the ideation stage. In addition, we predicted that heuristic use would be even more beneficial in redesign problems because of their utility in intentionally moving past design fixations.

Experimental Design

Six industrial designers with professional experience ranging between two and five years participated in the study. The expert designers were asked to generate as many different concepts as possible in a short amount of time, and their sketching was recorded along with retrospective interviews. Three of the designers generated concepts for a redesign task, and the other three designers worked on a novel design task for a novel product. Another difference between the two groups was the time constraint: Participants in the first group were given ten minutes, whereas participants in the second group had twenty five minutes. This time difference was reasonable because more time was required for the novel task, since the constraints were left vague for the problem. For both groups of designers, the hypothesis was that the application of Design Heuristics in the creative process would enhance the diversity, quality, and creativity of potential designs generated during the ideation stage.

It is proposed that specific Design Heuristics would help designers explore the problem space of potential designs, leading to the generation of creative solutions. The candidate set of heuristics included those identified in the product analysis (Yilmaz & Seifert, 2010) and expert protocol analysis (Yilmaz & Seifert, 2009) that were conducted prior to this study. These six new participants were expected to have learned how to generate concepts for vaguely defined design problems, and should exhibit creative and diverse design behavior due to their training and experience in industrial design. The specific questions addressed in this study were: What heuristics lead designers to novel concepts? Do they differ between the two types (novel vs. redesign) of design problems? And if so, how can these heuristics be transferred between the tasks?

The design tasks

The first data set (Park, Yilmaz, & Kim, 2008) focused on a redesign task. The data included three designers' sketching processes on the same task for approximately ten minutes. The design problem statement is presented in Figure 1.

In this task you are asked to devise a design for a new lemon squeezer. Your 'client' is a kitchen appliances manufacturer who wants to introduce a lemon squeezer into their range of products. The company has a reputation for manufacturing simple and effective designs. The outcome from the meeting between the design and management departments was the lemon squeezer concept shown below. As this is only a conceptual design it needs to be completed. You are asked to use this concept design and make it a real design proposal. Since the lemon squeezer only works manually you should not consider using any electrical motors in the design. In order to make an effective design, the new gadget should separate pips and pulp from the juice.

Figure 1
Redesign task

The industrial designers were introduced to the triquetra figure as a concept design for a lemon squeezer, and asked to make it a real design proposal in ten minutes for a company that has a reputation for simple and effective designs. The main constraints for the final concept were "manual control" and "separation of pips and pulp from the juice." The ideation performed by the participants was recorded on video. While sketching, designers made use of an A4 paper-based digital notepad, and this gave the dual advantage of resembling a traditional pencil-and-paper environment while facilitating the recording of pen strokes via screen capture software. A snapshot example of one of the participants' videos can be seen in Figure 2. The extended version of this data set, subsequently, was used in a different study with a broader perspective concerning how design shapes are generated and explored by means of sketching (Prats, Lim, Jowers, Garner, & Chase, 2009). The analysis examined three outputs: the sketches on paper, the video data showing the ideation process, and retrospective interview conducted at the end of each session.

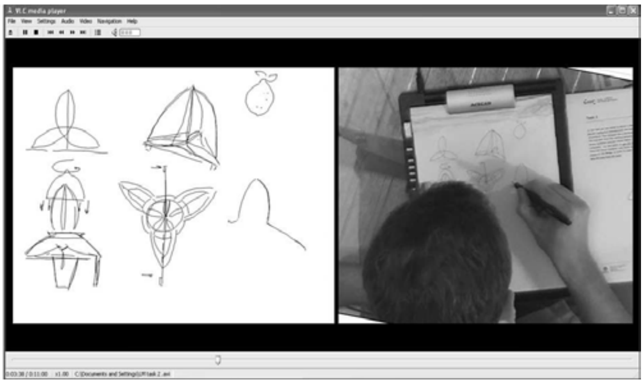

Figure 2

Synchronized video example of one of the participants

The second task used a think-aloud protocol to document and describe designers' approaches to generating concepts in a novel design task. The problem involved designing “a solar-powered cooking device that was inexpensive, portable, and suitable for family use”. The design problem statement, presented in Figure 3, also specified design criteria and constraints, and prompted participants to generate a variety of creative ideas for the solutions.

> Sunlight can be a practical source of alternative energy for everyday jobs, such as cooking. Simple reflection and absorption of sunlight can generate adequate heat for this purpose. Your challenge is to develop products that utilize sunlight for heating and cooking food. The products should be portable and made of inexpensive materials. It should be able to be used by individual families, and should be practical for adults to set p in a sunny spot.
>
> Note: Specific materials for a targeted temperature can be postponed to a later stage. Do not worry about the specific quantity of heat that can be generated. Please focus on conceptual designs. Please consider both the ways of capturing the light, and the structural variety of the concepts.
>
> Please draw as many concepts as you can on the papers provided to you. The concepts can be iterations of concepts you generate, or they can be entirely new ideas. Please try to use one page for each concept. Also, elaborate on each concept in writing, using labels and descriptions. Give specifics about what the concepts represent and how you came up with each idea. We want you to create concepts that are creative and appropriate.

Figure 3

Novel design task

Participants were given twenty five minutes for the task, and they were provided a paragraph of additional information about transferring solar energy into thermal energy after the first ten minutes, in case participants did not feel they had the technical knowledge to address the criteria. Participants were also asked to keep talking if they became silent at any point during the session.

The designers' drawings were captured in real time, along with their verbal comments, using an electronic pen. After the task was over, participants were asked to verbally describe the concepts they had generated, how they moved from one concept to another, and their approaches to ideation.

Analysis process

Verbal data from the experimental sessions were transcribed to supplement the audio and visual sketching data, and all data was analyzed for evidence of heuristic use. Two coders were given a list of heuristics extracted in prior studies and were asked to identify these heuristics in the concepts generated by the participants. The coders worked alone, and resolved any differences by discussion. The goal of the analysis was to compare the designers' concept generation approaches, and determine whether there were differences in the use of Design Heuristics in the two intentionally varied tasks. Thus, the analysis included determining the number and diversity of the concepts generated, and specific Design Heuristic use. These were considered for each concept, between concepts, and over the experimental session.

Because the tasks involved just the initial stage of the design process -- the idea generation phase -- it is difficult to know how concepts might be transformed as the process continued. For example, an idea that may seem impractical or unfeasible in the designers' sketches may become viable with further development throughout the design process. The focus of this analysis was on how heuristics helped designers explore varieties of designs within the design space. However, subjective coding (Amabile, 1982) of two criteria was also conducted: creativity and practicality. First, questions that would characterize creativity and practicality for the given design task were identified, and then each concept was coded for both criteria individually. Evaluators worked together to define the questions, but coded separately. Some of the questions considered for rating creativity were: Does it address a design criterion unique from the other designers' concepts? Is it considerably different from an existing well-known product? Does it use unexpected materials? For practicality, some of the questions were: Is it easy to use? Is it going to work?

Results

The results reported here include a discussion of the heuristics identified within and among the concepts generated by designers from the two tasks, participants' heuristic use, and the relationship of heuristics used with the diversity of the concepts, as well as the solutions' ratings for creativity and practicality. In each of these analyses, emphasis was given to differences between the two sets of designers working on two different design tasks.

Number of concepts

The number of concepts was defined, in part, through the use of cues from participants as they indicated the beginning and ending of each concept. New concepts were also evident in drawings when moving to a new illustration of an idea. However, the number of concepts generated alone does not necessarily reflect the diversity of the concepts, as similar concepts, or the evolution of one concept, could appear at any point within the session. Participants produced a total of 31 sketches (redesign task N=17; novel design task N=14). Of the 31 concepts, 21 appeared to be unique from the others. The ratio of diverse concepts to total number of concepts for the novel design task was considerably higher (novel design task=93%; redesign task=47 %).

The number of concepts generated and the diversity of these concepts by design task are shown in Table 1.

Design Task	*Designer*	*Number of concepts*	*Number of unique concepts*
Redesign	1	6	2
	2	6	5
	3	5	1
Novel Design	4	6	6
	5	4	4
	6	4	3
Total		31	21

Table 1

Number of concepts generated by each participant

Next, the key features were identified in the concepts according to user-interaction, form and function. These served as the criteria for describing the uniqueness or diversity of the concepts. For example, for the first task, design solutions could be either held in hand or placed on the table to achieve the function of squeezing the lemon. For the second task, solutions could direct the sunlight using mirrors, maintain heat by creating a closed product with a clear lid (to capture sunlight), use a magnifying glass to direct the sunlight, or use an insulated box to maintain the heat. Other solutions added straps so the product could be carried by the user, or converted into a foldable container for easy transport. Each of these solutions would be counted as distinct, unique concepts in the design space.

The redesign task was more constrained in that less time was given to the participants, and an initial visual representation of the form was provided. The designers started generating concepts with the given form, which resulted in less variation among the concepts. The novel design task, on the other hand, was limited in the technical information provided, which may have narrowed the range of options to achieve the functions defined in the design problem.

Heuristic use

The main focus of this study was to document how designers used heuristics to explore the design space; that is, how they made transitions to new concepts in the ideation stage, and how they created relationships within the design elements in each concept. Table 2 presents Design Heuristics observed locally (within each concept) in the concepts generated in both experimental setting, and how many times they were seen.

Design Heuristics Observed Locally		*Redesign Task*	*Novel Design Task*
1	Attach independent functional components within the product	14	4
2	Align components around a central, main function	11	0
3	Refocus on the core function of the product	9	2
4	Create modular units by repeating, substituting, or splitting components	7	3
5	Elevate or lower product base	8	2
6	Split or divide surfaces into components	6	2
7	Hollow out inner space for added component placement	7	0
8	Change where or how product will be used	4	2
9	Cover / Form Shell / Wrap surface for other use	2	3
10	Fold product parts with hinges, bends, or creases to condense size	1	4
11	Nest (Hide / Collapse / Flatten) elements within each other	3	2

12	Use a common component for multiple functions	2	3
13	Use the same surface area of the product for different functions	4	0
14	Apply an existing mechanism in a new way	0	3
15	Bend into angular or rounded curves	1	2
16	Integrate or attach the product to an existing item as an additional component	0	3
17	Make components attachable and detachable	1	2
18	Mirror shapes for symmetry	3	0
19	Scale size up or down	2	1
20	Unify design elements, color, and graphics for lower cost and visual consistency	3	0
21	Use an environmental feature as part of the product	3	0
22	Use the same material all throughout the product	1	2
23	Add features from nature to the product	2	0
24	Change the direction of orientation (flip vertical to horizontal)	0	2
25	Control / change in function through movement	2	0
26	Replace solid material with flexible material	0	2
27	Add portability	0	1
28	Attach the product to the user	0	1
29	Compartmentalize functions into distinct parts	0	1
30	Convert leftover packaging for another use	0	1
31	Design user activities to unite as a community	0	1
32	Extend surface area for more functions	1	0
33	Return sensory feedback to the user (tactile, audio, visual)	0	1
34	Roll product around a pivot point	0	1
35	Rotate on a pivot axis	0	1
36	Stack components	0	1
37	Transfer or convert to another function	0	1
38	Use the outer surface area for of the product for a different function	0	1
TOTAL		**97**	**55**

Table 2

Design heuristics identified locally (within each concept) in the content analysis of concepts generated by industrial designers

A total of 38 of the 77 Design Heuristics (Yilmaz & Seifert, 2011) were evident in the concepts generated in this study. The total number of heuristics per concept ranged from 1 to 6, and in almost all concepts (30 out of 31), the use of heuristic combinations were observed. Concepts in the redesign task made more use of heuristics (n = 97) than concepts generated in the novel design task (n = 55). This difference may be due to the nature of the two tasks. Designers seemed to use more heuristics when they were tackling the redesign task, possibly because their thinking process was restricted by the constraints provided in the task, along with the provided triquetra figure. On the other hand, designers who worked on the novel design task generated concepts that were very different from each other, and from existing products in the market. They used fewer heuristics; however the heuristics they preferred were more diverse (29 different heuristics in novel design task vs. 23 in the redesign task). This suggests that the heuristics used in redesign task are more focused and specific.

For both types of design tasks, *Attaching independent functional components within the product* was the most commonly applied heuristic. For example, in Figure 4a, Designer 2 attached the top component (used for squeezing the lemon) to the bottom component (container for the lemon juice) after he decided on the two functions and defined the forms for both functions separately. Designer 6, using the same heuristic, attached small solar panels in a row to the handle of the product, and attached the handle to the part where food would be cooked.

Figure 4a

Example from Redesign Task using Attaching independent functional components within the product heuristic

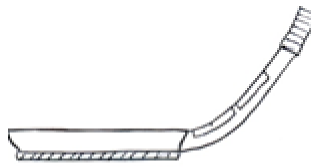

Figure 4b

Example from Novel Design Task using Attaching independent functional components within the product heuristic

Other common heuristics included within the redesign task were, *Aligning components around a central, main function*, and *Hollowing out inner space for added component placement*. Based on the context of the problem, these choices of heuristics may be expected, as existing product examples align the design components at the center, and shape a container with a hollow bottom. In the novel design task, the other most commonly used heuristic was, *Folding product parts with hinges, bends, or creases to condense size*. Since the problem statement required the design solutions to be portable, use of this heuristic was expected. All three designers in this task applied this heuristic to provide multi-functionality within the concepts by attaching solar panels to one surface (for example, the cover), or unfolding it when the other surface would be used for cooking. For example, in Figure 5a, Designer 4 used the outer surface of the cover as the component to capture and store sunlight, and used the inner surface as an additional cooking area by unfolding it. In the second figure (Figure 5b), Designer 5 used the outer surface as a sunlight collector when folded, and the inner surface for cooking (as a grill) when unfolded.

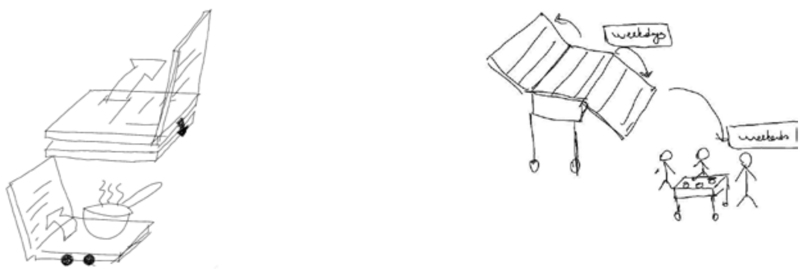

Figure 5a and 5b

Examples from Novel Design Task using Folding product parts with hinges, bends, or creases to condense size

There were also differences in the total number of heuristics and in the type of heuristic used in each task; only half (16 out of 38 heuristics) were used in both tasks. Designers in the redesign task more often used, *Refocusing on the core function of the product* (9 vs. 2) as a heuristic. They also used *Elevating or lowering product base* (8 vs. 2) more commonly. The reason for this difference seems to be related to the tendency to use an existing cup or glass to collect the lemon juice in the redesign task. This decision required the concepts to be elevated from the table surface to create a gap underneath the product for another collection container.

Designers in the novel design task, on the other hand, used, *Integrating or attaching the product to an existing item as an additional component* as one of the main heuristics in their concept generation process. This may be due to the nature of the problem, as some of the designers may not have had technical knowledge or confidence to feel comfortable with generating a concept from first principles to generate cooking devices with adequate heat.

Two of the 3 designers working on the redesign task continued to develop their initial ideas in further concepts, whereas all three designers working on the novel design task generated multiple concepts from scratch. This made the transitional use (between concepts) of heuristics more evident in the concepts generated for the redesign task. For example, Designer 1 started with the triquetra figure provided in the design task, and used it as the top view of the first concept he generated. Then, he developed his sequential concepts by repeating elements, elevating the product, and adding further details (Figure 6).

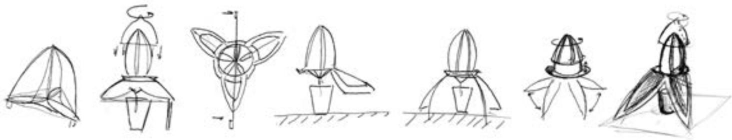

Figure 6
Sequential concepts generated by Designer 1

Certain heuristics appeared as transitions between concepts in a series; for example, Adding details to the previous concepts and Scale size up or down. Table 3 presents the transitional heuristics evident in the concepts generated by the six participants, and the number of times they were observed.

Design Heuristics Observed Transitionally		*Redesign Task*	*Novel Design Task*
1	Adding details to the previous concepts	3	0
2	Attaching the product to an existing item or a previous concept as an additional component	1	2
3	Scale size up or down	2	1
4	Split or divide surfaces into components	3	0
5	Attach independent functional components within the product	2	0
6	Change where or how product will be used	2	0
7	Elevate or lower product base	2	0
8	Fold product parts with hinges, bends, or creases to condense size	1	1
9	Refocus on the core function of the product	2	0
10	Add features from nature to the product	1	0
11	Cover / Form Shell / Wrap surface for other use	1	0
12	Extend surface area for more functions	1	0
13	Making a continuous surface out of multiple components by merging them	1	0
14	Nest (Hide / Collapse / Flatten) elements within each other	1	0
15	Replace solid material with flexible material	0	1
16	Reverse direction or angle of component for alternate	1	0

	function		
TOTAL		**24**	**5**

Table 3

Design heuristics identified transitionally (between concepts) in the content analysis of concepts generated by industrial designers

Though there were fewer heuristics observed as transitions between concepts (n = 29), more of them occurred in the redesign task.

To understand these results further, it is helpful to follow individual designers through their ideation session, and see how each type of heuristic was applied during their work session. The following paragraphs provide a sample of one designer's work from each of the two design tasks.

In the redesign task, Designer 3 generated only one concept; however, he worked through 5 iterations of that concept (see Figure 7). The designer interpreted the form provided in the task as a cross-section of the lemon squeezer, and began by attaching two independently functioning components to create a product: a squeezer, and a container for collecting the juice. In concept 2, he built on his initial idea and created a solution that would use a continuous surface. He then split this surface into two pieces to distinguish the two functions from each other, and added another component to hold the pulp of the lemon. In the next concept, he covered the top part of the product to explore alternate ways of squeezing the lemon, such as using a second component. In a fourth concept, he extended the top piece all the way to the bottom of the product, and in the final concept, he used the same material throughout the product by creating a continuous surface out of the multiple components.

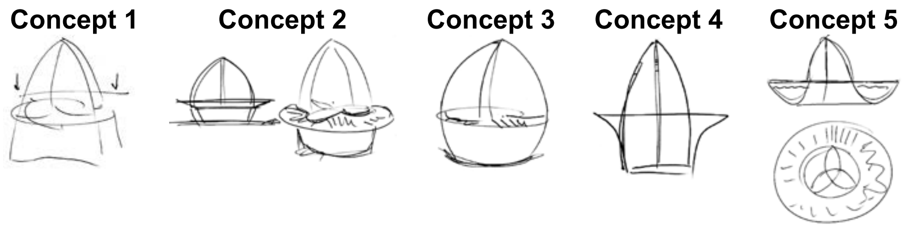

Figure 7

Sequential concepts generated by Designer 3

Though his concepts were not very different from each other, Designer 3 demonstrated successful use of heuristics as transitions to move and explore the design space within a single concept. For example, from concept 2 to concept 3, he used *Covering / Forming Shell / Wrapping surface for other use*, and from concept 2 to concept 5, he used *Making a continuous surface out of multiple components by merging them*, as he combined the squeezer and the container into one product. While the set of resulting concepts showed common features, they also reflect the iteration of design through the repeated application of Design Heuristics.

In the novel design task, a higher number of different concepts was generated, and more diverse heuristics were observed. On this task, Designer 5 generated four concepts; all were considered unique (Figure 8). In the first concept, he described a context in which the user was a hiker, and designed an integrated backpack with a heat pot attached to it. The second concept was a barbeque using solar panels on one side, and a cooking surface on the other. Solar energy was captured when the panels were unfolded fully, and the product was used with the panels folded. The next concept used multiple mirrors to direct sunlight onto one part of the product that could be attached to another part for cooking. The location of those components could be switched; that is, the heat unit was on top of the pot for collecting sunlight, and switched below it for providing heat from the bottom when cooking. His final concept was a set of small black cubes that could be utilized to absorb heat, and their orientation could be changed according to cooking needs.

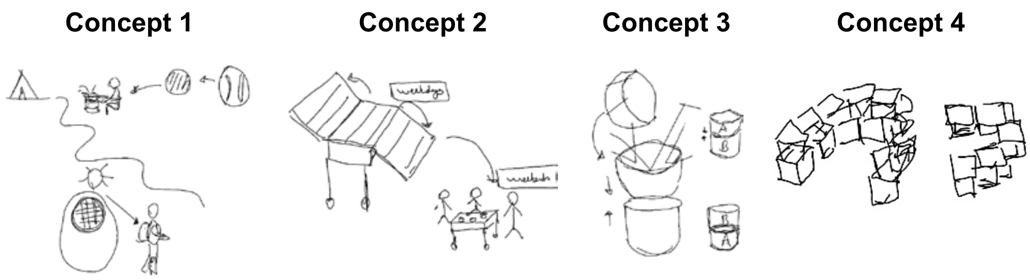

Figure 8

Sequential concepts generated by Designer 5

The *Change the direction of orientation* heuristic was evident in his third concept, where two components of the product were switched from top to bottom depending on the function to be achieved (cooking or trapping heat). Consistent with the fact that there was no evidence of transitional heuristics, he seemed to use an approach of sampling from very different areas in the problem space. The only consistency among his design concepts was the idea of capturing the heat during one time period and utilizing it at a later time.

The relationship between design heuristics, creativity and diversity ratings of concepts

Creativity scores demonstrated a similar pattern between the two tasks. Six concepts generated in both the redesign and the novel design tasks had average creativity ratings over “4” (with "7" as the "most creative design"). However, on average, creativity ratings were higher in the novel design task (43% above “4”) vs. redesign (33% above “4”).

On the other hand, there were no differences between the two design tasks on either creativity ratings (Redesign: M = 3.41 vs. Novel: M = 3.64) ($t < 1$) or on practicality ratings (Redesign: M = 3.82 vs. Novel: M = 3.00). This finding may be due to low statistical power (three subjects in each group). However, across the sample, the average creativity (r=.54) and practicality (r=.53) ratings correlate highly with the number of heuristics used by each designer (p <.01 for both) (Table 4).

Design Task	*Designer*	*Number of design heuristics used*	*Average creativity*	*Average practicality*
Redesign	1	42	4.08	3.58
Redesign	2	32	3.08	3.42
Redesign	3	23	3.00	4.6
Novel Design	4	19	3.17	3.25
Novel Design	5	22	4.50	2.88
Novel Design	6	14	3.50	2.75

Table 4

Average ratings and local heuristics observed for each participant

The more heuristics used the more creative and practical the designs were rated. This suggests that heuristics served to identify different, innovative solutions. This also suggests that the industrial designers were not blocked by their lack of technical knowledge; instead, they may have used Design Heuristics to compensate for this lack of knowledge.

In both of the design tasks, averaged creativity scores were higher in concepts using more Design Heuristics. Even though this indicates coherence between the number of heuristics used and the creativity of the design solutions, the heuristics used for each task differed (other than *Attaching independent functional components with the product,* which was also the most-commonly used heuristic out of 38). For example, the concept seen in Figure 9a used a combination of ten heuristics, with *Controlling/changing in function through movement*, and *Adding features from nature to the product* used only in this concept. The concept seen in Figure 9b was also scored as highly creative, and used another unique heuristic (*Compartmentalizing functions into distinct parts)* as one of six heuristics applied. Thus, the high creativity ratings of design solutions may be due to these three heuristics, or to the number of heuristics used within each concept.

Figure 9a

Example using Control / Change in function through movement, and Add features from nature to the product for a creative solution

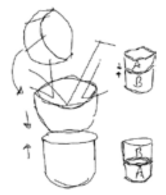

Figure 9b

Example using Compartmentalize functions into distinct parts for a creative solution

Diversity in the solutions from designers working on the redesign task was more limited. Redesign was constrained by the provided form and the existing product known to designers. It is observed that the designers working on the redesign task used their declarative knowledge as a main source for solving problems, while designers working on the novel design task relied on procedural knowledge, where they utilized heuristics as part of their idea generation process.

The diversity of concepts did arise from the use of diverse Design Heuristics. Another interesting finding is that heuristics used in redesign task were more focused, specific, and applied. In contrast, heuristics use in novel design task shows the use of more diverse heuristics, suggesting that they were exploring different parts of the design space, and using a variety of heuristics to do so.

Figure 10a shows that the designer produced a concept that requires both hands to function; the bottom part is for holding, the middle part is for the juice, and the top part is for squeezing. Once the designer had decomposed his design concepts into this particular set of elements, different heuristics were applied, including *Change where or how product will be used*, and *Add portability*. In the novel design task, designers used more diverse heuristics, resulting in more diverse concepts. For example, as shown in Figure 10b, the designer used *Replace solid material with flexible material*, and *Roll product around a pivot point* to generate an easy to carry and efficient surface that would both capture the light, convert it into thermal energy, and also be used as a cooking surface.

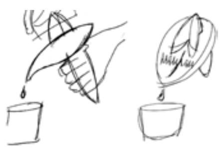

Figure 10a

Example using Change where or how product will be used, and Add portability for a diverse solution

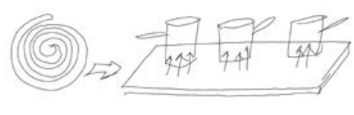

Figure 10b

Example using Replace solid material with flexible material, and Roll product around a pivot point for a diverse solution

In most cases observed, changes in design solutions occurred after applying an uncommon heuristic, such as a lemon squeezer without a base to sit on a table, or a solar-powered cooker made out of flexible pad. Concepts generated for the novel design task were judged more creative and diverse compared to the solutions proposed in the redesign task. The novel design task required more detail and concern about technicality due to the specifics given in the problem statement. Designers working on the redesign task appeared to experience "fixation" more commonly than in the novel design task. Jansson and Smith (1991) found that designers are sometimes trapped by the characteristics of a possible solution that has been developed as an example, and by existing precedents for the design. In this study, the type of the design problem did affect idea generation, as designers appeared to use their previous knowledge of existing products, and built their concepts accordingly in the redesign task. By contrast, designers in the novel design task were forced to explore new areas of the design space since there were few existing products for comparison; so, the Design Heuristics they used varied greatly to help them explore this new design space.

Discussion

The present study examined six experienced industrial designers working on short design tasks of two types: one a routine redesign of an existing product, and the other, a creative design of a novel product. The results showed evidence of frequent Design Heuristic use, and their involvement in generating diverse, creative, and practical concepts. Further, the study revealed some differences between designers' behavior in the two types of design problems. Specifically, designers working on the novel design task generated a more diverse set of concepts by using a more diverse set of heuristics. In this task, the designers also heavily weighed the context of product use, and approached the problem from the user perspective. In contrast, while working on the redesign task, the designers did not appear to consider different contexts for product use. Though they all identified specific differences in the means of user interaction with the product, this did not lead to the broad consideration of context seen in the novel design problem. As a consequence, the set of heuristics used most frequently in the novel design task were observed much less often in the redesign task. The difference of time (10 min. vs. 25 min.) between the two experiments may also have effect on the results. However, since the goal of the study was to explore how the heuristic use would differ between different design tasks, this difference does not play a strong role. Another different that has to be counted for is the use of retrospective interview in one experiment, and a combination of think-aloud and retrospective interview in the other. This difference also does not have a critical influence on our analysis since the verbal data was only used to understand the details of the concepts.

Despite the observed differences in heuristic use, the most striking finding in this study is the pervasive presence of heuristics in both of these design tasks. The results showed significant evidence of Design Heuristic use, and a great deal of overlap within the set of heuristics found in prior studies (Yilmaz, Seifert, & Gonzalez, 2010; Yilmaz & Seifert, 2011). The results also showed the effectiveness of heuristics in generating diverse concepts, suggesting they may stimulate creating novel concepts.

In both tasks, attention to users was evident. Industrial designers in the novel design task structured the context and approached the problem from the user perspective, considering the product's use by families versus individual hikers, the product's use in kitchens versus backyards, and the product as a single entity versus attached to existing products such as a grill or stove. Designers in the redesign task did not appear to consider different contexts; however, they identified differences in the interaction with the user, such as, holding the product with one hand and squeezing the lemon with the other hand, versus placing the lemon squeezer on the table to achieve the function.

The success of this heuristic analysis method in characterizing differences among candidate designs may suggest ways to assist designers in exploring new concepts. Training on Design Heuristics may improve the diversity of designs generated. Further, this further validation of the set of specific heuristics used by industrial designers may suggest methods for the development of computational tools to assist in design. For example, the frequency of heuristic application could be analyzed in order to understand which heuristics are most commonly used, what kind of design problems they are best applied to, what kind of new problem spaces they generate, and which heuristics may be relevant given the observed patterns. In particular, this approach may hold promise in instruction for novices as they build their experience with heuristic use and design in general.

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