COLLABORATIVE IDEA GENERATION USING DESIGN HEURISTICS

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ABSTRACT

Creative strategies play a central role in successful concept generation; however, few studies have documented the application of creative strategies in engineering design. From protocol studies of engineering and industrial designers, heuristics, or cognitive shortcuts, were identified that support novel and diverse concept generation [1]. In this study, professional engineers from a manufacturing company participated in a small group innovation workshop using the developed “Design Heuristics.” The team was videotaped as they worked with the instructional cards we developed based on the heuristics. This paper reports on the investigation of the design team’s idea generation process with five of the cards, analyzing the diversity of their ideas, how Design Heuristics were used, and their role in stimulating both new design solutions and problems. The introduction of a specific design heuristic often guided designers to a different part of the design space, and facilitated them in considering other unprompted heuristics.

Keywords: Engineering design, innovative thinking, idea generation, teamwork in design

1 INTRODUCTION

Increasing reliance on group decision-making in complex business environments, along with amplified competition for innovative ideas in engineering design, has created a growing interest in collaborative idea generation techniques. In response to this demand, several idea generation methods have been developed [2-8]. While a variety of techniques exists, there is limited research about their utility. In addition, there is very little evidence about collaborative design teams in professional industry settings. It is often assumed that teams output more creative designs than individuals because of the inherent structure of groups, where different approaches are "pooled" from individual designers.

Little is known about the cognitive processes of group members that lead to innovative design groups [9]. Research focus has been on group *brainstorming* [2], a method of collective idea generation where groups are instructed to generate as many different ideas as possible, avoid criticism, and iterate on others’ ideas. Though brainstorming enhances potential idea generation, participants may be unwilling to state some of their ideas because of potential negative evaluation by their peers. *Brainwriting* [10] is an alternative group idea generation strategy, where ideas are written rather than spoken, allowing individuals to produce ideas faster without waiting for a break in the discussion to voice them. Its other advantage is a reduction in evaluation apprehension, since ideas can be pooled anonymously. Brainwriting retains key aspects of the purported advantage of groups; namely, to see other’s ideas on the problem, to view alternative perspectives, and to build upon the ideas of others [11]. *Nominal Group Technique* [7] adds an initial session of individual idea generation to brainstorming or brainwriting, followed by a group ranking of all ideas. Nominal groups were found to outperform brainstorming groups, perhaps because the individual ideation stage is uninterrupted.

Similarities exist among these group idea generation techniques. All of them rely on individuals to generate as many ideas as they can, and then pool their ideas. The result, most people believe, is that groups outperform equivalent sets of non-interacting individuals, or what Paulus et al. [12] has termed the “illusion of group productivity.” On the other hand, research has shown that working individually can exceed the results of collaboration [13-14], termed as group “process loss” [15]. However, some studies have found a process gain effect [16], with groups outperforming combinations of individuals [17]. For example, IDEO, Inc.’s innovation teams were found to benefit from a variety of professionals gathered to generate potential solutions [18]. Brainstorming, Brainwriting, and Nominal Group Technique all rely on the idea that an environment and method that allows ideas to freely flow will result in creative outputs. They do not provide specific ways for design teams to transform ideas. In this study we investigated how the Design Heuristics ideation tool impacted designers from a professional corporation, specifically in regard to the number of ideas generated, and how alternate concepts and perspectives were raised.

2 DESIGN HEURISTICS

Design heuristics have been identified in the ideation processes of individuals in a number of prior studies [1, 19-21]. This approach assumes a “design space” consisting of all feasible designs (based on Newell and Simon's [22] definition of the "problem space"). Among these potential designs, some are easy to generate because they involve simple combinations of known features or elements. However, some of the possible designs within this space may never be uncovered by a designer because they do not come easily to mind. Design heuristics are cognitive strategies that facilitate exploration of the design 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 [23].

The term "heuristic" has been defined in psychological research as a simple, efficient rule used to generate a judgment or decision, especially for complex problems and vague information [24]. Behavioral research shows that experts use heuristics very effectively, and their efficient use of domain-specific heuristics distinguishes them from novices (e.g., [25]). In design, heuristics were identified through protocol studies of industrial and engineering designers as they worked on open-ended problems. An important feature of all heuristics is that they do not lead to a determinate solution; rather, they lead to "best guesses," resulting in varied and creative solutions.

Heuristic-based approaches to design differ significantly from other approaches to idea generation. Rather than allowing naturally occurring ideas to flow [2], heuristic theories specify transformations to apply to designs, such as "substituting," "rearranging," and "eliminating" design elements. A variety of heuristics have been proposed in the literature (e.g., SCAMPER [4], Synectics [26], and TRIZ [8]). For example, the SCAMPER approach defines seven general strategies (substitute, combine, adapt, modify, put to other uses, eliminate, and rearrange/reverse) to apply to all design problems. No specifics are given to guide the designer about how, or when, they can be useful. For example, given a design problem like "redesigning a hand soap dispenser," applying the heuristic, "modify," provides little direction for exploring potential alternative designs.

The Synectics framework encompasses different phases of ideation, combining more (n=22) and different, heuristics. Some of the heuristics proposed in Synectics provide very general theme suggestions, including "parody, prevaricate, metamorphose, and mythologize." So, a designer utilizing Synectics may try to “animate” the soap dispenser by applying human qualities, such as adding a smiling face. Synectics also suggests the use of past experiences and analogies, and includes marketing strategies based on competitive products. As a theory, it encompasses a broad range of heuristics that may appear dissimilar and difficult to use. In contrast, TRIZ provides a technical “contradiction matrix” of 39 common engineering problems and 40 related possible solutions. For example, in designing a soda can, a designer employing the TRIZ system may first analyze the technical conflicts caused by engineering parameters; specifically the wall thickness of the can has to be strong enough for stacking purposes yet as light as possible for cost. Then, using “Increase the degree of an object's segmentation” heuristic, the wall of the can could be redesigned from flat to corrugated to increase strength. In order for the TRIZ heuristics to be employed, a base concept must exist and specific characteristics of the solution identified. As a result, the TRIZ method is highly specific to the implementation of functions that often takes place much later in the design cycle, after the design concept has been selected and implemented.

The most useful heuristics for creating new design concepts may lie at an intermediate level between these approaches: more general and earlier in the design process than TRIZ, but more specific than the broad suggestions posed in SCAMPER and Synectics. This intermediate level of description would provide a closer link between the heuristics and their application and be applicable to more types of designs. In previous work, a set of 77 heuristics was developed by analyzing the protocols of designers. This set of Design Heuristics emerged from concepts of industrial and engineering designers [1], across design problem types [20], and among designers with varying expertise [23, 27].

Unlike other heuristic approaches, Design Heuristics have been tested and shown to produce more and more varied, engineering designs [1]. In a study with novices, the use of heuristics was found to result in more creative designs [23]. In an analysis of a professional designer's work on a project over a two-year period, Design Heuristics were discovered to account for a significant portion of the transitions between concepts [27]. Finally, 400 award-winning products were coded for their use of Design Heuristics, and all of them were found to have incorporated one or more [20].

3 HEURISTICS IN COLLABORATIVE DESIGN

Based on the ubiquity of observed Design Heuristic use, one goal of this study was to test how the intentional use of Design Heuristics impacted exploration of the solution space to achieve more creative and diverse ideas. We expected that the introduction of specific design heuristics would motivate the generation of alternative concepts, helping to explore more varied designs.

A second goal for the study was to assess the success of the Design Heuristic approach with teams of designers as opposed to individuals. The use of heuristics in a collaborative design task has never been investigated. If successful, the guidance provided by Design Heuristics may promote a more efficient exploration of the design space than other group methods, resulting in more varied concepts for consideration. While this study was not designed to compare group ideation methods, it can give evidence to Design Heuristics as a viable alternate method.

Finally, by studying professional engineers in their workplace, we hope to learn about the validity and applicability of design heuristics within real-life design problems and settings. The participants in this study had years of experience working with design processes and the specific product they were transforming with heuristics. The ability to generate novel concepts within this experienced design team would provide impressive evidence of the power of Design Heuristics.

In this study, we examined how heuristics directed groups in generating innovative design concepts by providing a set of “heuristic cards" to the design team and studying the ideation path. How does the group implement the use of specific heuristic cards in concept generation? How does the team respond to the various components of the heuristic card tool, i.e., heuristic description, abstract image, design criteria, and product examples? Does group interaction result in emergent or group-level heuristics incorporated into concepts? If so, how can such processes be facilitated to promote successful team-based design?

4 EXPERIMENTAL APPROACH

This study focused on the instructed, conscious application of design heuristics to an ongoing project within a design team. The existing team was gathered in a workshop setting to attempt to innovate on their current concepts. We observed the design team as they made use of Design Heuristics tool through video recordings. We sought to answer the following questions, addressing both the applicability of heuristics to the design problems, and their effectiveness in group ideation sessions:

1. How does the group implement the heuristic card idea generation tool?
2. How does the group respond to the various components of the tool, i.e. description, abstract image, product examples?
3. Do the concepts generated reflect the use of Design Heuristics?

3.1 Participants

A design team, including design engineers and marketing experts, at a major international corporation participated in the study. The designs under consideration were for outdoor consumer products. A total of fourteen participants (with varying levels of expertise) generated concept ideas in two, two-hour long work sessions over two days. The participants were split into two design teams to allow more interaction in their conversations. In this paper, we report on one of the team’s collaborative process using the heuristic cards, comprising approximately fifty minutes of the first work session.

The seven-person team reported in this study was comprised of six design engineers and one marketing expert who had multiple years of experience working with each other on various tasks. Most were very familiar with brainstorming [2] as an idea generation technique. However, in a survey, they did not identify any other strategies as part of their creative thinking processes. The list of participants with their age, gender, and experience level is shown in Table 1.

Table 1. Participants' age, gender, design-related experience, and current position at the company

Participant	Age	Gender	Design related Experience	Current position
Participant 1	30	F	6 years	Design engineer
Participant 2	50	M	30 years	Global R&D director
Participant 3	50	M	25 years	Global product manager
Participant 4	29	M	4 years	Design manager
Participant 5	34	M	6 years	Design engineer
Participant 6	48	M	23 years	R&D manager
Participant 7	45	M	20 years	Project manager

3.2 Method

The design engineers were in the process of creating a new product line targeting different consumer markets, and made use of the session as part of their innovation process. Throughout the sessions, design engineers worked on developing their product line, and were highly engaged in solving issues and seeking ways to generate novel concepts. As this task was their on-going project, they already knew many areas where they could potentially improve the products.

In total, thirty heuristic cards were randomly selected from a larger set, and sent to the workshop for engineers' use in creating innovative solutions to the problems they identified in their product lines. 15 heuristics were introduced to the team on the first day, and the second 15 heuristics on the second day. Idea generation sessions were video recorded for further analysis. The workshop leader introduced the intent behind the cards, emphasizing the exploration of diverse ideas in the early stages of the product design process. The design team members were asked to read the details on each card separately, and then to start exploring ways to apply these heuristics to their design problems as a group. Participants were also asked to fill out a survey at the beginning and at the end of the workshop. The first survey collected demographic information, and the second asked what the engineers thought about the workshop in general, whether they would suggest any improvements, and whether they would apply these heuristics to their future design projects. All of these questions were open-ended.

Each heuristic card had the heuristic's title, a number, an abstract illustration of the heuristic, and a description, along with criteria linking the heuristic with product attributes on the front. An example heuristic card (front and back) can be seen in Figure 1. On the back of the cards, two product examples were provided. One of these examples (on the left) showed the use of the heuristic in an existing product. The example on the right always illustrated some kind of "seating" to show how each of the heuristics could be applied to one consistent product (a seating unit).

Verbal data from the video session were transcribed, and all data were analyzed for evidence of heuristic use. Three evaluators, one experienced in industrial design, one experienced in engineering education, and the other with a background in engineering and art & design, examined the transcriptions. The goal of the analysis was to characterize the patterns evident in participants' performance on the task. Thus, the analysis included identifying each concept generated as a separate idea, categorizing characteristics of the solution concepts generated, determining the number and diversity of the concepts, and determining when specific design heuristics were mentioned in concept generation. The evaluators worked separately and then met to resolve the conflicts.

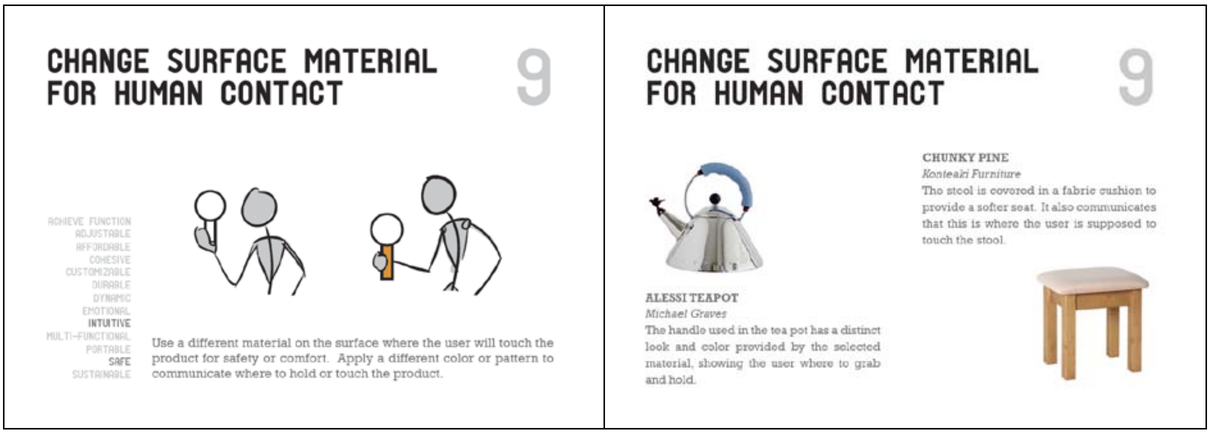

Figure 1: Front and back of one heuristic card

5 RESULTS

The results include a report on the use of the first five Design Heuristic cards the team randomly selected from the set of 15. Since the design team was not asked to use the cards in any order, the first five cards used do not follow the assigned numbers shown in Table 2. The qualitative results presented include a discussion of how the heuristics assisted the design engineers in generating alternative solutions, how they served as "idea triggers," initiating new perspectives in the group discussion, and the relationship of the heuristics used to the diversity of concepts formed and the creativity and practicality of the concepts. Because the sample size is small (seven designers working with five heuristic cards), we do not attempt to generalize, however, as with rigorous qualitative research, results may be transferable to similar situations [28]. The design engineers used the heuristic cards as a means to tackle novel design problems in a familiar domain, and since the workshop was structured as a discussion session, participants did not focus on sketching. Instead their priority was bringing more concept ideas to the table.

The analysis of card use was split into three categories: (1) Description: the general approach the team had in using the card, and whether they used additional approaches, such as analogies or brainstorming; (2) Process: how they used and interpreted the information on the cards (abstract image, heuristic definition, criteria, and product examples) and how each card led the engineers to different design concepts; and (3) Summary: how the engineers integrated other design heuristics not provided by the experimenters, and what additional criteria each card triggered for further consideration.

Heuristic Card 1. "Adjust function through movement: *Identify stages or degrees of the product's function and define transitions between. Allow the user to adjust the function through moving the product or its parts. Consider different types of motions (i.e. rotating, sliding, and rolling) and control mechanisms."*

<u>Description:</u> The team used this heuristic to rotate multiple parts of the product to see how it could change the design. After considering adjusting the functionality of separate parts within the product, they assessed their feasibility and logistical details of concepts such as whether to include stationary or non-stationary parts. These evaluations led the team to explore different ways of adjusting functionality using movement. They talked about multiple ways to technically achieve the goal, as well as how one change would affect the rest of the system. The team members built several ideas sparked from earlier ideas in the session, while continuously evaluating their feasibility.

<u>Process:</u> The first concept generated focused on the rotation movement shown on the product example listed on the card (a circular, adjustable shower head for different levels of water). They used this as an analogy, and applied it to the circular formed component within their product. They suggested that this circular part would rotate for different types of functions. The second concept also used rotation as the movement to adjust the function; however, this time, they focused on adjusting another function by rotating a component on an already moving part. This made use of the movement action already assigned to that part. In the third concept, the designers looked at difficulties in how adjusting function through movement already existed in the product and how they could make it simpler. They changed the movement from rotational to lateral, and used the heuristic to identify challenges in the operation of the product. Within this concept, engineers incorporated ideas, such as pressing one part to engage another set of functions, adjusting the handle to control the rotation, and splitting parts in the existing product to allow for individual rotations. Application of the heuristic card served to identify existing problems, and the team used the given heuristic to suggest solutions to each newly identified problem.

<u>Summary:</u> The use of *Adjust function through movement* prompted the engineers to apply this heuristic to individual parts within their existing products. If the parts were not separate from each other, they would first separate them in order to be able to embed the rotation motion independently from other parts. Multi-functionality appeared to be the main criteria this heuristic stimulated within the team, as they focused on the separation of parts, and then implementing functional adjustment through different types of rotational movements, which suggested functional combinations. The engineers also assigned the control of some of these functions to the handle of the product, which resulted in incorporating user input for converting from one function to another.

Heuristic Card 2. "Adjust function for a specific demographic: *Design the functions of the product around the characteristics of a population such as age, gender, education, occupancy, and diverse abilities. Or allow each user to adjust functions to their own characteristics."*

Description: The design team approached this heuristic with a specific focus on gender differences. Because the existing product is used mainly by male consumers, marketing for female consumers was viewed as promising. This emphasis brought demographic differences into the discussion, including making the product smaller and thus more appealing and accessible to females. The team reanalyzed the existing product line, and discussed how they were not working well for people other than average-sized adult male consumers. Then, using the analogy of cell phone skins for customizing to personal tastes, the engineers discussed how the same approach could be applied to their product lines. The designers seemed to reevaluate their tradeoffs for female users, and came up with potential solutions. While doing so, they carried over the "adjust function" concepts from the previous card, and reevaluated the problems once again, but this time for female users. Coming up with potential solutions based on the heuristic cards appeared to lead to better understanding of the core problem, and they focused on the problem-solution cycle within the idea generation phase.
Process: First, the engineers discussed how the product should look for this new demographic. In the first concept, they addressed issues such as, changing its size to require smaller forces to operate the product, incorporating a starter, and integrating adjustable grips. The second concept was built upon the idea of customization; customization of the product's appearance using skins, stickers or multiple different cover options. Another customization was the addition of accessories, such as hub caps. Within this conversation, the team also discussed some brands that are famous for their customizable backpacks, and sports team shop-vacs. They used these brands as analogies that they could use in customizing their product. In the third concept, the team decided to hide the technical components within the product by putting a façade on it to make it more intuitive for non-mechanical customers. Even though their focus was female users, this approach suggested inclusion of other demographics as well, such as elderly people. Analogies were also part of the ideation phase for this concept. For example, the team suggested incorporating the height adjustment pedals used in vacuum cleaners as an analogy to be applied to their own product in order to provide height options to different users. The third concept involved supporting the needs of elderly people. The team's main concern with this new demographic group was safety, and how different safety features could be added to the existing product. The solutions discussed here were creating a smoother start, slowing down the speed or adjustable speed, creating a very stable machine, and requiring a low speed for start-up. The final concept in this discussion was redesigning the interface of the product to make it more intuitive for a broad range of people. The engineers suggested alternative ways to visually cover the inner mechanisms to reduce accessibility, to redesign the gasoline input to make the process less messy, and to use the same component for two different functions.
Summary: Safety, intuitiveness, and customization seemed to be the most critical criteria the team focused on while applying the heuristic, *Adjust function for specific demographic*. All three criteria focus on the user, and how the user would interact with the product. This appears to be due to the integration of the specific demographic within the heuristic, as the focus of concepts shifted from multifunctionality to user-centered design problems.

Heuristic Card 3. "Attach independent functional components: *Identify different parts or systems with distinct functions and combine them to create a single device. Define each function independently, assign form to each, and add a connection between parts."*
Description: This heuristic, unexpectedly, led the engineers to generate concepts focusing on the perceived value of efficiency. They viewed this heuristic as a means to improve efficiency by attaching components to the existing product. Since it specifically suggested the inclusion of multifunctionality, the engineers explored additional tasks consumers often tackle while using the product. This heuristic directed the team into the use of a wide variety of other heuristics.
Process: For the first concept, the engineers discussed adding components and compartments to the existing product for storing tools. The idea was initiated by defining what other items the user would likely need while using the existing product. To meet those needs, the team simply added a storage unit to the product in case the user would need it. The second concept was framed around an analogy of attaching an additional component to the back of a product, which also supported a secondary function. In this way, the engineers attempted to increase the versatility of the product. The third concept, while still emphasizing multifunctionality and efficiency, focused on a more integrated system. The team proposed using the existing product's mechanism for an additional, secondary task that was not an attachment but an integration of the secondary function to the existing mechanism. This concept was essentially the merging of two existing products that work on similar mechanisms.

Summary: While applying this heuristic, the engineers also evaluated the concepts by creating a variety of user scenarios, including going through each step as the user would for each additional function. Multi-functionality was again the major criterion for the engineers. Even though the heuristic suggested independent component attachments, the designers took it a step further, and integrated those attachments within the already existing mechanisms by creating systems.

***Heuristic Card 4. "Attach product to user:** Design the product around user so that the user becomes part of the function. Attach the product to different body parts, such as user's head, finger, or feet, and redefine how the product will be used by that part."*
Description: The approach to this heuristic was different than the prior heuristics. One of the participants suggested skipping this heuristic because it would not be as relevant to their ongoing project. However, the rest of the team wanted to explore how they could apply this heuristic, and considered user interaction as a broad topic, including safety, comfort and users' misuse of products.
Process: The team entered the discussion with an existing battery pack as the energy source. This was initiated by the abstract image on the heuristic card. Since the image suggested attaching the product to the back of the user, the engineers used this as an analogy to start the conversation. Using a backpack battery source to power the product was evaluated right after the idea was proposed, and rejected immediately because it would be too heavy to carry. The second concept was attaching a strap to the user as a power-off switch for safety reasons. The team used both the product example provided on the back of the heuristic card, as well as boat keys with wristbands as analogies in this concept. The suggestion was for the product to stop the operation by itself when the person stops using the product. The third concept, building on the prior idea, integrated sensors on the handlebars to control the power. In this concept, engineers did not focus on using Heuristic #4; instead, they carried the problem of safety forward and tackled this issue from a different perspective by integrating sensors.
Summary: Safety became the priority while engineers applied this heuristic. They emphasized the relation between control mechanisms and misuse, which was triggered by the heuristic provided. While this heuristic did not seem to be immediately relevant, the team found ways of applying it to solve or identify problems that were not previously noted.

***Heuristic Card 5. "Bend:** Form an angular or rounded curve by bending a continuous material in order to assign different functions on the bent surfaces. The up and down indents can also be used as part of an elevation or a stand."*
Description: The design team initiated the conversation about this heuristic by discussing competitive brands, and their use of "bending" as a way to improve the aesthetics of their products. They evaluated the components in their existing product to figure out what could be bent. This was supported by one of the engineers saying: “It doesn't say what's bent; it could be the handle, or the knob, or something else in the product”.
Process: The initial concept focused on improvements of aerodynamics, and how bending the components underneath the product would enhance the function of internal moving parts. The second concept was about bending the handle of the product to create spots for different kinds of attachments. This concept was initiated by the use of a long tube as the handle, which was not as efficient as it could be. The goal here was to add more functions to this bent handle by attaching different components.
Summary: Efficiency and multi-functionality were again the criteria discussed by the team. In addition to the heuristic provided, they discussed competitors' solutions, and implemented them in similar ways to their own product.

Use of Additional Heuristics.
In addition to the heuristics provided on the cards, we observed the use of other heuristics (that we have identified in our previous work) subconsciously by the design team. This spontaneous access to heuristics was also examined in prior studies [1, 19]. This observation reveals the tendency for the design team to combine design heuristics within individual concepts. In addition to the five heuristics that were provided, a total of 26 additional heuristics (of our total set of 77) were observed, suggesting that the conscious application of heuristic use prompts the use of other, similar heuristics subconsciously. This adds validity to the Design Heuristics approach because it shows the ready use of these heuristics in the absence of any instructional training. Table 2 shows how other heuristics were integrated into the design space.

Table 2. Concepts generated with each heuristic card, and added heuristics (not provided)

	Adjust function through movement			*Adjust function for specific demographic*					*Attach independent functional components*			*Attach product to user*			*Bend*	
Concept Number	**1**	**2**	**3**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**
Add gradations							X									
Add motion	X															
Apply to existing product				X					X					X		
Apply existing mechanism in a new way	X					X							X			
Change geometry															X	
Change the direction of user approach			X													
Convert for second function			X													
Cover / form shell / wrap						X		X								
Create a system											X					
Create hierarchy of features								X								
Distinguish functions visually								X								
Elevate / lower		X														
Incorporate user input			X	X			X									
Make components attachable/detachable										X						
Make components multifunctional	X		X							X	X			X		X
Offer optional components					X											
Repeat								X								
Rotate	X	X	X													
Scale up or down				X												
Separate parts	X		X									X				
Substitute													X	X		
Synthesize functions										X						
Twist															X	
Use alternative energy source											X	X				
Use common base to hold components																X
User customization					X					X						
TOTAL ADDED	5	2	5	3	2	2	2	4	1	4	3	2	2	3	2	2

In summary, we answered these questions:

How does the group implement the heuristic card idea intervention tool?

Our results indicate that using design heuristics helped the designers to be more aware of design issues. The team did not appear to follow a specific strategy. Instead, the presentation of each design heuristic served as a "jumping off" place, leading to the consideration of other heuristics. The heuristic card served as a point of organization, and led to related concepts. Often, the designers would stick with one card for ten minutes or more before moving on. Once a heuristic is viewed, the design team kept using it. In this task when the team switched to a new heuristic card, they used it, but they came back to the trusted heuristics that worked in previous concepts. So while working on a heuristic card provided, they used other heuristics too.

How does the group respond to the various components of the tool, i.e. description, abstract image, product examples?

The engineers mentioned the contribution of the product examples to the process of applying the heuristics, suggesting that seeing the application of the heuristics in real-life examples facilitated the intent of each heuristic. They suggested that the cards could be improved by providing more product examples like the ones given on the back of the cards. On the other hand, the abstract image did not appear to have the same effect. The team discussed these abstract images in the initiation of their discussions, and how they led to inspirations for their design problems. The criteria defined on the front of the cards were integrated within the team’s conversations. They did not use each criterion, but the team often brought up criteria to strengthen their statements about additional problems.

Do the concepts generated reflect the use of Design Heuristics?
In the designers' self-assessment of the session, they credited the heuristic cards as leading directly to product innovations they generated. From the five cards analyzed here, a total of 16 concepts were generated, and five innovations listed below were clearly tied to the use of the cards:

- providing a lanyard indicating when the operator is present
- powering additional tools from one base
- adding a complementary function to the product
- adding adjustable height functions
- adding pull-out handles

Some topic overlap was displayed in conversations across the heuristic cards. For example, both *Adjust function through movement* and *Attach independent functional components* stimulated thinking about adding functions to the product. Even though the outcomes of these discussions were different, the main criterion considered for both heuristics was multifunction integration. Some heuristics led to ideas or insights that the engineers had tried in the past; however, most of the team's conversation reflected ideas that were genuinely new to the team.

6 DISCUSSION

The study evaluated Design Heuristics within the ideation process of a team of professional product engineers, and provided evidence for the success of heuristics in generating novel solutions and overcoming design fixation. In the workshop session, the design team applied heuristic cards to their existing products. The designers felt the cards stimulated novel thinking even though they had been considering these products for many years. This supports earlier results [20] that design heuristics are context-independent, and can be applied to a variety of design problems. These expert engineers found ways to use the heuristics in their concepts without difficulty. In addition, the team readily added other heuristics to the concepts. This suggests design heuristics may capture an aspect of expertise in product design, and that these results may be applicable to other experts.

Some limitations of the study were the small number of designers involved, and the analysis of the sessions from a single team. A larger study with more cards and a more generalizable account of the group process is needed to support these preliminary conclusions. In addition, only one type of consumer product served as the design problem. While the design heuristics were developed through the analysis of diverse products, further studies are required to demonstrate their practical utility in product design firms.

The design team's use of heuristics served as focal points in their discussions, leading to related ideas and constraining the group to consider one type of innovation at a time. In contrast, idea generation techniques like brainstorming emphasize the "random" contribution of ideas to the session. Presumably, the process of interleaving ideas from unrelated sources is the spur that produces new ideas in the brainstorming approach. The design heuristic approach may be an alternative account that explains the course of idea generation in the group process; or it can be used in combination with brainstorming. The space of potential designs may be large, and individuals and groups appear to become fixated within a particular approach, constraining their ability to generate varied alternative solutions. Presumably, the more alternative, varied possibilities generated, the greater the likelihood of identifying an innovative solution. Methods like Design Heuristics may help to direct exploration to parts of the design space that are normally unvisited.

After the study, the design team stated that the heuristic cards were effective, forced them to stay on track, and helped to focus their attention on one topic at a time. The designers also felt the method was successful in leading them to create innovative ideas they had not previously considered, which is remarkable because of the long experience the team had with designing this particular product. This study demonstrates that the design engineers, in a group setting, can use heuristics for defining new design concepts, and generating new concepts for well-established products.

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