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Keywords
Design strategies, Industrial design, Engineering design, Creativity

Disciplines
Industrial and Product Design | Industrial Engineering | Industrial Technology | Operational Research

Comments
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COMPARISON OF DESIGN APPROACHES BETWEEN ENGINEERS AND INDUSTRIAL DESIGNERS

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ABSTRACT
Design Heuristics are an idea generation tool based on empirical evidence from successful designs. The heuristics serve as cognitive "shortcuts" that encourage exploration of novel directions during concept generation. Design Heuristics were identified from an analysis of hundreds of innovative products and from studies of expert engineering and industrial designers. The research reported in this paper examines the utility of Design Heuristics instruction in two different classroom settings with engineering and industrial design students. The aim was to test whether design heuristics can play a useful role in creating new designs and overcoming fixations in the design process. Twenty novice industrial design students and forty-eight novice engineering students were given a short design task along with a set of twelve Design Heuristics. The heuristics were illustrated on cards describing their use and two example images of products using each heuristic. The students participated in a short instructional session on the use of heuristics, and were asked to generate concepts for a given problem. The results showed that the Design Heuristics helped the students to generate more diverse candidate concepts, and that the concepts they produced were creative and complex. Students sometimes applied multiple heuristics within a single design, leading to more complex and well-developed solutions.

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1 INTRODUCTION AND BACKGROUND

Designers must continually create novel solutions for the global challenges of our world. Concept generation – also called "ideation" – is critical to developing innovative designs. During the ideation process, designers can create a wide variety of concepts, and the creativity of the proposed solutions ultimately defines the potential for innovation. Thus, the challenge becomes how to support creativity during concept generation to give rise to novel ideas. While later stages of the design process may vary across fields, there is considerable overlap in the work performed by engineering and industrial designers in the product design process. Their roles include creating new products, redesigning existing ones, and "designing pieces of technology and initiating change in man-made things" [9]. In both domains, creativity plays a critical role in the success of new products. However, designers in these two professions may differ in their design processes, creative outcomes, and training.

Engineering design has been characterized as applying scientific knowledge to design useful products for improving human life [11]. Innovative solutions are important to engineering organizations as changes in our needs accelerate [3]. While some engineering programs include training on creativity [6], most engineering students find creative thinking to be given less emphasis than technical thinking [6]. This orientation may make it challenging for engineers to generate creative concepts, and supports the crucial need identified by engineering educators to teach "real-world" engineering design in a way that fosters critical judgment and creativity [7].

Industrial design training emphasizes repeated experience in generating and developing design concepts, followed by critique sessions led by instructors or professional designers. Critiques address issues such as material and processes, ergonomics (operation, safety, usability, and sensation), marketing and branding, aesthetics, and even social, environmental, and cultural influences [12]. In contrast to engineering, where product design is driven by functional constraints, industrial design is more focused on aesthetic values. However, industrial designers also experience limitations in generating diverse concepts [5]. This may be due to a lack of technical knowledge, difficulties in eliciting user needs, or a lack of the process knowledge emphasized in engineering training.

Pedagogy for enhancing design creativity is essential because many design problems demand innovative outcomes. This demand arises from the market, new technologies, new legislation, or new criteria such as sustainability concerns. The result of design activity is often expected to be original, adding value to the base of existing designs by solving technical problems in new ways. Bradford [4] suggested that toolkits should be made available to assist in creative exploration.

1.1 Creative design strategies

Design undergraduates are sometimes provided with general instructions about concept generation techniques, such as how to "brainstorm" [10]. However, it is less common to teach specific cognitive strategies that may help to generate more creative and diverse ideas. Providing these specific strategies may be just as important as instruction in the technical skills for the development of design skills. A variety of design tools are currently available. For example, brainstorming [10] is aimed at facilitating the flow of ideas, Synectics [8] stimulates the formation of initial ideas, and TRIZ [1] is aimed at solving contradictions in developed design ideas. However, none of these approaches have been empirically validated as helpful in successful concept generation.

1.2 Design heuristics

Design heuristics were identified in award-winning products and the protocols of professionals performing design tasks. Design Heuristics are intended to help explore a solution space, guiding the designer towards non-typical, non-obvious ideas that also differ from one another. Design Heuristics can help designers become "unstuck" when they are struggling to generate more, and more different, ideas. In previous research, 77 Design Heuristics have been identified (see Figure 1).

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

Figure 1. Descriptions of the 77 Design Heuristics

Each Design Heuristic is represented on two sides of a 5.5 x 8 inch card. Each card includes a specific description of a heuristic, an abstract image depicting how to apply the heuristic, and two product examples that show the application of the heuristic to existing consumer products (see Figure 2).

Figure 2. Heuristic card example: "Use continuous material"

2 EXPERIMENTAL METHOD

In this study, we extend our previous work to engineering and industrial designers working on a new design problem. Our goals were to gain evidence that the Design Heuristics identify key strategies used by designers, and to compare the use of strategies by different types of designers. Industrial design and engineering are different in their educational approaches, yet designers in these disciplines can perform similar product design tasks. Testing both types of experts may reveal evidence of design heuristic use across two disciplines. In addition, it may identify commonalities and differences in design heuristic use in the two fields.

The research reported here examined design heuristics in idea generation through a controlled laboratory study. Both engineering designers and industrial designers were observed as they created designs for an open-ended problem. They were given a subset of heuristics and were told they could use them to support their concept generation processes, as they desired. We collected written concepts designed by study participants, and extracted the design heuristics they used.

2.1 Participants

Participants included 48 engineering students (ages 17-19; 39 males, 9 females) in an Introduction to Engineering course, and 20 industrial design students (ages 18-24; 15 males and 5 females) in an Introduction to Industrial Design course, both at large Midwestern universities. The semester-long engineering course provided first-year students with an introduction to topics such as computer coding, Microsoft Excel, communication skills, and teamwork. Students also participated in a guided design team project to learn the stages in design. The semester-long industrial design course covered the history, definition, scope and basic principles of industrial design, including research, idea generation, visual communication and sketch modelling. This class was the first the students took in the industrial design program after completing the core program in their first year. Both types of students are considered novices and reported little or no previous experience in design.

2.2 Data collection and analysis

Both studies were conducted in a classroom setting under the supervision of the instructors. Students participated in 80-minute sessions focusing on creative concept generation. The sessions included twenty minutes of introduction about Design Heuristics, where 3 heuristics cards were provided as examples to train the students in their use. The three heuristic cards presented were *Bend*, *Synthesize functions*, and *Use packaging as a functional component*.

Next, students were given a simple design task, and asked to generate as many concepts as possible within 25 minutes while using the heuristic cards. Each participant received a subset of 12 cards assigned at random. A total of 74 heuristics (the 3 example cards were excluded) were employed in the study; across the 20 students, each card appeared between 1 and 5 times. The students were instructed to use any Design Heuristic or combination as they desired during ideation. The task involved an open-ended design problem, "designing a solar-powered cooking device that was inexpensive, portable, and suitable for family use." A brief outline of solar energy methods for heating (e.g., concentrating, absorbing, and trapping) was also provided as instructional information. Students sketched or described a concept on a blank piece of paper, and were asked to use a new sheet for each new concept. When finished, the students were asked to respond to the following prompts for each concept they generated: 1) "Describe the concept in detail. How does it work? What are the unique features, mechanisms, and details?" and 2) "What made you think of this concept? Where did this idea come from?" For the second prompt, we instructed students to list the heuristic card numbers, if any, they used in that concept.

The concept sketches, written descriptions, and questionnaires were analysed by three coders trained in identifying Design Heuristics. One coder had a background in engineering and in art & design, and coded both studies; the second coder had a background in industrial design, and the third had a background in engineering. The second and third coders only coded the studies in their design domains. The three coders scored every concept for:

- *Evidence of heuristic use:* Both the sketches and the descriptions were assessed for heuristics provided in the set that were evident in the participants' concepts. Coders noted whether the participant claimed that he/she used the heuristic for that specific concept. If the heuristic was both observed by coders, and claimed by the participant, then it was coded as "evident and claimed."
- *The creativity of each concept:* A variation of the widely accepted Consensual Assessment Technique [2] was used by two independent coders with no prior experience with Design Heuristics

who were seniors in either engineering or industrial design domains. Each rated a randomized ordering of concepts. For creativity, each coder sorted every concept on a 1 (not creative) to 7 (very creative) Likert scale. The ratings were then averaged and rounded down.

- *The diversity (differences among concepts) of each concept set:* For diversity, all of the concepts generated by a single participant were considered as a set. The coders followed the same Consensual Assessment Technique procedure to consider each student's set, and rated the diversity of the concepts within the set on a scale from 1 (not very diverse) to 7 (very diverse). For example, a concept set of 6 that used a mirror array with only minor changes between concepts would be rated as not very diverse, while a set of 3 including one with a mirror array, one with a magnifying glass to concentrate light, and one with a reflective surface may be rated as more diverse.

3 RESULTS AND DISCUSSION

Here, we report outcomes that helped us answer our primary research question: "How does the use of Design Heuristics influence the exploration of solutions?" Students in both groups generated between 1 and 8 concepts that varied in methods of heat collection, portability, and usability features. Among the twenty industrial design students, 78 concepts were generated or 4 concepts on average. Among the 48 engineering students, 161 concepts were generated, or 3.4 on average. Even within a 25-minute period, both groups were able to generate many ideas for concepts, with industrial design students producing more concepts.

To explore differences among concepts with and without Design Heuristics, we compared concepts showing heuristic use to those without heuristics evident. Table 2 shows a comparison between engineers and industrial designers in terms of the number of concepts generated and heuristic use in those concepts, and in their concept creativity and concept set diversity.

Table 1. Distribution of the concepts in both data sets

Engineers	*Claimed*	*Not Claimed*	**Industrial designers**	*Claimed*	*Not Claimed*
Evident	35%	20%	*Evident*	54%	22%
Not Evident	6%	40%	*Not Evident*	17%	8%
N	161 concepts		*N*	78 concepts	

The results reveal some differences in the use of heuristics in the two groups. Among engineering students, 55% of the concepts included evidence of heuristic use, with 76% for the industrial design students. In addition, engineering students claimed heuristic use in only 35%% of their concepts, while 54% of industrial design students did so. The industrial design students used and reported greater use of the design heuristics in each of their concepts. On average, Industrial Design students used an average of 3.9 heuristics within their solution sets, and engineering designers used an average 3.1 heuristics in their solution sets. Figure 3 compares examples with and without evident heuristics.

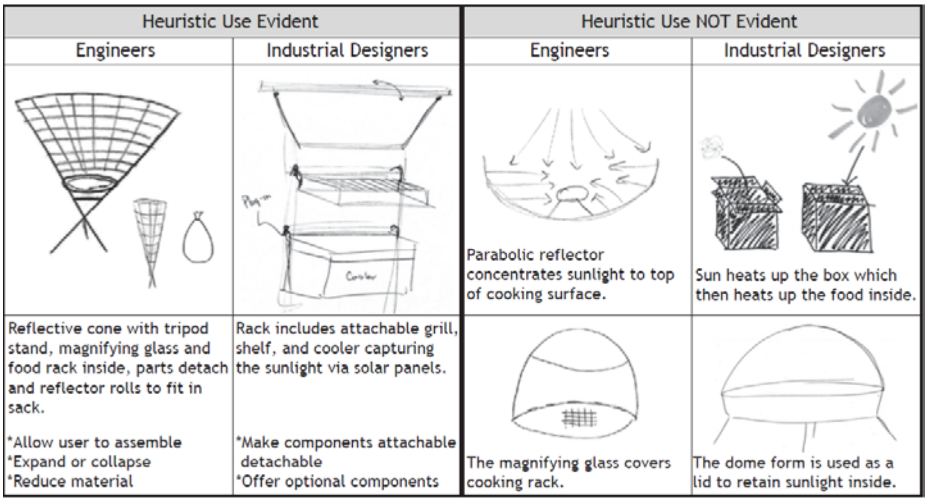


Figure 3. Example concepts with evident and not evident heuristics, in both design domains

From these examples, the impact of heuristic use on solution types is clear: Concepts without evidence of heuristic use were often simpler solutions, while those showing heuristic use appeared to go beyond "typical" solutions. For example, one design used a magnifying glass to heat a black object, but used heuristics to address portability by making the parts detachable for easy storage. With no heuristic evident, the designs included differences such as substituting solar panels for typical power sources, or used basic forms focused only on harnessing energy from light.

In Figure 4, the creativity ratings for concepts where heuristic use was evident (either self-reported or coded) is compared to creativity ratings for concepts where heuristic use was not evident. (Note that the same 7 point scale was used for both sets, but the average across the two coders is reported here.)

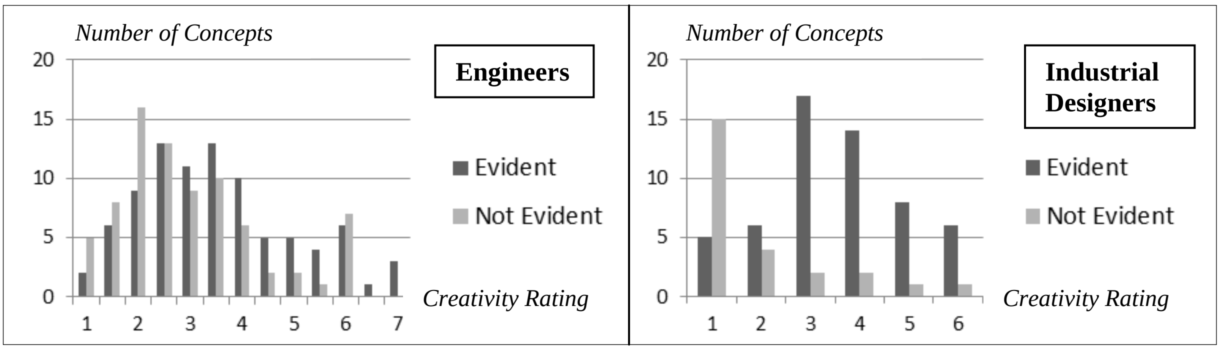


Figure 4. Creativity ratings for concepts with and without evidence of heuristic use.

The graphs show a positive trend: Concepts with evidence of heuristic use tend to have higher creativity ratings. For the Industrial Design students, the 59 designs where heuristic use was evident received an average creativity rating of 3.7, while the remaining 23 designs averaged a 2.3 rating, $p < .001$. For the engineering students, the designs with evident heuristic use averaged a 3.5 rating, and without evident heuristics, 3.1, $p < .01$. This suggests the use of design heuristics led to more creative concepts.

Figure 5 illustrates distinct differences in concepts rated high and low on creativity in both design domains. Creative concepts using heuristics appear to consider aspects beyond the primary function of "collecting sunlight," such as user features, more developed sketches, and more elaborate forms.

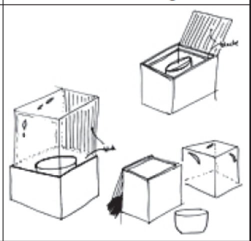
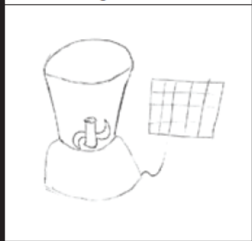
High Creativity		Low Creativity	
Engineers	Industrial Designers	Engineers	Industrial Designers
			
Solar cells attached to outside of 'flower petals' to change when closed, when cooking, open petals reflect and focus light to central cooking surface. *Allow user to assemble *Expand or collapse *Reduce material	The packaging box doubles its function as a stand for the magnifying cube and metal bowl once it's turned upside down. *Make components multi-functional *Repurpose packaging *Reverse the direction or change the angle	Solar panel used to power food processor.	A giant magnifying glass is used to start fires to cook food.

Figure 5. Concept examples with high and low creativity scores

Diversity ratings of each student's concept set were used to explore the impact of heuristics on variations in design. Figure 6 depicts the relationship between the number of heuristics evident in a concept set and its diversity rating. From this graph, it is clear that using more diverse heuristics does not guarantee higher diversity among concepts. However, there is an upward trend: For engineering students, heuristic use is correlated with higher diversity scores, $r = .39$, and for Industrial Design students, $r = .36$. This indicates that more heuristic use in idea generation can increase the potential for more diverse concepts.

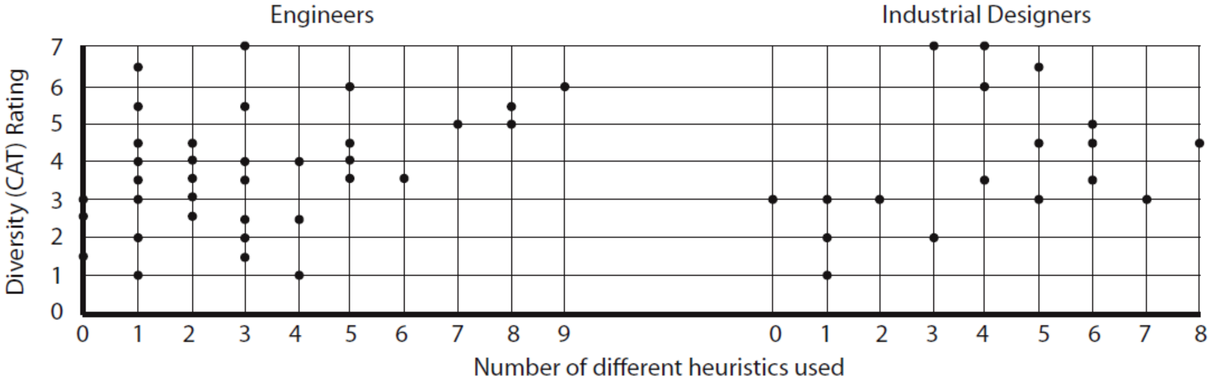


Figure 6. Diversity ratings as a function of the number of different heuristics used in the set.

In summary, in the number of concepts generated, creativity ratings, and set diversity, concepts with evident heuristics were more successful. Design heuristics appear to be a useful tool for both engineering and industrial designers, and facilitate exploring the space of possible solutions. Some differences were observed between engineers and industrial designers in their use of Design Heuristics to generate alternative concepts, with more frequent use occurring among Industrial Design students.

4 CONCLUSIONS

This study explored the impact of Design Heuristics on novice students' exploration of varied and creative solutions. While concepts with evident heuristics included a focus on function, they often included features that went beyond basic principles by considering the context of product use. Concepts without heuristics were often either replications of, or minor changes to, existing concepts. These concepts were rarely developed further to consider context or users. These findings are consistent with previous research on concept generation of novice designers, where design elements are often less well developed [13].

Even though there are differences in education and training, both industrial and engineering designers were able to use the Design Heuristics tool to generating diverse and creative concepts. For many students, simply having an arsenal of design heuristics to employ seems to lead to improvement in their approach to creative design. This research demonstrates that designers in both domains can use the Design Heuristics effectively with minimal training as a tool for creating new concepts.

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