THE PSYCHOLOGY OF DESIGN

Creating Consumer Appeal

Edited by Rajeev Batra, Colleen Seifert, and Diann Brei

Routledge
Taylor & Francis Group
NEW YORK AND LONDON

24

DESIGN HEURISTICS

A Tool for Innovation in Product Design

Colleen Seifert, Richard Gonzalez, and Shanna R. Daly

UNIVERSITY OF MICHIGAN, ANN ARBOR

Seda Yilmaz

IOWA STATE UNIVERSITY

Examples of bad product design are common (Norman, 1993). It is interesting, though, that poor design is not immediately salient to most designers and consumers. Products with less than adequate functionality remain on the market, and are sometimes successful despite their flaws in design. Product designers have a tremendous influence on how easily, and how well, individuals' goals are met each day. Norman (1993) has characterized good design as "user-centered," where the human interacting with a designed artifact finds it useful and easy to use, and readily adopts it in favor of existing alternatives (cf. Krishnan & Ulrich, 2001). But while good product design seems to have consensual, even testable, standards for evaluation (Obradovich & Woods, 1996), little is known about the cognitive processes leading to innovation in design, nor the group processes that identify successful design groups (Wilpert, 2005; Heerkens, 2006).

Most research efforts to understand design focus on the evaluation of identified designs through focus groups, prototypes, user testing, and design critique sessions. These studies operate in a context where a candidate design is complete (Otto & Wood, 2001). However, to create an innovative design, the process begins when the designer first considers possible ideas, or concepts, for a new or redesigned product. How do designers generate novel concepts for a product and consider a varied set of potential designs in order to select an innovative design? We suggest that the process of idea generation can be enhanced to help designers uncover a variety of perspectives on the design problem (Kruger & Cross, 2006). By building variations into the design process, the potential designs considered will be more likely to reflect new and useful concepts to address consumer needs. However, to impact the design process, we need to develop a method for intervention during the process of generating novel designs. How can we develop a process to stimulate innovation? The early stages of design often take place under conditions when the designer may not have clear view of consumer goals, functions the product might serve, and forms that may better suit the problem. Further, many studies show that designers may become "fixated" on a particular design or direction, and as a result, have increased difficulty in generating alternatives (Jansson & Smith, 1991; Purcell & Gero, 1996). Fixation may limit the diversity, and therefore the quality of ideas in the resulting set of ideas generated.

Our goal in this research is to apply the models and methods from the fields of cognitive and decision science towards understanding the designer's process in creating innovative designs. Can we help designers create more, and more varied designs to consider, resulting in final designs that are more innovative?

Cognitive Heuristics

Traditional problem solving theory begins with generating a search space of all possible features of the problem considered in all possible combinations, and then this space is searched for a solution (Newell & Simon, 1972). If done systematically, this approach guarantees that the designer will find a successful solution, though the search may take a long time. However, this basic characterization of an (artificially) intelligent search diverges from the observations of human reasoners at every level of expertise (Newell & Simon, 1972; Simon, 1981). Most human problem solvers engage instead in a "heuristic" search (Klein, 1993; Kleinmuntz, 1985). Simon (1990) argued that heuristics are "methods for arriving at satisfactory solutions with modest amounts of computation," suggesting heuristics are useful in reducing the effort associated with a task (p. 11). Heuristics have been identified as cognitive "rules of thumb" that reduce the effort required by a task (Shah & Oppenheimer, 2008) in specific ways, such as examining fewer cues or alternatives. The use of heuristics in problem solving and decision-making has been established through an extensive body of research in cognitive science (Gigerenzer & Todd, 1999; Klein, 1998; Newell & Simon, 1972). These studies have identified the characteristic pattern of reasoning where people "jump" into the problem space using heuristics, and may or may not be successful in solving the problem (Kotovsky & Simon, 1990).

As used to describe thinking, heuristics often play the role of reducing the amount of information considered (Tversky & Kahneman, 1973, 1974). Studies in consumer behavior and marketing also demonstrated the narrowing of choices facilitated by heuristic use (Chang, 2004; Darke, Freedman, & Chaiken, 1995), and been found to be important in designing product warning labels (Zuckerman & Chaiken, 1998) and in determining consumers' frequent purchases (Hauser, 2011). However, in some cases, heuristics are not limits to information considered, but instead, perform as guidelines for focusing on key features in complex problems. For example, in fire fighting, the context of the physical setting and a variety of

factors in the blaze bring to mind heuristics for approaching the blaze (Klein, 1998). Research suggests that heuristics can lead to optimal solutions when they focus attention on key variables (e.g., Dijksterhuis, Bos, Nordgren, & van Barren, 2006; Gigerenzer & Todd, 1999). Cognitive heuristics in some complex domains serve as well-known paths frequently travelled, and known to lead to useful solutions. Heuristic use by experts is one feature that distinguishes them from novices (e.g., Klein, 1998), and evidence of their use appears in many creative endeavors, such as mathematicians working on research problems (Sriraman, 2004), successful negotiations (Huber & Neale, 1986), managerial decision making (Schwenk, 1988), project scheduling (Bock & Patterson, 1990), creating instructional games for learning (Malone, 1980) and software design (Guindon & Curis, 1988).

The problem space for the process of design has been termed the "design space" (Goel & Pirolli, 1989). One approach to organize the tools for searching the design space makes use of the extensive body of designs already created by expert designers. *TRIZ* captures specific design elements from an analysis of successful patent applications (Altshuller, 1984, 1997). Case-based reasoning (CBR; Schank, 1982; Kolodner, 1993) provides designers with previous designs that may help with new situations (Maher & Gomez de Silva Garza, 1997; see also Ball, Olmerod, & Morley, 2004). These tools make use of the same process seen informally in experts; namely, the use of previously used patterns in creating new ones (see Cross & Cross, 1998, for a case study in engineering design). Similarly, analogical thinking (e.g., Ball, Olmerod, & Morley, 2004; Visser, 1996) is sometimes used by experts to apply existing designs to generate similar solutions to new problems. Analogical reasoning focuses on specific past designs, and the designer applies these past designs to new problems (Dahl & Moreau, 2002; Markman, Wood, Linsey, Murphy, & Laux, 2009).

However, rather than considering a specific past design, it may be possible that expert knowledge is encoded at a higher, more abstract level than the specific case (cf. Bailey, 2006; Eberle, 1995; Gordon, 1961). Based on an experience, a strategy or guideline may be abstracted from the specific case, and recalled at later times to lead to a new solution. This seems more likely to happen in settings where task demands require shortcuts. Ash and Smith-Daniels (1999) argue that because product development is a time-based competition, designers would benefit from heuristic methods that lead to fast project completion. Studies of heuristics in the field of marketing have uncovered common principles that guide decisions, referred to as "market orientation" by Kohli and Jaworski (1990). Narver and Slater (1990) have suggested a series of heuristics that, when followed, will result in a firm being "market-oriented." By analyzing protocols from practicing marketers (Merlo, Lukas, & Whitwell, 2008), a consensus emerged that a firm must adopt and implement an orientation towards its customers and competitors, and respond to the intelligence received from these market factors in a coordinated manner (see Narver & Slater, 1990). While these heuristics for marketing may appear too general to be useful (Merlo, Lukas, & Whitwell, 2008), more specific heuristics such as a "competitor-oriented strategy" were also identified.

Building on this research in cognitive and decision science, we set out to identify the cognitive heuristics used by expert designers to generate innovative product designs. We focused on use of heuristics (or general guidelines already known) used by designers to create novel product designs. Our approach was to learn from expert designers by following their steps through the generation of designs and identifying specific strategies they use in creating variations in design. An experienced designer has likely considered a variety of products, and has examined objects from multiple sources and perspectives. Their experiences with design have taught them the cognitive "shortcuts" (Merlo et al., 2008) that are likely to be useful to consider when designing new product ideas. This is a *generative* use of heuristics, where multiple ideas are formulated for later consideration, rather than a "fast and frugal" jump to a single option (Gigerenzer & Todd, 1999). By studying the designs of experts, we hoped to uncover the cognitive heuristics they use to generate innovative ideas for products.

Evidence for Design Heuristics

In most design problems, the space of all possible designs is never defined. Rather, the goal is to create *new* features not previously applied to the given design problem, and not already identified as relevant. For example, creating a problem space for a design of a wedding cake could be accomplished by varying the

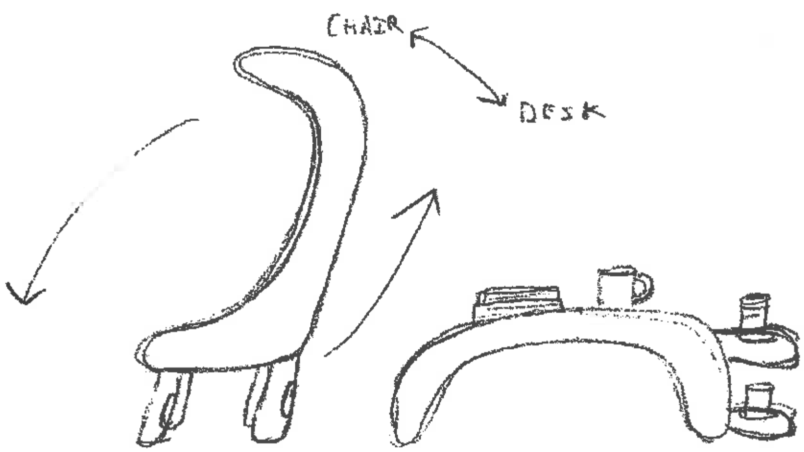


FIGURE 24.1 A design involving reorienting the form (a chair) for a new function (a coffee table). The idea of adding reorientation by the user to serve two purposes results in a novel form.

Source: Seda Yilmaz.

known attributes (tiers, color, height, toppings, flavors, etc.) to create an unusual combination. However, creating a novel design may require adding an element that was never before considered; for example, varying the shape of the tiers. Changing the design from round to square tiers may be an innovative option, but it cannot be discovered through simple combinations of existing alternatives. Innovation in design may require the *creation* of new features.

How would a designer use a heuristic to generate a new feature for a design? One heuristic involves transforming an object's orientation across an axis, either top to bottom or left to right, so that it can support a second, alternative use (see Figure 24.1). Once a dual purpose form has been identified, it necessarily differs from any canonical form. An object or its elements can be reoriented by the user in a new way, producing a novel design. The "Allow User to Reorient" heuristic is one specific strategy to create novel forms, and it is possible to apply it in many design problems to produce new concepts to consider. In this way, "Allow User to Reorient" appears to be a *design heuristic*: It's a rule of thumb that can be applied to introduce intentional variation into a design. It does not always lead to a viable alternative, but choosing to apply this heuristic generates a "guess" at a design that differs from existing ones. The design heuristic serves as a "short-cut" to a novel design that can then be considered for its value.

The heuristics employed by expert designers appear to have a quality of "suggestion," of introducing variation with intention and then considering the resulting concept. We posit that expertise in creative design arises from the accumulation of heuristics built through experience. An expert, then, may bring to bear their own personal toolbox of acquired "design heuristics," starting points for introducing novelty into designs. Heuristics offer a means of generating possible designs by guiding designers to apply specific, interesting variations to their designs. To explore how design heuristics may appear in the work of product designers, we conducted several studies of design involving a wide variety of products.

Longitudinal Study of an Expert Designer

A first source of evidence for use of heuristics emerged by studying a single expert industrial designer (Yilmaz & Seifert, 2011). Designers sometimes use "scrolls," a rolled paper record, to lay out their thinking during product design, working further down the scroll in each work session. As a result, the position of concepts, sketches, and labels on the scroll reflects the general sequencing of work, and suggests the types of designs and transformations that have considered during an extended design process. The scrolls provide a record of the designer's thought process and how ideas evolved in much the same way that a lab notebook provides a record of a scientist's work. For this study, a highly experienced designer with over 30 years of active work in the field was actively engaged on a single project over a two-year time period. The goal was to design a universal access bathroom that could fit within existing home spaces. For our study, the designer provided all of his scrolls for the project, and was interviewed retrospectively by prompting his thoughts as each design was reviewed. The scrolls included over 200 different concepts recorded sequentially on the scrolls. For example, at one point on the record, the designer drew three fixtures (shower, sink, and toilet) that all used the same form (a large rectangular block with a semicircle hanging below). As the designer stated, "So, that same shape represents the toilet to sit on, the sink to stand at, and a shower to stand under, and it just reminds me that there are three levels of function just like it said." The presence of this "repeated forms" concept on the scroll is evidence of a different type of design heuristic: "For multiple objects, consider a design that *repeats the same form*."

The scrolls made it possible to follow the designer's thinking through each conceptual approach to a solution. Some concepts in succession appeared to be unrelated, such as a concept for the layout of fixtures in the space followed by a design for the control of water through a spigot. However, other sequences showed a relationship between concepts, such as a bowl drawn to capture waste water at the sink, followed by the same bowl form used for the toilet and shower. When a relationship was detected, we attempted to capture it in abstract form. Each potential heuristic described a specific change within a concept that added variation to produce a new concept. The occurrence of each heuristic was noted for every concept. The scoring of the heuristics was confirmed by a second coder who examined a quarter of the concepts with 91% agreement between coders. Each heuristic was described so as to be (1) readily observable as a new element within a given concept, and (2) applicable to other different design concepts.

The presumed goal of the designer is to generate as many varied concepts as possible in order to maximize the variety and novelty of candidate concepts for selection and refinement. The complete analysis of 218 different concepts sketched on the scrolls resulted in identification of over fifty different design heuristics. Because the heuristics can be applied repeatedly to a similar concept, and because multiple heuristics can be simultaneously applied to create a new concept, over 1,200 separate instances were noted. Each concept was identified as involving between 2 and 15 different design heuristics. The designs in this expert's work were rich with abstract connections across concepts, and allowed the observation of design heuristics in highly detailed, labeled concept drawings. Each design heuristic requires specific features within the problem in order to be applicable, and produces a changed concept altered in a specific fashion. As a result, the choice of which heuristic to use highly depends upon the immediate problem context. As implied by the use of "heuristic," there is no determinate heuristic that will lead to a definitive solution.

Interestingly, while the expert concurred with the analysis of the work, he did not identify specific heuristics in his work. He appeared to use the heuristics without conscious consideration, and implicitly invoked them as he worked. This observation fits Kavakli and Gero's (2002) protocol analysis findings, suggesting

that experienced designers use strategic knowledge, but do not identify or communicate their existing strategic knowledge.

Comparative Study of Innovative Products

A second source of evidence for design heuristics is a study examining a wide variety of award-winning consumer products (Yilmaz, Daly, Christian, Seifert, & Gonzalez, 2012). Examining the specifications and sketches for winners in design competitions, and comparing their designs to existing competitive products, allowed us to identify places where heuristics may be useful (see Purcell & Gero, 1998, on ways to infer process from drawings). We found designs identified through existing, independent award competitions (the International Design Excellence Awards (2009),[1] Red-Dot Product Design Awards (2009),[2] iF Product Design Awards (2008),[3] Good Design Awards (2008–2009),[4] and the National Design Awards (2009)[5]) and published in compendiums of innovative products (Haller & Cullen, 2006; Hudson, 2008; IDSA, 2003; Lidwell & Mansacsa, 2009; Proctor, 2009). The information available about each product included the product descriptions, design criteria, constraints, scenarios, and sometimes critiques provided by professional designers. A detailed investigation was performed on approximately 400 products. We performed a content analysis of the major elements and key features of the products' functionality, form, user-interaction, and physical state. The descriptions of each heuristic were extracted by comparing these innovative designs to existing consumer product designs.

Across 400 diverse products, we identified 40 different heuristics appearing in at least four different products. In some of the products, multiple heuristics were observed, so that over 650 separate instances of design heuristic application were noted. For example, one award-winning product allowed a high-chair for feeding a baby to swivel on an axis to provide a lower "toddler chair" that fits at a standard table height. Comparing this product to existing highchairs, this product adds an entirely new function to the product to increase its value. The dual functions are accomplished by "flipping" the chair on a pivot point. In addition to "flipping," another heuristic identified in this product is, "provide multiple functions within a product," along with "adjust functions based on demographics of users."

Another heuristic identified was, "Use packaging as a functional component within the product." The packaging for the product performs a different function: Create a shell or cover for a component or the entire product that is uncovered when used. When opened, the package provides supporting structure, and functions as a necessary component rather than a separate, unneeded wrapping to be discarded (see Figure 24.2).

A third heuristic example from the award-winning products is, "Flattening design elements when they are not in use using elements nested inside each

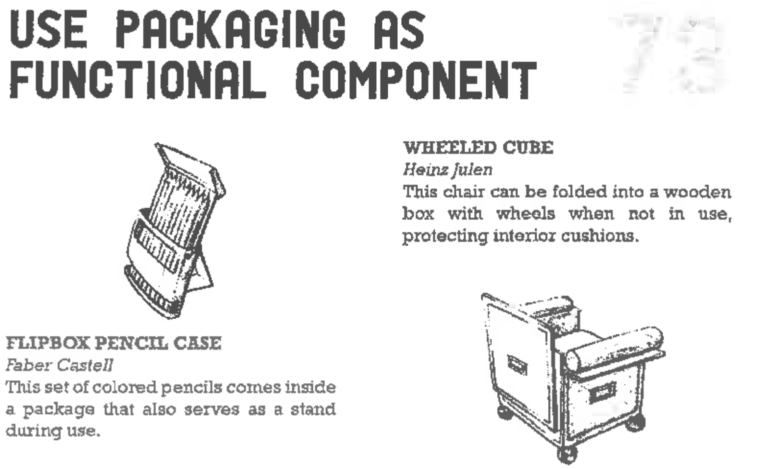


FIGURE 24.2 On the left, a set of colored pencils is located inside a package that also serves as a stand during use. On the right, the chair is packed in a way that it can be enclosed inside a box when not in use.

Source: Design Heuristics, www.designheuristics.com.

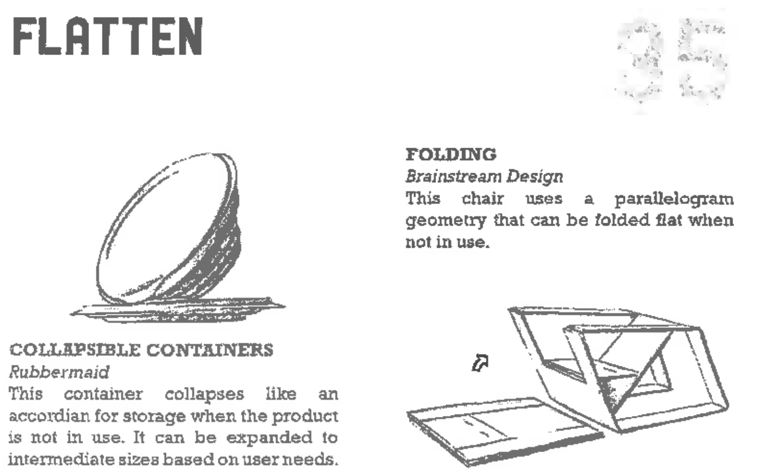


FIGURE 24.3 On the left, the bowl has several layers that are nested inside each other for storage when the product is not in use. On the right, the chair collapses flat when not in use.

Source: Design Heuristics, www.designheuristics.com.

other." This involves placing an object inside another object (entirely or partially), where the internal geometry of the containing object is similar to the external geometry of the contained object (see Figure 24.3). This heuristic allows the quick collapse of structure to flatten for easy storage.

There was substantial, but not complete, overlap in the design heuristics observed in the longitudinal study and the innovative products study. In sum, 74 separate heuristics were identified across the two studies. Thirteen of these were new heuristics appearing only in the innovative products dataset. These heuristics tended to address design issues that occur in the later stages of the process. For example, one heuristic observed in the consumer products was, "Cover joints for safety and visual consistency." This heuristic could potentially be applied to longitudinal design problem, but it would likely be considered only once a final concept had been selected, and further design refinements were taking place. This suggests that some heuristics may be suited to specific stages of the design process, may not be applicable to a given design task, and may depend upon the designer's personal preferences.

Protocol Studies With Experts in Engineering and Industrial Design

A third source of evidence emerged through a protocol project (Gero & McNeill, 1998) investigating professional and student engineering (n = 36) designers as they worked on a novel problem (Daly, Yilmaz, Christian, Seifert, & Gonzalez, 2012; Yilmaz, Daly et al., 2013). The problem involved designing a product that used sunlight to heat and cook food, and was portable and inexpensive. The participants were asked to draw as many concepts as possible and to elaborate on their designs with labels and descriptions. They worked for 25 minutes and generated an average of five different concepts. The designs varied in heat source identified (magnifying glass, reflectors), form (open box with extended sides, covered canister), and even function (water immersion, smoker).

The designers talked aloud as they worked, and their concept sketches and elaborations were captured. There was abundant evidence of design heuristics in the concepts created, and the more expert designers tended to display more evidence of heuristic use. Fifty-three heuristics used spontaneously by participants in this study were also identified in the previous research (Daly et al., 2010; Yilmaz & Seifert, 2010, 2011). By comparing how the concepts related to each other, it was possible to identify nine novel heuristics not observed in the previous studies.

77 Design Heuristics

Combining the results of these three studies (the expert's longitudinal design sketches, 400 award-winning products, and think-aloud protocol studies), a set of 77 Design Heuristics were extracted (see Table 24.1).

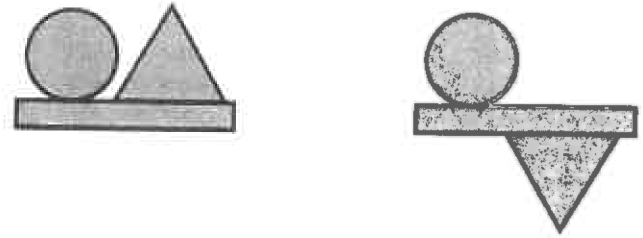
Each Design Heuristic is described on a notecard including a text and graphic description, and two examples of products where the heuristic is evident (see Figure 24.4A and 24.4B). The cards facilitate use of individual heuristics and comparison of product designs across cards (Daly, Yilmaz et al., 2012).

TABLE 24.1 The 77 Design Heuristics Observed Across Three Empirical Studies

1) Add levels	40) Incorporate user input
2) Add motion	41) Layer
3) Add natural features	42) Make components attachable or detachable
4) Add to existing product	43) Make multifunctional
5) Adjust function through movement	44) Make product recyclable
6) Adjust functions for specific users	45) Merge surfaces
7) Align components around center	46) Mimic natural mechanisms
8) Allow user to assemble	47) Mirror or array
9) Allow user to customize	48) Nest
10) Allow user to reconfigure	49) Offer optional components
11) Allow user to reorient	50) Provide sensory feedback
12) Animate	51) Reconfigure
13) Apply existing mechanism in new way	52) Redesign joints
14) Attach independent functional components	53) Reduce material
15) Attach product to user	54) Repeat
16) Bend	55) Repurpose packaging
17) Build user community	56) Roll
18) Change direction of access	57) Rotate
19) Change flexibility	58) Scale up or down
20) Change geometry	59) Separate functions
21) Change product lifetime	60) Simplify
22) Change surface properties	61) Slide
23) Compartmentalize	62) Stack
24) Contextualize	63) Substitute way for achieving function
25) Convert 2-D material to 3-D object	64) Synthesize functions
26) Convert for 2nd function	65) Telescope
27) Cover or wrap	66) Twist
28) Create service	67) Unify
29) Create system	68) Use common base to hold components
30) Divide continuous surface	69) Use continuous material
31) Elevate or lower	70) Use different energy source
32) Expand or collapse	71) Use human power
33) Expose interior	72) Use multiple components for one function
34) Extend surface	73) Use packaging as functional component
35) Flatten	74) Use recycled or recyclable materials
36) Fold	75) Utilize inner space
37) Hollow out	76) Utilize opposite surface
38) Impose hierarchy on functions	77) Visually distinguish functions
39) Incorporate environment	

Source: Adapted from Daly, Yilmaz et al. (2012).

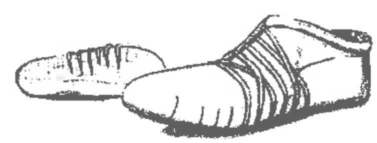
UTILIZE OPPOSITE SURFACE 76



Create a distinction between exterior and interior, front and back, or bottom and top. Make use of both surfaces for complimentary or different functions. This can increase efficiency in the use of surfaces and materials, or facilitate a new way to achieve a function.

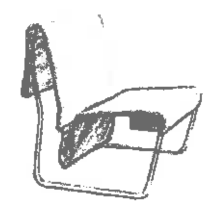
A

UTILIZE OPPOSITE SURFACE 76



980 TATOU
Annika Luber
The laces wrap around the bottom of this shoe and connect with the sole.

FARALLON CHAIR
fuseproject
The back side of this chair has a pocket for storage.



B

FIGURE 24.4 The information on the heuristic, "Utilize Opposite Surface," includes a graphic depiction, text description, and two product examples where the heuristic is evident. Each heuristic is demonstrated in a design for a chair to show that each can be applied to the same product problem.

Source: Design Heuristics, www.designheuristics.com.

These Design Heuristics represent an empirically derived body of cognitive strategies used by experts to add novelty to their designs. Collected from the work of many designers, these cognitive strategies provide specific directions for considering how to intentionally introduce variations among the concepts generated, and allow further exploration of the space of possible design solutions. As a result, the selection of a final concept can be made from among a richer, more diverse set of candidate concepts.

Implications for Designers

Now that these heuristics have been identified, they can be used by designers to prompt consideration of variations in design. Starting with a problem, the Design Heuristics can be applied to help the designer generate more, varied concepts to consider. Rather than relying heuristics built from experience (Moss, Kotovsky, & Cagan, 2006), designers can "jump start" the process of generating concepts by choosing to apply Design Heuristics. As a result, their process will be aided by the expertise captured by the Design Heuristics, and the result will be a larger set of concepts enriched by the variations introduced. Design Heuristics can provide explicit instruction on how to intentionally vary concepts during the design process.

For example, consider the problem of designing a liquid hand soap dispenser. How might Design Heuristics be applied to explore new concepts? In Figure 24.5, the design process begins with a concept, and then three different Design Heuristics are applied to suggest changes to create new concepts to consider.

The 77 Design Heuristics captured through empirical studies provides a new method for designers to add to their potential designs. A study to test this approach included design teams from a commercial product company (Yilmaz,

Initial Concept.	Make the individual parts attachable-detachable.	Attach the product to an existing item as an additional component.	Remove the moving parts.
Top part is nested inside the main structure, which holds the soap. Soap is dispensed by a push-motion from the top. The central open space is used for hand placement.	The two parts are separated easily with a snap-on motion. The location for connecting the parts is also used as the opening to fill it with soap.	The product can be attached to the faucet through a sliding motion. This way the soap dispenser does not occupy additional surface space on the countertop. Soap comes out from the channels on the sides, and the product can be filled with soap from the top part, which also serves as the part users push to receive soap.	Soap is dispensed through the top of the tubing component by rotating the entire product around its center. The cavity on the bottom of the product is used for filling it with soap.

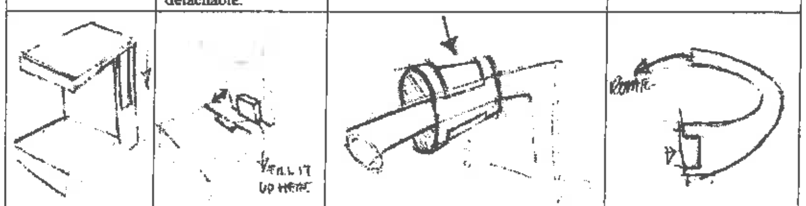


FIGURE 24.5 An illustration of how design heuristics can be applied to a novel problem to generate three new concepts (shown in successive panels).

Source: Seda Yilmaz.

Christian et al., 2013). These professional designers had worked on a specific product line for many years, and were looking for new ideas. Working in a small group of seven, the engineers looked through a subset of 30 of the Design Heuristics in two, two-hour sessions, and discussed how they could be applied to their product concepts. Video recordings were analyzed to reveal how the heuristics were used to stimulate new designs for their product line. We found that Design Heuristics led to new ideas and further elaboration on ideas, resulting in novel designs even in this highly familiar problem domain (as reported by the participants). This case study shows using Design Heuristics can assist even expert design engineers to increase the variety of concepts generated, resulting in a larger set of ideas to consider.

Implications for a Theory of Design

The success in identifying Design Heuristics from empirical studies of professional designers points the way toward an evidence-based approach to design. While an innovative design can be viewed as something "magical," research in cognitive and decision science has been shown to provide a means to study the design process. By systematic analysis of designers and their work process and products, we can learn more about successful design. Interesting, innovative designers appear unable to tell us what they do to make the "magic" happen; instead, identifying the cognitive heuristics that occur instantly and seamlessly during their work must be performed by an observer. As with other heuristics, the individual is not able to reflect upon their use of specific strategies or information because of the speed of mental processing and the implicit nature of much of our cognition (Ericsson & Simon, 1980; Nisbett & Wilson, 1977). The approach presented here provides a means to systematically observe and analyze the cognitive processes in design.

Further research has shown that what we have learned—the 77 Design Heuristics—can help even novice designers create more varied designs, resulting in more developed and more creative concepts (Daly, et al., 2013; Daly, Christian, et al., 2012). Through identifying the heuristics used by professional designers, and facilitating the use of those heuristics in novice designers, we have demonstrated the feasibility of enhancing creativity and innovation in design. This understanding of successful design will improve instructional methods in engineering and industrial design, providing an opportunity to create new instructional methods. Further, the heuristic approach and pedagogical techniques studied in this project may transfer to other professional domains (e.g., art, choreography, software, marketing campaigns) and educational settings (such as K–12, business training, design workshops) to provide new approaches for teaching creativity and innovation (cf. Kokotovich & Purcell, 2000). In addition, identifying team processes that encourage innovation by helping groups to consider a wider variety of candidate designs may provide practical guidelines to make design teams more cost-effective (Hargadon & Sutton, 1997; Podsakoff, Ahearne, & MacKenzie, 1997; Sutton & Hargadon, 1996; Yilmaz, Christian, et al., 2013). Most importantly, specific methods for creating innovative designs may have a broad impact on products and consumers.

Acknowledgements

This research project was funded through the NSF Engineering Design and Innovation (EDI) Grant 0927474. Thanks to James L. Christian, who was an integral part of the Design Heuristics project. The authors would like to thank Panos Papalambros and Jan-Henrik Andersen for their support on the development of this research program.

Notes

1 http://www.idsa.org
2 http://www.red-dot.de
3 http://www.ifdesign.de
4 http://www.g-mark.org/english/
5 http://www.nationaldesignawards.org

References

Altshuller, G. (1984). *Creativity as an exact science: The theory of the solution of inventive problems.* New York, NY: Gordon and Breach.

Altshuller, G. (1997). *40 principles: TRIZ keys to technical innovation.* Worcester, MA: Technical Innovation Center.

Ash, R., & Smith-Daniels, D.E. (1999). The effects of learning on decision rule performance in Multi-Project Scheduling. *Decision Sciences, 30*(1), 47–82.

Bailey, R. (2006). *Work in progress: Using engineering design experts to validate a design process knowledge assessment tool.* ASEE/IEEE Frontiers in Education Conference, San Diego, CA.

Ball, L., Ormerod, T., & Morley, N. (2004). Spontaneous analogizing in engineering design: A comparative analysis of experts and novice. *Design Studies, 25*, 495–508.

Bock, D., & Patterson, J.H. (1990). A comparison of due date setting, resource assignment, and job preemption heuristics for the Multiproject Scheduling Problem. *Decision Sciences, 21*(3), 387–402.

Chang, C. (2004). Country of origin as a heuristic cue: The effects of message ambiguity and product involvement. *Media Psychology, 6*, 169–192.

Cross, N., & Cross, A. C. (1998). Expertise in engineering design. *Research in Engineering Design, 10*, 141–149.

Dahl, D. W., & Moreau, P. (2002). The influence and value of analogical thinking during new product ideation. *Journal of Marketing Research, 39*(1), 47–60.

Daly, S. R., Christian, J., Yilmaz, S., Seifert, C. M., & Gonzalez, R. (2012). Assessing Design Heuristics in idea generation within an introductory engineering design course. *International Journal of Engineering Education (IJEE), 28*(2), 463–473.

Daly, S., Yilmaz, S., Christian, J., Seifert, C. M., & Gonzalez, R. (2012). Design heuristics in engineering concept generation. *Journal of Engineering Education, 101*(4), 601–629.

Daly, S. R., Yilmaz, S., Seifert, C. M., & Gonzalez, R. (2010). Cognitive heuristic use in engineering design ideation. *Proceedings of American Society for Engineering Education* (AC 2010-1032), Washington, DC: American Society for Engineering Education.

Darke, P. R., Freedman, J. L., & Chaiken, S. (1995). Percentage discounts, initial price, and bargain hunting: A heuristic-systematic approach to price search behavior. *Journal of Applied Psychology, 80*, 580–586.

Dijksterhuis, A., Bos, M. W., Nordgren, L. F., & Van Baaren, R. B. (2006). On making the right choice: The deliberation-without-attention effect. *Science, 311*(5763), 1005–1007.

Eberle, B. (1995). *Scamper.* Waco, TX: Prufrock.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological Review, 87*, 215–251.

Gero, J. S., & McNeill, T. (1998). An approach to the analysis of design protocols. *Design Studies, 19*(1), 21–61.

Gigerenzer, G., & Todd, P. (1999). *Simple heuristics that make us smart.* New York, NY: Oxford University Press.

Goel, V., & Pirolli, P. (1989). Motivating the notion of generic design within information processing theory: The design problem space. *AI Magazine, 10*, 19–36.

Gordon, W.J.J. (1961). *Synectics.* New York, NY: Harper & Row.

Guindon, R., & Curis, B. (1988). Control of cognitive processes during software design: What tools are needed? In J. J. O'Hare (Ed.), *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '88) (pp. 263–268). New York, NY: ACM.

Haller, L., & Cullen, C. D. (2006). *Design secrets: Products 2: 50 real-life product design projects uncovered* (Vol. 2). London: Rockport.

Hargadon, A., & Sutton, R. I. (1997). Technology brokering and innovation in a product development firm. *Administrative Science Quarterly, 42*(4), 716–749.

Hauser, J. (2011). A marketing science perspective on recognition-based heuristics (and the fast-and-frugal paradigm). *Judgment and Decision Making, 6*(5), 396–408.

Heerkens, H. (2006). Assessing the importance of factors determining decision making by actors involved in innovation processes. *Creativity and Innovation Management, 15*, 385–399.

Huber, V. L., & Neale, M. A. (1986). Effects of cognitive heuristics and goals on negotiator performance and subsequent goal setting. *Organizational Behavior and Human Decision Processes, 38*(3), 342–365.

Hudson, J. (2008). *Process: 50 product designs from concept to manufacture.* London: Laurence King.

Industrial Designers Society of America. (2003). *Design secrets: Products.* London: Rockport.

Jansson, D. G., & Smith, S. M. (1991). Design fixation. *Design Studies, 12*(1), 3–11.

Kavakli, M., & Gero, J. S. (2002). The structure of concurrent cognitive actions: a case study on novice and expert designers. *Design Studies, 23*(1), 25–40.

Klein, G. A. (1993). A recognition-primed decision (RPD) model of rapid decision making. In G. A. Klein, J. Orasanu, R. Calderwood, & C. E. Zsambok (Eds.), *Decision making in action: Models and methods* (pp. 138–147). Westport, CT: Ablex.

Klein, G. (1998). *Sources of power.* Cambridge, MA: MIT Press.

Kleinmuntz, D. N. (1985). Cognitive heuristics and feedback in a dynamic decision environment. *Management Science, 31*(6), 680–702.

Kohli, A. K., & Jaworski, B. J. (1990) Market orientation: The construct, research propositions, and management implications. *Journal of Marketing, 54*, 1–18.

Kokotovich, V., & Purcell, T. (2000). Mental synthesis and creativity in design: An experimental examination. *Design Studies, 21*, 437–449.

Kolodner, J. L. (1993). *Case-based reasoning*. San Francisco, CA: Morgan Kaufmann.

Kotovsky, K., & Simon, H. (1990). What makes some problems really hard: Explorations in the problem space of difficulty. *Cognitive Psychology, 22*, 143–183.

Krishnan, V., & Ulrich, K. (2001). Product development decisions: A review of the literature. *Management Science, 47*, 1–21.

Kruger, C., & Cross, N. (2006). Solution driven versus problem driven design: Strategies and outcomes, *Design Studies, 27*, 527–548.

Lidwell, W., & Manacsa, G. (2009). *Deconstructing product design: Exploring the form, Function, usability, sustainability, and commercial success of 100 amazing products*. London: Rockport.

Maher, M. L., & Gomez de Silva Garza, A. (1997). Case-based reasoning in design. *IEEE Expert: Intelligent Systems and Their Applications, 12*(2), 34–41.

Malone, T. W. (1980). What makes things fun to learn? Heuristics for designing instructional computer games. *Proceedings of the 3rd Association for Computing Machinery SIGSMALL Symposium* (pp. 162–169), New York, NY.

Markman, A. B., Wood, K. L., Linsey, J. S., Murphy, J. T., & Laux, J. (2009). Supporting innovation by promoting analogical reasoning. *Tools for Innovation, 1*(9), 85–104.

Merlo, O., Lukas, B. A., & Whitwell, G. J. (2008). Heuristics revisited: Implications for marketing research and practice. *Marketing Theory, 8*, 189–204.

Moss, J., Kotovsky, K., & Cagan, J. (2006). The role of functionality in the mental representations of engineering students: Some differences in the early stages of expertise. *Cognitive Science, 30*(1), 65–93.

Narver, J. C., & Slater, S. F. (1990). The effect of market orientation on business profitability. *Journal of Marketing, 54*(October): 20–35.

Newell, A., & Simon, H. (1972). *Human problem solving*. New York, NY: Prentice Hall.

Nisbett, R. E., & Wilson, T. D. (1977). Telling more than we can know: Verbal reports on mental processes. *Psychological Review, 84*(3), 231–259.

Norman, D. A. (1993). *Things that make us smart: Defending human attributes in the age of the machine*. New York, NY: Basic Books.

Obradovich, J. H., & Woods, D. D. (1996). Users as designers: How people cope with poor HCI design in computer-based medical devices [Special Section]. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 38*(4), 574–592.

Otto, K., & Wood, K. (2001). *Product design: Techniques in reverse engineering and new product development*. New York, NY: Prentice Hall.

Podsakoff, P. M., Ahearne, M., & MacKenzie, S. B. (1997). Organizational citizenship behavior and the quantity and quality of work group performance. *Journal of Applied Psychology, 82*, 262–271.

Proctor, R. (2009). *1000 new eco designs and where to find them*. London: Laurence King.

Purcell, T., & Gero, J. S. (1996). Design and other types of fixation. *Design Studies, 17*(4), 363–383.

Purcell, T., & Gero, J. S. (1998). Drawings and the design process: A review of protocol studies in design and other disciplines and related research in cognitive psychology. *Design Studies, 19*(4), 389–430.

Schank, R. C. (1982). *Dynamic memory: A theory of learning in computers and people*. Cambridge: Cambridge University Press.

Schwenk, C. R. (1988). *The essence of strategic decision making*. Lexington, MA: Lexington Books.

Shah, A. K., & Oppenheimer, D. M. (2008). Heuristics made easy: An effort-reduction framework. *Psychological Bulletin, 134*(2), 207–222.

Simon, H. A. (1981). *The sciences of the artificial* (2nd ed.). Cambridge, MA: MIT Press.

Simon, H. A. (1990). Invariants of human behavior. *Annual Review of Psychology, 41*, 1–19.

Sriraman, B. (2004). The characteristics of mathematical creativity. *Mathematics Educator, 14*, 19–34.

Sutton, R. I., & Hargadon, A. (1996). Brainstorming groups in context: Effectiveness in a product design firm. *Administrative Science Quarterly, 41*(4), 685–718.

Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive Psychology*, 5, 202–232.

Tversky, A., & Kahneman, D. (1974, September 27). Judgment under uncertainty: Heuristics and biases. *Science, 185*, 1124–1131.

Visser, W. (1996). Two functions of analogical reasoning in design: A cognitive psychology approach. *Design Studies, 17*, 417–434.

Wilpert, B. (2005). Psychology and design processes. *European Psychologist, 10*(3), 229–236.

Yilmaz, S., Christian, J. L., Daly, S. R., Seifert, C. M., & Gonzalez, R. (2013). Can experienced designers learn from new tools? A case study of idea generation in a professional engineering team. *International Journal of Design Creativity and Innovation, 1*(2), 82–96.

Yilmaz, S., Daly, S. R., Christian, J. L., Seifert, C. M., & Gonzalez, R. (2012, May 21–24). How do design heuristics affect outcomes? In M. M. Andreasen, H. Birkhofer, S. J. Culley, U. Lindemann, & D. Marjanovic (Eds.), *Proceedings of 12th International Design Conference (DESIGN)* (pp. 1195–1204), Dubrovnik, Croatia.

Yilmaz, S., Daly, S. R., Seifert, C. M., & Gonzalez, R. (2013, September 5–6). Comparison of design approaches between engineers and industrial designers. *The 15th International Conference on Engineering and Product Design Education*, Dublin, Ireland.

Yilmaz, S., & Seifert, C. M. (2010). Cognitive heuristics in design ideation. *Proceedings of 11th International Design Conference, DESIGN 2010* (pp. 1007–1016), Dubrovnik, Croatia.

Yilmaz, S., & Seifert, C. M. (2011). Creativity through design heuristics: A case study of expert product design. *Design Studies, 32*, 384–415.

Zuckerman, A., & Chaiken, S. (1998). A heuristic-systematic processing analysis of the effectiveness of product warning labels. *Psychology & Marketing, 15*(7), 621–642.