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Can experienced designers learn from new tools? A case study of idea generation in a professional engineering team

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Generating novel ideas is a challenging part of engineering design, especially when the design task has been undertaken for an extended period of time. How can experienced designers develop new ideas for familiar problems? A tool called *Design Heuristics* provides strategies that support engineers in considering more, and more different, concepts during idea generation. *Design Heuristics* have been shown to help novice engineers create a set of more diverse and creative candidate concepts. In this case study, we extended this approach to a group of professional engineers who had worked on a specific product line for many years. In a workshop format, a small group of engineers worked with the heuristics in two separate sessions and generated ideas collaboratively. Video recordings were analyzed to reveal how the heuristics were used to stimulate new designs for their product line. We found that *Design Heuristics* bring order in ideas and elaboration on ideas, perhaps through coordinating effort on idea evaluation, increasing capacity to improve the ideas of others, and facilitating interaction between participants. This case study shows using *Design Heuristics* can assist even expert engineers to increase the variety of concepts generated, resulting in a larger set of ideas to consider.

Keywords: engineering design; idea generation; teamwork in design

1. Introduction

How do engineers create novel designs? For any design problem, it can be challenging to generate a wide range of concepts that vary in their qualities, and to create concepts that are different from existing products. At the same time, the stakes are high for generating novel, creative designs. Conceptual design has been shown to have the most significant impact on the cost of a product compared to the other phases of design (Römer, Weißhahn, & Hacker, 2001). Existing approaches to idea generation include Synectics (Gordon, 1961), SCAMPER (Eberle, 1995), advanced systematic inventive thinking (ASIT; Horowitz, 1999), morphological analysis (Zwicky, 1969), parameter analysis (Kroll, 2013), analogical thinking (Casakin & Goldschmidt, 1999; Finke, Ward, & Smith, 1992), and the

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Theory of Inventive Problem Solving (TRIZ) (Altshuller, 1984, 1997; Terninko, Zussman, & Zlotin, 1998). These approaches vary in their focus, specificity, and usability.

Specific creativity methods such as TRIZ (Altshuller, 1984, 1997) and ASIT (Horowitz, 1999) have been proposed as formal theories (Reich, Hatchuel, Shai, & Subrahmanian, 2012). Both of these methods are derived from practice in engineering, and draw creative ideas from past solutions. However, a work product such as a patent is the result of many hours of design work, so these advanced techniques may not support the ideation stage of the design process. Morphological analysis (Zwicky, 1969) has been shown to improve engineers' designs, but is highly dependent on individuals' past knowledge and experience. Parameter analysis (Kroll, 2013) is a coaching approach that enables to study and analyze existing technological products and apply this knowledge to create new concept configurations. Analogical thinking is supported by experimental studies in design (Christensen & Schunn, 2007; Linsey, Murphy, Markman, Wood, & Kurtoglu, 2006). However, the meaningfulness and relevance of the analogy to the design task has shown to be critical to the success of the method (Holyoak & Thagard, 1995), so the designer must generate an appropriate exemplar.

The ideation technique called *Design Heuristics* was proposed as a tool to help designers generate more, and more creative, concepts (Design Heuristics, 2012; Yilmaz, Seifert, & Gonzalez, 2010). *Design Heuristics* are simple, cognitive "rules of thumb" (Nisbett & Ross, 1980) that capture specific ways of introducing variation.

Design Heuristics were identified by examining existing designs and abstracting the central transformation represented in concepts (Christian, Daly, Yilmaz, Seifert, & Gonzalez, 2012; Yilmaz & Seifert, 2010; Yilmaz & Seifert, 2011). The designs included a wide variety of award winning products (Yilmaz, Seifert, Daly, & Gonzalez, 2013), along with a series of concepts developed for a single product (Yilmaz & Seifert, 2011). In addition, protocols from engineering and industrial designers working on novel problems were collected (Daly, Christian, Yilmaz, Seifert, & Gonzalez, 2012; Daly, Yilmaz, Christian, Seifert, & Gonzalez, 2012; Yilmaz, 2010; Yilmaz, Daly, Seifert, & Gonzalez, 2010). From these examples, a set of 77 individual heuristics that appeared repeatedly were identified and described (Daly, Yilmaz, et al., 2012).

We developed instructional cards (Figure 1) to illustrate each heuristic (designheuristics.com). One side describes the heuristic with a depiction, and the other side offers two example products. One of these commercial product designs is always a chair, demonstrating that each heuristic can be applied to a single product.

The intent of *Design Heuristics* is to capture the "educated guess" that moves towards novel designs, drawing upon the psychological definition of heuristics as an important part

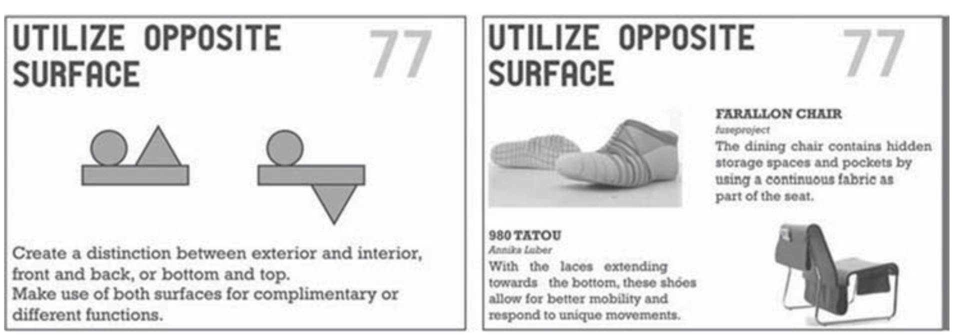

Figure 1. Front and back of one of the 77 *Design Heuristic* cards.

of the cognitive process of solution development. The term "heuristic" has been widely used in the literature to describe strategies that make use of readily accessible information to guide problem solving (Pearl, 1984). In psychology, research in decision making has shown that judgment applied under uncertainty often depends on simplified heuristics (Kahneman, Slovic, & Tversky, 1982). Heuristics have also been defined as ways of self-inquiry and dialogue with others aimed at finding the underlying meanings of important human experiences (Moustakas, 1990). They serve to identify and explore relevant problem aspects, assumptions, questions, or solution strategies (Ulrich, 2005); however, they do not guarantee a solution or a useful transformation, but derive their validity from the usefulness of their results (Cox, 1987). Heuristics have been identified and used in many domains. Ulrich (2005) proposed critical system heuristics to demonstrate a deductively derived set of heuristics used in system evaluation, Riel (1996) described 61 heuristics used by computer scientists, Nielsen (1993) used heuristic evaluation as a usability-testing technique, and Koen (2003) proposed engineering heuristics to describe the engineering method.

There are some similarities between *Design Heuristics* and other ideation tools (Daly, Yilmaz et al., 2012). However, *Design Heuristics* have been empirically studied in many different cases as real empirical situations, experimental empirical cases, and case studies. In an experiment with novices, use of the heuristics was found to produce more creative designs (Yilmaz, Daly, et al., 2010; Yilmaz, Seifert, et al., 2010). A study in a classroom setting with engineering students (Daly, Christian, et al., 2012) showed that using *Design Heuristics* produced more creative and varied engineering designs. A further study comparing engineers with industrial designers found that *Design Heuristics* were an effective tool for both groups (Yilmaz et al., 2013).

While *Design Heuristics* were shown to be effective with students (Daly, Christian, et al., 2012; Yilmaz, Daly, et al., 2010; Yilmaz, Seifert, et al., 2010; Yilmaz et al., 2012), it is not clear how they might impact practicing designers. One major difference is that professional engineers often work on the same products over many years, accumulating experience and expertise in a given domain. In commercial design, product specialists may have a dozen or more years of experience working on a single product. It is possible that experienced designers have already accumulated the guidance provided by *Design Heuristics*. Thus, a central question is whether *Design Heuristics* could be useful to a team of professional engineers in considering new ideas for familiar products. Additionally, previous studies on *Design Heuristics* focused on individuals working alone to produce design concepts (Daly, Yilmaz, et al., 2012; Yilmaz, Daly, et al., 2010; Yilmaz, Seifert, et al., 2010; Yilmaz et al., 2012). For professional engineering projects, teams of designers often work together to generate new concepts rather than working individually (Paulus & Yang, 2000).

Research on idea generation in groups has mainly focused on brainstorming (Osborn, 1957), a method of collective idea generation where groups are instructed to think of as many different ideas as possible while avoiding criticism, and to build upon each other's ideas. Other methods include brainwriting (Geschka, Schaude, & Schlicksupp, 1976), where ideas are anonymously shared in written format rather than spoken, and the nominal group technique (Van de Ven & Delbecq, 1974), where the group ranks the ideas after a brainstorming or brainwriting session. Most people believe that groups outperform equivalent sets of non-interacting individuals, or what Paulus et al. (1993) has termed, the "illusion of group productivity." However, many studies show that working individually is *more* efficient than collaborating (Diehl & Stroebe, 1987; Mullen, Johnson, & Salas, 1991), termed "group process loss" (Steiner, 1972), while a few studies have found a process gain effect (Collins & Guetzkow, 1964; Laughlin, 2002). All of these group studies have taken place in laboratory settings.

Few studies have examined teams of designers in professional work settings. Because this work tends to be proprietary, it is difficult to gain access to the target population of professional engineering teams (Hargadon & Sutton, 1997). For the present study, we were able to videotape a group of professional product design engineers during an in-house workshop intended to motivate new approaches to their product line. The participants were expert engineers at a major manufacturing company with a successful, ongoing product line. This case study allowed an in-depth investigation of the feasibility of *Design Heuristics* as a tool for one team of professional designers in the work setting.

2. Exploratory case study

2.1 Participants

An engineering design team at a major international corporation participated in the study. The product designs under consideration were consumer products used outdoors. The participants were already working on existing design problems related to one of the company's products as a team. Their in-house training effort included a team workshop to generate new design concepts, and was led by one of the company's design engineers. The design team comprised of seven members with varying levels of expertise, with six design engineers and one marketing expert. The team had multiple years of experience working together on various engineering tasks. One was female and six were males, and their ages ranged from 29 to 50. Their titles were design engineer (2), design manager (1), product manager (2), and R&D manager (2). Three members had between 4 and 6 years of experience, and four had between 20 and 30 years on the job.

2.2 Materials

Each heuristic was presented as shown in Figure 2. One additional feature on the cards was a list of design criteria (e.g., functionality, usability, and pleasure) to provide guidance about how each heuristic might be helpful in creating a new design.

2.3 Procedure

We provided the workshop facilitator with a set of *Design Heuristics* to determine whether this professional design team would find the tool useful in a real-life setting. During the workshop, the group used only the *Design Heuristics* materials supplied, and worked in two 2-h long sessions over 2 days. For both sessions, the seven engineers were grouped

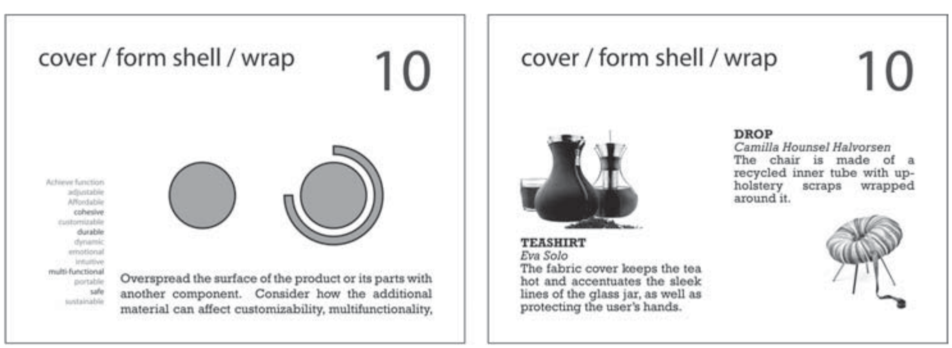

Figure 2. Example of a *Design Heuristic* card in the study.

together, and the entire meeting was videotaped. No researchers attended the workshop. The workshop facilitator, a design engineer, introduced the cards as a tool for the exploration of diverse ideas in the early stages of product design. First, two sample cards were discussed as an introduction to the *Design Heuristics* approach. Then, the team members were asked to read each card one by one, and start exploring ways to apply the heuristics to their design problems. Due to the time limits, a subset of 30 *Design Heuristics* was selected at random from the larger set of 77 (Daly, Yilmaz, et al., 2012; Design Heuristics, 2012) (shown in Table 1, in alphabetical order).

During the first 2-h workshop session, the first 15 heuristics were introduced to the team, and the engineers worked through this first set of cards. On the following day, the group was given the second set of 15 cards, and again worked at their own pace for 2 h. This day, the moderator told the participants when they had 10 min remaining in the workshop, and they moved from the 26th through 30th cards at an accelerated pace.

2.4 Analysis

Verbal data from the video sessions were transcribed. Two coders, one experienced in industrial design and one with a background in engineering and art and design, examined the transcriptions. First, each separate concept under discussion was identified, and the transcript segmented in order to characterize the number of concepts considered during the session. Then, each separate concept was compared to the set of heuristics shown in Table 1. Each heuristic evident in the proposed concept was identified, and multiple heuristics could be found within a single concept. This method of coding for the appearance of heuristic use in concepts has been successfully performed in prior studies (Daly, Christian, et al., 2012; Daly, Yilmaz, et al., 2012). In addition, the coders identified themes in heuristic card usage using an inductive coding approach to examine the data for patterns in heuristic application strategy. The coders worked separately with each transcript, and then resolved any conflicts.

3. Results

The purpose of a case study is to explore an event in detail; thus, the focus of our report is the in-depth explanation of how the team used the heuristics to generate ideas. In the sessions, the engineers worked on developing concepts for their product line, and appeared highly engaged in idea generation. The engineers talked to each other as ideas came to mind, focused on the heuristic cards one at a time, and their priority seemed to be to generate more novel concept solutions.

One hundred separate concepts were identified in the protocols within the two 2-h sessions. The team considered each heuristic for a period ranging between 1:48 and 19:29 min ($M = 8{:}01$), and created between 1 and 8 concepts per heuristic ($M = 3.7$). There was a significant positive correlation between time spent on a card and the number of concepts generated, $r = .65$ (Figure 3). The number of concepts generated from each heuristic and time spent in discussion is shown in Figures 3 and 4. The grayed out area in Figure 3 shows the 95% confidence interval around the regression line. Even though the regression was significant, the figure shows a large dispersion as many of the points are far from the confidence interval. This suggests that the team used some heuristics in a more effective way than the others, and that the number of concepts generated was independent of the amount of time spent on each heuristic.

Table 1. *Design Heuristics* cards and descriptions used in the study.

Design Heuristic	Summary description
1. Add gradations	Use series of gradual/transitional changes in the use of design elements
2. Add to existing product	Use an existing item as part of the product's function
3. Adjust function w/ movement	Allow the user to adjust the function through moving the product or its parts
4. Adjust function by demographic	Design the functions of the product around the characteristics of a population
5. Attach components	Identify different parts or systems with distinct functions and combine them
6. Attach product to user	Design the product around user so that the user becomes part of the function
7. Bend	Bending continuous material to assign different functions on the bent surfaces
8. Change direction of approach	Use different ways of approaching the product to create flexible solutions
9. Change contact material	Use a different material where the user will touch for safety or comfort
10. Cover/forms shell/wrap	Overspread the surface of the product or its parts with another component
11. Cover or remove joints	Remove joints in the design, cover with other materials, or change orientation
12. Create hierarchy of features	Present the user with functions in a set order to assist use of the product
13. Elevate/lower	Raise or lower the entire product or its parts
14. Expand/collapse	Design the product to get larger or smaller to adjust or change function
15. Extend surface	Widen or expand surfaces to enhance, adjust or add new functions
16. Flatten	Compress the product until it becomes a flat surface
17. Fold	Create relative motion between product parts by hinging, bending, or creasing
18. Hollow out	Remove parts for better fit to other products, functions, or the user's body
19. Incorporate user input	Identify functions that are adjustable and allow users to make changes
20. Make components detachable	Make individual parts attachable or detachable for additional flexibility
21. Merge energy source	Combine products that work separately but use the same energy source
22. Merge surfaces	Join the surfaces of two or more components with complimentary functions
23. Nest	Fit one object within another
24. Offer optional components	Provide additional components that can change or adjust function
25. Provide sensory feedback	Return perceptual information to user to aid in the use of the product
26. Reconfigure	Change the configuration of these components, or allow the user to adjust
27. Recycle to manufacturer	Compose products as part of a manufacturer system, with return after use
28. Reduce material	Remove material by eliminating unnecessary components or shaving elements
29. Use continuous material	Create connections between parts and apply one continuous material to attach
30. User customization	Involve the user in the design process by giving them customization options

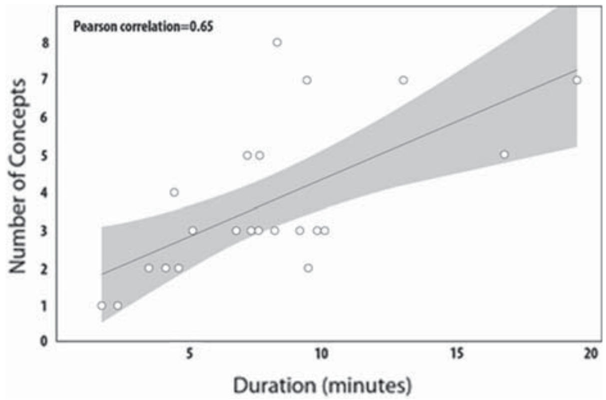

Figure 3. Relationship between time spent on each *Design Heuristic* and number of concepts generated.

In the second session, following the warning that they had 10 more minutes and four heuristic cards remaining, and they produced ideas more quickly. On average, they spent 4:38 min per card for the last 4 cards, compared to 8:58 average minutes throughout the first 24 cards.

3.1 An example of heuristic card use

To illustrate the engineering team's process with the *Design Heuristics*, we describe how the team responded to one heuristic, *Incorporate user input (session two, fourth heuristic)*. This heuristic card described the strategy as: *Identify product functions that are adjustable and allow users to make those changes through an interface. This can be achieved with buttons, sliders, levers, dials, touch screens, etc. Consider how these mechanisms can be integrated in a cohesive, intuitive way.*

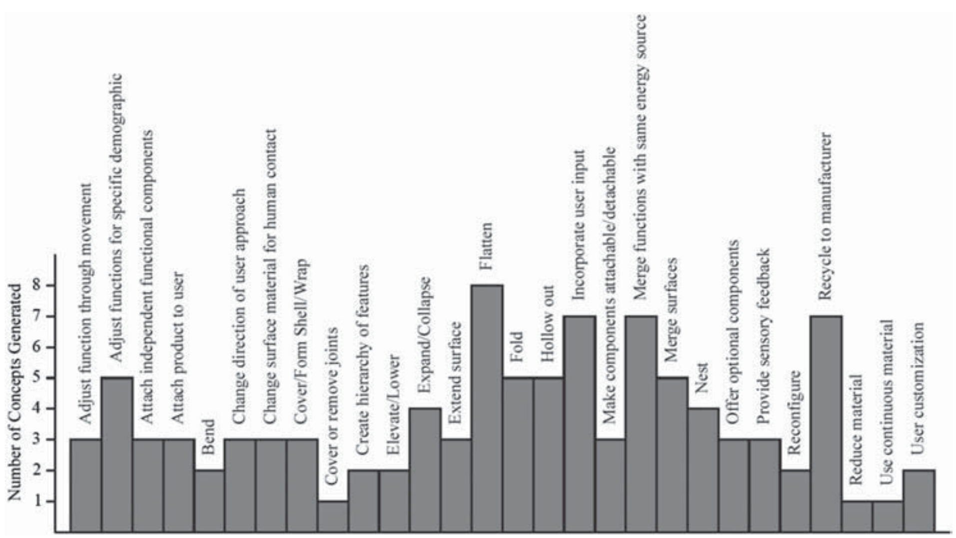

Figure 4. Number of concepts generated from each *Design Heuristic*.
Note: The 28 heuristics (preceded by two example heuristics) are shown in the order presented.

The team used this heuristic to consider adjustment and setting options they could provide to users, and how much resolution each setting should have. They talked about multiple ways to provide user feedback, and incorporate adjustability. Prior personal experiences with similar products and their challenges were also embedded in the conversation. There was some evidence of the effect of the heuristic language (that they had become familiar with on previous cards) on the engineers' vocabulary, as the team mentioned, "… adjust the height …" (*Adjust function through movement*) and "… give the user enough options …" (*Offer optional components*).

The first concept generated using *Incorporate user input* focused on a "tilt" device to disengage rear wheel drive when the user pushes down on a handle. The engineers discussed ways to maintain the current mechanism, and add a new rear-wheel drive system. The engineers acknowledged that this would make the product more intuitive since this mechanism was familiar to most users. Following this idea, they immediately assessed the feasibility and the details of the concept. One engineer said, "… and maybe the movement of the handle itself is spring loaded, and when you press down it … disengages the drive …" Another commented, "You need to design it in such a way that you could still use it on bumpy surface …"

The second concept was in response to the technical problems identified in the first. The engineers proposed to create a third set of wheels that would act as a turning pivot when the product was tilted back, lifting the driving wheels off the ground. Then, in the third concept, using the analogy of rolling a suitcase, the engineers discussed how an additional set of wheels could function as support for an enlarged collection bag. The fourth concept focused on how to empty this larger bag, and how the additional pair of wheels would support an extra-large bag. This conversation resulted in changing the direction of use by tilting the bag to the side to unload, instead of lifting it from behind. The guiding consideration was that people may not be strong enough to carry the extra weight of the larger bag. They compared this to competing products:

> … well, I think most of the ones we tested were beyond 15 or 18 pounds, because they had smaller capacity containers. So, I think ours is by far the heaviest but can hold the most, and it also fills pretty well …

The fifth concept extended the prior solution with a different mechanism – a zipper or flap on the opposite side of the bag. In the sixth concept, the engineers discussed hand guards on the handles to protect hands from external elements, referring to motorcycles' protection sheaths on handles.

The last concept, however, focused on a very different approach to the problems discussed – integrating controls that could be tailored for individuals. This final concept brought the design team back to the heuristic they were discussing. This heuristic asked the engineers to think about the user perspective. They seemed to realize there were challenges with the existing product shared by all users. This opened the field for anecdotal stories about their own struggles using the product. Throughout the discussion, the team considered the appropriate amount of user input; for example, one engineer said: "Do you give enough settings? Are there low, medium, high levels? Or may be you don't give the user enough options …"

3.2 The processes of Design Heuristic use

In this study, we sought to observe the processes employed by the team while using the heuristic cards. Building from previous analysis (Yilmaz, 2010), the observed patterns that emerged from the team's use of the *Design Heuristic* included the following.

Heuristics were directly applied to transform existing designs. *Attach product to user* is an example of a heuristic in which the design team saw direct applications, and it led to multiple and varied ideas. The team began with a battery pack as an energy source. Since the card image suggested attaching the product to the back of the user, the team evaluated the idea of a backpack battery source to power the product, and rejected it 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 examples provided on the back of the heuristic card, as well as the example of boat keys with attached wristbands, as analogies in this concept. The third concept, building on the prior idea, integrated sensors on the handlebars to control power. Another heuristic directly applied was *Adjust function through movement*, prompting 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. The team used existing designs as their starting point while applying most of the *Design Heuristics*. This may be because they had spent many years in working on the same product line, and their experience led them to start with their current designs. Designers experience 'fixation' or the tendency to become focused on specific options early in the design process, limiting the consideration of a variety of alternative designs (Purcell & Gero, 1996).

Product examples on the cards served as initiators of ideas. The engineers created analogies by using the product examples provided on the heuristic cards. For example, while exploring ways to implement *Merge surfaces*, they identified locations on their existing product for a cleaning tool attachment. A hand tool was one of the product examples on the card, and the engineers modified its function (maintenance tool to cleaning tool) and suggested adding it as an additional feature: "... like a cleanup tool ... and just have some sort an easy way to hold it like a hand tool and get in there and clean out the under the product ..."

Similar products were used as analogies. In many cases, the design team initiated the conversation for each heuristic by discussing a variety of products related to the heuristic. The team emphasized how other products used the heuristic as part of its features or mechanism. At times, they used these product examples as analogies and adapted them to their existing product line. For example, while discussing *Adjust function through movement*, the team suggested incorporating height adjustment pedals used in vacuum cleaners as an analogy to be applied to their own product. *Expand or collapse* also prompted the team to think of other products. They discussed how airbeds expanded and collapsed, and how they could use the same mechanism in their product line. Following this discussion, one of the engineers proposed a concept, saying "What you can do is hit a special button and it lowers the bottom part all the way to the ground, so it doesn't allow any air underneath, creates like a super vacuum ..."

Personal experiences were often raised in discussions. Engineers used personal experiences to relate to existing problems with the product, and to give additional insights about users. While exploring potential ways to apply the Nest heuristic, one engineer said, "I have so much stuff in there, it's like a nightmare and it's a problem for me ... compartments for storage and stuff both in hand and on top of the product ...," suggesting that the top part of the product could be used as a storage unit. In this example, he relied on his experience of storing items that are related to the function of the product. Another example was observed in the discussion of *Adjust function for specific demographic*. One engineer said,

> I can say my wife would never mess with this product. Never. I would say it once and she will never mess with it. She will say, 'It looks like it's going to hurt my fingers or something.' She'd never touch that.

This feedback led the team to consider how they could redesign the existing product in a way that it would appeal, rather than intimidating for women users.

The team struggled to apply some of the cards. For some heuristic cards, the team's immediate response was either that the heuristic did not apply or that they had used the heuristic in prior concepts. For example, *Merge functions using the same energy source* suggests combining products and aligning them around the source to create a single functional device. Engineers initially suggested that the heuristic did not apply because they were already limited to one type of energy source. This led to a discussion of the challenges and requirements that they must address given this limitation, which suggested new problem spaces to explore. Also, the team began the discussion of *Nest* by saying they had talked about this heuristic while working on previous heuristics. Similarly, with *User customization*, the team said,

> We talked about this yesterday too, about maybe building, like a, building some sort of base model with black wheels, and no hub caps and no cover or something like that and then having available at the store a list.

They also found similarities in *Adjust function for specific demographic*, and, *Offer optional components* as both heuristics related to the addition of a second component or function, as well as providing flexibility in deciding which component or function to use.

The team sometimes rephrased the heuristics. The team discussed the definition of each card after they read it in order to come to a common agreement about what the heuristic meant. The definition provided on the card for *Create hierarchy of features* was, "Present the user with functions in a set order to assist them while using the product. Make the steps for reaching each function clear, for example, by not allowing the user to access the second function without the first." One of the engineers rephrased this as "A sequence of events that need to happen, predefined sequence or otherwise the part won't do what you expected ... " Using their definition, the team then related it back to current mechanisms in their existing products. *Use continuous material* also prompted the engineers to consider a variation of the definition, reinterpreted as, "This is almost like Design for Manufacturing, if the parts don't move in relation to each other, why do they need to be different parts? Do they need to be different material?"

Heuristics led to better understanding of the design problems. Heuristics aided in problem exploration; for example, the discussion on *Fold* started with the acknowledgement of a need for compactness in the company's existing product line. With this new issue, the team immediately pointed out new problems with folding, such as cables bending when the components were folded. Heuristic use prompted another, different challenge, and then the team's focus shifted to developing concepts for this new challenge. The introduction of a new problem sometimes led the engineers to further evaluations, and eventually to solutions that no longer involved the current heuristic.

Heuristics were combined across concepts. In the initial stages in the workshop, the design team seemed to start with a more or less "clean slate." In the latter stages, the design team often referred to and built upon previously generated concepts. For example, the engineers created an extended lever to adjust the height of the product with the use of *Extend surface*. Later in the session, when they were prompted with *Hollow out*, they referred back to this extended height adjustment lever as the component to hollow out. More than one heuristic can be applied within a concept, as previous work has shown

(Yilmaz et al., 2012). The engineers' discussion sometimes carried over concepts from earlier discussions.

Evaluation took place during idea generation. The design team assessed feasibility by discussing how concepts could be manufactured, sold, and benefit both the company and the user. For these reasons, they discussed user needs, their potential preferences, manufacturing processes, manufacturing companies, how much the additional parts would cost, and how much profit they would bring to the company, and whether all these were reasonable assumptions. For example, after considering *Adjust function through movement*, the design team adjusted the functionality of separate parts within the product and assessed their feasibility, 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. While the team's discussion of each card to generate ideas can be considered a process similar to brainstorming (Osborn, 1957), they did not follow the brainstorming guideline. In particular, evaluation of ideas is explicitly prohibited during brainstorming, while numerous instances were evident in the team's discussions while concepts were considered.

The team built on each other's ideas. During the discussion of the heuristic, *Provide sensory feedback*, the engineers added onto each other's solutions. For example, one engineer said the product "... could just send continuous useful information like telling when the power goes out ...," and another added,

> You come up with the fact that maybe 20 h of usage on the average blade is what you want to do, it keeps track of how many hours you have on your blade, it could reset once you change the blade or sharpen the blade ...

This conversation continued with a third person contributing,

> If you have some kind of electrical system you can add more info in that little screen you can say, oh, you're now walking two meters an hour and you have do this job for an half an hour ...

Team discussion dynamic was highly interactive. The team appeared to rotate turns in presenting new concepts, discussing them as a group, and building off of each other's ideas. Typically, each team member commented at least once in the discussion of every card, and the discussions showed frequent pairwise interchanges of clarification or adding onto ideas. On some cards, a single discussion leader emerged who dominated the discussion interchanges, but most typically, the conversations rotated among members so that no one speaker predominated. The number of interchanges of speaker per card discussion ranged from 8 (on the 28th card when they were warned that time was running out) to 126 on card 4, with an average of 43.5. Each card discussion, even when shorter, showed a lively interchange among group members. While two members spoke up less frequently than others, they also contributed to the discussion actively, pitching in phrases or comments to add to prior ideas.

Our results indicate that using *Design Heuristics* helped the engineers to become aware of alternative design choices. The presentation of each heuristic served as a "jumping off" place in their discussion, leading to the consideration of new concepts. Yet the heuristic cards also served as points of organization for the team's discussion, and the team would stick with one card for as long as 10 min before moving on. When the team switched to a new heuristic card, they often came back to the prior heuristics that worked in previous concepts. Each of the heuristics was used to generate at least one novel concept, and most produced several. Given that these engineers were working with a familiar product line they had already spent many hours reviewing, the utility of *Design Heuristics* in the study is informative. Potentially, this may mean *Design Heuristics* were helpful in considering new approaches even for very experienced engineers.

4. Discussion

Our analysis of a design team's use of *Design Heuristics* provides evidence that this idea generation tool was useful for professional engineers who had worked on their design problems for extended periods in the past; in a total of 4 h, they were able to use this tool to generate novel concepts for their product line. The engineers reported that they felt the cards stimulated original thinking even though they had been considering these designs for many years. 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 group process evident in the recordings showed that the team appeared to rotate in presenting new concepts, discussing them as a group, and building off of each other's ideas. This was found to be a critical component in the success of innovative design teams (Hargadon & Sutton, 1997).The team's process was also markedly different from the "freely generated ideas" in the brainstorming approach (Osborn, 1957). Instead, the design team's process was to use each *Design Heuristic* as a focal point for their discussions, leading to related ideas and constraining the team's discussion to consider one type of innovation at a time. This process suggests that *Design Heuristics* bring order in ideas and elaboration on ideas, perhaps through coordinating effort on idea evaluation, increasing capacity to improve the ideas of others, and facilitating interaction between participants. The *Design Heuristic* approach may provide a structured organization for the course of idea generation in the group process.

This study is a case study of field practice in engineering design. Qualitative case studies with small sample sizes (such as ours) do not claim generalizability. Instead, the details provide grounding for transferability to other contexts (Creswell, 2003). One limitation of the study was that we were not able to objectively assess design quality. However, in the post-workshop survey, the engineers themselves credited the *Design Heuristic* cards as leading directly to product innovations. Most of the team's conversation reflected ideas that were genuinely new to the team. In addition, only one consumer product line served as the design problem in this study. It is also possible that the instructions for the task may have encouraged the engineers to emphasize the exploration of diverse ideas in ways not typical for this group. If so, such an effect may be desirable as part of *Design Heuristics* intervention. We would expect the designers to take a different view on the design process as a consequence of using this tool. To further validate the impact of the *Design Heuristics*, our future work should ideally include multiple methods to compare their impact to other idea generation techniques. However, the evidence from this case study shows that the team found the *Design Heuristics* to be helpful in idea generation for products with which they had a long history.This suggests the *Design Heuristics* tools were helpful to these experienced professionals in this case study, and may be in others as well.

Previous studies have shown the effectiveness of *Design Heuristics* in undergraduate design and engineering (Daly, Christian, et al., 2012; Yilmaz et al., 2012). This study provides evidence that professional engineers can also use *Design Heuristics* for idea generation. Workshops like the one in this study can provide instruction and practice using the heuristics within the span of a single session. Further studies are needed to determine the impact of *Design Heuristics* on ideation processes for professionals in controlled experimental settings, as well as to examine longer-term impact from the training.

Overall, our findings from this exploratory case study of a working engineering team suggest that the introduction of *Design Heuristics* maybe sufficient to stimulate novel and diverse concepts during idea generation. *Design Heuristics* are readily grasped by novices, yet specific enough to guide professional engineers in applying them within a problem context. The Design Heuristic approach was shown to facilitate idea generation in a professional engineering design team working on commercial products, thus indicating their potential to facilitate success in real-world contexts in ways previously demonstrated in laboratory and classroom research. *Design Heuristics* may improve the idea generation process even for expert practitioners on the job.

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