IDEA GENERATION IN COLLABORATIVE SETTINGS

Seda YILMAZ[1], James L CHRISTIAN[2], Shanna R DALY[2], Colleen M SEIFERT[2] and Richard GONZALEZ[2]
[1]Iowa State University
[2]University of Michigan

ABSTRACT
Creative strategies play a central role in design ideation; yet, few studies have empirically tested the success of ideation strategies in engineering design. In previous work, we extracted and further developed design strategies, called "design heuristics," to support exploration of the space of potential designs. Once integrated into an engineer's ideation process, they serve as cognitive "shortcuts" for generating multiple, diverse, and creative ideas. In this study, professional engineers from a manufacturing company applied the design heuristics to their current work as part of a small group innovation workshop. Using design heuristics not only allowed the team to generate new solutions to their existing problems, but also to discover and define new design opportunities. Additionally, the group spent a much longer time developing multiple designs for each heuristic than individuals have in past studies [1]. Our results suggest that the combination of heuristics and group interplay may enhance diverse idea generation.

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

1 INTRODUCTION

With the current emphasis on innovation in engineering practice and education, a need clearly exists to identify best practices in innovation. As innovation relies on success in idea generation, and as many challenges in the world rely on multidisciplinary solutions, group ideation is an important area of research. Group can pool multiple individual approaches to enhance design ideation [1-2]. Surprisingly, little is known about how groups generate innovative solutions [3]. While the outcomes of product design seem to have consensual, even testable, standards for evaluation [4-5], the processes for achieving these outcomes have been more difficult to identify.

Group ideation research has focused primarily on group brainstorming [6], 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. In another approach, *Brainwriting* [7], ideas are written and shared rather than spoken. As compared to brainstorming, brainwriting offers reduction in evaluation apprehension, since ideas can be pooled anonymously, while still maintaining the advantages of exposure to other's ideas on the problem, the opportunity to view alternative perspectives, and the ability to build upon the ideas of others [8]. A third approach, the *Nominal Group Technique* [9], adds an initial session of individual idea generation to brainstorming or brainwriting, followed by a group ranking of all ideas. Nominal groups have been found to outperform brainstorming groups, perhaps because the individual ideation stage is uninterrupted [9].

The success of these approaches relies on the free flow of ideas within non-evaluative environment. However, they do not provide specific ways for design teams to generate ideas. In addition, there is limited evidence about the utility of group ideation techniques in engineering design problems, and virtually no studies of design teams in professional industry settings. In this study, we observed expert engineering designers at a major manufacturing company with a successful ongoing product line to examine the ideation process.

2 DESIGN HEURISTICS

Design heuristics are cognitive strategies that facilitate exploration of a design "space" consisting of all feasible designs (based on Newell and Simon's [10] definition of the "problem space"). Some potential designs are easy to generate, while others are less obvious and more challenging to find. Each design heuristic provides a prompt for the designer to take a known solution and transform it to a new solution. We propose that the key to finding diverse and creative solutions is to apply different design heuristics and combinations of heuristics [11].

Heuristic-based approaches define simple, efficient rules to generate judgments or decisions [12], Behavioral research shows that experts effectively use heuristics, and their efficient use of domain-specific heuristics distinguishes them from novices [13]. An important feature of all heuristics is that they do not lead to a determinate solution; rather, they lead to "best guesses."

Several heuristic approaches to design exist, including SCAMPER [14], Synectics [15], and TRIZ [16]. 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. The Synectics framework, which includes 22 strategies, also proposes fairly general heuristics, for example: parody, prevaricate, metamorphose, and mythologize. In contrast, TRIZ provides more specific prompts, with their use guided by a "contradiction matrix" of 39 common engineering problems and 40 possible solutions, called principles. The most useful heuristics for creating new design concepts may lie at an intermediate level of specificity among these approaches, more general and earlier in the design process than TRIZ, but more specific than the broad suggestions posed in SCAMPER and Synectics.

In previous work, a candidate set of 77 Design Heuristics was developed through the analysis of design protocols, award-winning products, and a case study of an industrial designer' work [11, 17-20]. While the development of Design Heuristics has been studied empirically in individual industrial designers and engineers, this same approach may facilitate innovation in design teams. In this study, we investigated how the Design Heuristics ideation tool impacted the design approaches and outcomes of the team.

3 EXPERIMENTAL APPROACH

This study explored the use of Design Heuristics by an existing design team within a workshop setting. We sought to answer the following research questions:

1. How does the group apply Design Heuristics? What is their approach to using them?
2. How do the various components of the Design Heuristics cards provided, (description, abstract image, product examples) impact the design teams' ideas?
3. In what ways do the concepts generated reflect the use of Design Heuristics?

3.1 Participants

A design team at a major international product corporation participated in the study. The team was comprised of seven participants with varying levels of expertise (shown in Table 1).

Table 1. Participants Information

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

3.2 Method

The design engineers were currently working on a new outdoor product line for the consumer market, and made use of the session as part of their design process. They were video recorded as they generated concepts in two, two-hour long work sessions over two days. During the sessions, the seven designers were seated as a small group. The workshop leader provided some background on the provided Design Heuristic cards. The team and moderator discussed the first two cards as an introduction. Then, the design team was asked to work as a group, reading each card aloud, and exploring ways to apply each heuristic to their current design work. The 30 Design Heuristics in the study (selected at random from the larger set) are shown in Table 2.

Table 2: Set of 30 Heuristics Provided in Study

Add gradations	Add to existing product	Adjust through movement
Adjust for demographic	Attach / detach components	Attach independent components
Attach product to user	Bend	Change approach direction

Change contact surface	Cover / Form shell / Wrap	Cover or remove joints
Create hierarchy of features	Elevate / Lower	Expand / Collapse
Extend surface	Flatten	Fold
Hollow out	Incorporate user input	Merge if same energy source
Merge surfaces	Nest	Offer optional components
Provide sensory feedback	Reconfigure	Recycle to manufacturer
Reduce material	Use continuous material	User customization

Each heuristic was presented on a two-sided 5 x 7 inch card. The heuristic's title and number were presented on both sides of the card. For each heuristic, an abstract illustration, a description, and a list of “criteria” linking it to design goals was provided on the front of the card. Several potential design criteria (of 13 total) for each heuristic were based on three levels of consumer needs: functionality, usability, and pleasure [21] and results from an earlier study of award-winning products [19] (see Figure 1). The back of each card included two product examples related to the heuristic. One of these examples (on left) showed the use of the heuristic within an existing product design. The example on the right illustrated the application of each heuristic to the design of a seating unit.

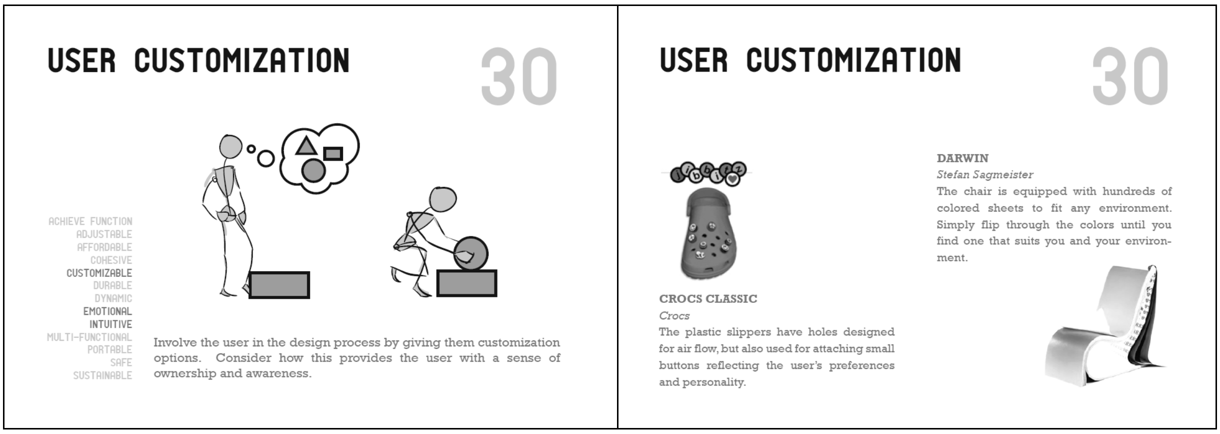

Figure 1. Design Heuristic Card Example

During the first study session, after introducing two cards, the designers worked through the next 13 cards in one two-hour session. On the following day, the group was given the second set of fifteen cards, and again worked at their own pace while discussing design ideas aloud. At the end of the 26th card, the moderator told the participants that they had ten minutes remaining before the end of the innovation workshops. They then discussed and applied the remaining cards at an accelerated pace.
Verbal data from the video session was transcribed, and analyzed for evidence of heuristic use. Two coders examined the transcriptions. The goal of the analysis was to characterize the patterns evident in participants' performance during the sessions. The analysis included identifying each concept generated, categorizing characteristics of the concepts generated, comparing concepts to characteristics of the cards, and determining evidence of heuristics in generated concepts. The coders worked separately with each transcript, and then met to resolve any conflicts.

4 RESULTS

The study's sample size is small; thus, care must be taken in generalizing from the observations. However, qualitative results may be transferable to similar situations.

4.1 Two Examples Cases of the Team's Heuristic Card Use

1. Example illustrating productive use of a heuristic:

Heuristic Card: "Incorporate user input: *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, screens, etc. Consider how these mechanisms can be integrated in a cohesive, intuitive way."*

Description: The team used this heuristic to consider product adjustability and setting resolution. The card prompted discussion on solutions reliant on natural or learned human behavior. They considered multiple ways to provide user feedback, which would inform the user to make adjustments. Prior personal experiences with similar products and their challenges were also discussed.

Process: The first concept generated focused on a "tilt" device to disengage the rear wheel drive when the user pushes down on the handle to turn the product. The engineers wanted to maintain an old

mechanism, yet incorporate a new rear wheel drive system through a mechanism familiar to most users. The second concept was in response to a technical problem: The engineers proposed adding a third set of wheels to act as a turning pivot when the product is tilted back, lifting the driving real wheels off the ground. In a third concept, using the analogy of a rolling suitcase, the engineers discussed how an additional set of wheels could function as support for an enlarged version of the collection bag on the product. The fourth concept focused on how to empty this larger 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 fifth concept extended the prior solution with a different mechanism: A zipper or flap on the opposite side of the bag. In a sixth concept, the engineers discussed hand guards on the handles to protect from external elements, by analogy to motorcycles' protective sheaths on handles. The last concept did not continue along the same lines. For this, the team suggested integrating controls that are tailored for individuals, a final concept directly related to the card prompt.
Summary: This heuristic prompted idea generation related to user perspective. The team considered user challenges with the existing product. This opened the field for anecdotal stories about their own struggles using the product. This card prompted the designers to reconsider options for user input.
2. Example illustrating less productive use of a heuristic.
Heuristic Card: "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: Prompted by the card, the design team discussed competitive brands, and their use of "bending" as a way to improve aesthetics. They evaluated components of existing products 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 improving aerodynamics, and how bending the components underneath the product would enhance the function of internal moving parts. The second concept was a bent handle that would create space for a variety of attachments. The goal here was to add more functions to this bent handle by attaching different components.
Summary: Efficiency and multi-functionality were the main 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.

4.2 Number of Concepts Generated

During the ideation sessions, the design team generated 100 concepts. They spent between 1:48 (*Reduce material*) and 19:29 (*Incorporate user input*) minutes on each heuristic (*M*=8:11), creating between 1 and 8 concepts per heuristic (*N*=3.6). Idea counts for each card are shown in Figure 2.

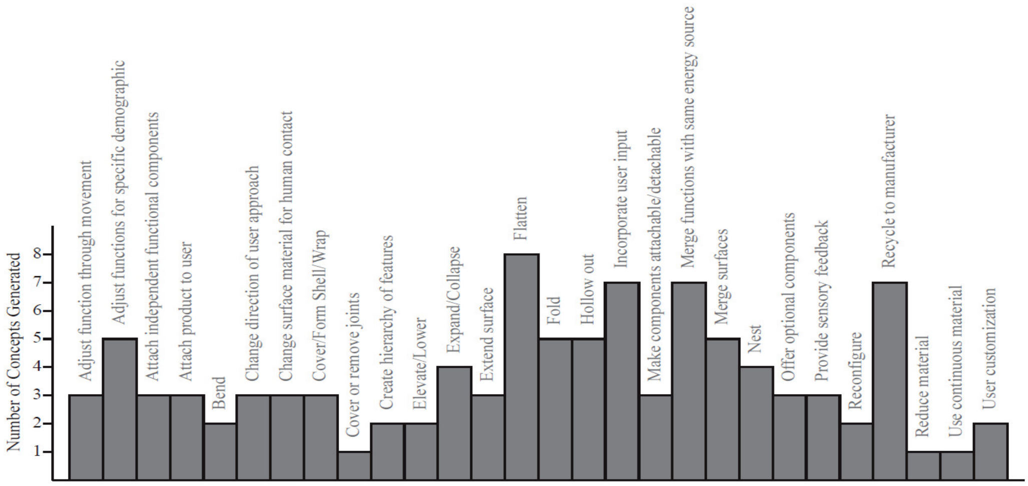

Figure 2. Concepts Generated per Heuristic Card

The most generative heuristics appeared to involve design features the design team may not have previously considered. For example, "Recycle to manufacturer," and "Flatten" may have led to more ideas because those design aspects had not previously received much attention. In contrast, heuristics with the fewest new concepts focused on engineering design issues ("cover joints," "reduce material," and "use continuous material"), which may have already been considered in the existing designs.

Another possible reason for the varying number of concepts resulting from each of the cards is the sequence of their application. The designers may have interpreted latter heuristics as similar to earlier heuristics. For example, the card before *Cover or remove joints* was *Cover/form shell/wrap*, and their similarities may have constrained the team from generating new ideas. Further investigations of heuristic sequences will be necessary to draw more definite conclusions.

Most notably, each of the heuristics was used to generate at least one novel concept, and most worked to produce several. Thus, the generative power of Design Heuristics as a guide in ideation is evident in these results. 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. This indicates that Design Heuristics were helpful in considering new approaches even for experienced designers.

4.3 Absence of Target Heuristic Use

Of the 100 concepts generated by the team, 30 of them did not show evidence of the application of the prompted heuristic. This may be attributed to the following reasons:

Following Listed Design Criteria instead of the Heuristic: In 12 concepts, the team seemed to be driven by a criterion. The team may have started by applying the heuristic, but were then focused on a listed design criterion rather than the heuristic prompt.

Problem Elaboration: Six concepts were the results of improving an understanding of product problems that emerged by considering the heuristic card. This approach helped them to understand the design problems more deeply, but did not involve applying the heuristic.

Heuristic Reversal: At times, the team applied the heuristic in the opposite way as suggested on the card (such as reversing what the card suggested, as in contracting rather than expanding).

Similar Interpretation: At times, some of the heuristics were interpreted similarly to others. For example, *Incorporate user input* was interpreted as "adjustable" product functions, similar to the heuristic, *Adjust function for specific demographic*.

Misinterpretation: Eight concepts appeared to be the result of misunderstanding the heuristic cards, leading to multiple concepts unrelated to the heuristic provided. For example, with *Create hierarchy of features,* the engineers did not understand that the hierarchy of features was intended to support user intuition. Instead, they interpreted it as finding ways the user would not misuse the product.

The 30 concepts that did not show evidence of the provided heuristic occurred under the prompts of 9 different heuristic cards. It is important to acknowledge that, with the exception of those that came from misinterpretation, most concepts were prompted at least indirectly by the provided heuristic through a previous concept that came from the card, or by criteria implied by the heuristic.

5 CONCLUSIONS

Our results indicated that using design heuristics helped designers generate new ideas as well as become more aware of design issues. In the designers' self-assessment of the session, they credited the heuristic cards as leading directly to the product innovations they generated. The generated 100 concepts and seventy of them were clearly tied to the use of the cards. The heuristic cards served as a point of organization, and led to new and diverse concepts. In contrast, IGTs like brainstorming do not provide this organization and rely on the "random" contribution of ideas. The design heuristic approach may be an alternative approach or used in combination with brainstorming.

Regarding the card content, the engineers stated the product examples supported idea generation by illustrating the application of heuristics in real products. They suggested the cards could be improved by providing even more product examples. Less frequently, the designers felt inspired by the abstract images. The criteria defined on the front of the cards were also integrated within the team's conversations. They did not use every criterion, but often discussed those printed on the cards.

The study provides evidence for the success of heuristics in generating novel solutions and overcoming design fixation. The designers reported that they felt the cards stimulated novel thinking even though they had been considering these product designs for many years. After the study, the design team stated they felt the heuristic cards were effective, forced them to stay on track, and helped to focus their attention on one topic at a time. 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. These findings are consistent with earlier results that design heuristics are context-independent, and can be applied to a variety of design problems [17].

Limitations of the study include the small number of designers involved, and the analysis of the sessions from a single team. A larger study would provide a more generalizable account of the group process. In addition, only one type of consumer product served as the design problem. While the design heuristics used here were developed through the analysis of diverse products within this company's product line, further studies are required to demonstrate their practical utility in product design firms. Overall, the findings suggest that introduction of design heuristics can stimulate divergent thinking. The design heuristic approach was shown to facilitate the ideation process in a professional engineering design team working on actual products for their firm. These findings suggest some real-world validity to the Design Heuristic approach.

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