# Design Heuristics Support Two Modes of Idea Generation: Initiating Ideas and Transitioning Among Concepts


## Abstract

Design Heuristics is an empirically driven design ideation tool intended to support variation and novelty in concept generation. The set of heuristics was extracted from observations of professional and novice designers at work, and by analyses of a large set of award-winning products. Through the observations of designers at work, we realized that the subconscious use of heuristics could manifest as either a modification of an existing concept or as the development of a new idea seemingly from scratch. Acknowledging this, we sought to understand how Design Heuristics are best taught to novice designers. In this study, we conducted separate instructional sessions on Design Heuristic use, teaching them as a concept generation technique and as a concept transformation technique. Our results show that both approaches yielded design improvements, though the variation between concepts tends to be larger when using a generative approach. Also, Design Heuristics in both approaches helped students elaborate their concepts, generate new ideas, and encouraged them to push forward with previous ideas. These findings contribute to our knowledge about how to best teach Design Heuristics in the classroom.


## Introduction

Supporting innovation in engineering education is critically important to face the Grand Challenges of the 21st Century[1]; however, instructors find it difficult to teach students to "think innovatively," and often do not provide students with systematic ways to generate creative designs. Creative thinking during idea generation in design work has been traced to successful innovation[2,3]. Thus, there has been substantial effort to develop rigorous and teachable strategies that can help designers to come up with creative ideas. While there are a variety of proposed methods for idea generation[4], only one has been systematically derived and empirically validated in scientific studies: Design Heuristics[5,6,7,8]. The Design Heuristics were developed through protocol studies with expert industrial and engineering designers, and through analyses of creative products. They are prompts that facilitate and guide design space exploration. A single heuristic can produce a variety of designs depending on how it is applied within a problem. Design Heuristics hold promise as a pedagogical method for training novice engineers, and supporting more proficient designers, to generate creative concepts.

In this paper, we report the outcomes of a Design Heuristic implementation study in an introductory engineering course. In one section, students were instructed on the use of Design Heuristics as a means of generating new ideas for an unfamiliar design task. In a different second section, students were asked to use Design Heuristics as concept modifiers with their existing ideas for a class project. Our goal was to observe the ways students used Design Heuristics in these two different scenarios. In this paper, we present five case studies from each scenario, showing ideation outcomes as a result of working with the heuristics, and discuss successes and obstacles involved in the implementation of Design Heuristics in the engineering classroom. The findings contribute to a research-based pedagogy for using Design Heuristics to support successful ideation in engineering instruction.

**Background**

The initial phases of design, especially idea generation, have significant impact on the success of a product and the potential for innovation[9]. Common measures of success in idea generation include the quantity, diversity, and novelty of ideas generated[10,11]. The chance of generating an innovative idea increases when more possibilities are considered. Developing a larger, more diverse pool of options during evaluation and concept selection would seem to maximize the potential for innovation. To visualize these ideas, design researchers often talk about the "design space" (following Newell and Simon's "problem space"[12]). Some ideas in this space are easy to find because they are obvious, or they have been seen before in existing products. Other, less obvious ideas require more effort to identify. Ideally, this search for less obvious ideas would entail visiting all feasible ideas in the design space. The resulting set of design solutions is better informed by understanding all possibilities.

Novice and experienced designers often struggle with divergent thinking[13]. Sometimes, limitations in technology or technical expertise make it difficult to generate multiple *different* solutions to a design problem. Often, novices struggle to think of solutions that differ from existing products or examples. Attempts at diverging from these solutions either result in only minor tweaks to known designs or fixation with an existing solution, leaving very little chance for innovation. This type of design fixation, or an attachment to the early ideas generated, has often been observed[14]. Once designers see the potential of their initial ideas, they often fail to seek alternatives or other transformations. Since early ideas are only rarely successful, this leaves novices more likely to fail in creating innovative solutions.

A variety of tools have been proposed to help designers explore design spaces for successful ideation. For example, brainstorming[15] and brainwriting[16] are intended to facilitate the flow of ideas without providing any structure. Analogical thinking[17], morphological analysis[18], and Synectics[19] support what Finke et al.[20] characterized as *generative* because they stimulate the formation of an initial idea. Other methods such as lateral thinking[21], SCAMPER[22], and TRIZ[23] provide ways to *transform* and improve upon existing ideas. However, which methods are most effective, and which can be effectively taught in the classroom, is unclear.

Design Heuristics have been proposed and derived from research as a new method for generating novel and diverse ideas[24,25,26]. The current study sought to understand how Design Heuristics could be used for both generative and transformative ideation.

Design Heuristics

In behavioral psychology, a heuristic is a cognitive problem-solving tool used to quickly and efficiently generate judgments or make decisions[27]. Heuristics are developed through experience, and studies have shown that experts are effective with domain-specific heuristic use[28]. They allow experts to generate best guesses quickly, but they do not guarantee a determinate solution[29]. Applying this concept to product design, we developed a set of Design Heuristics that are intended to facilitate idea generation[5,6,7,8]. Instead of aiming to generate a single solution, the goal is to promote the generation of multiple, diverse ideas through repeated application of different Design Heuristics.

Potential heuristics were identified through previous studies where we observed expert designers and analyzed award-winning products. In one study, we observed the entire ideation process of an expert designer as he generated over two hundred designs for a universal access bathroom[25]. We were able to identify repeated application of heuristics to generate new ideas or modify existing ones. Additionally, we analyzed over 400 award-winning products[30]. From these, we sought to identify the use of design strategies that made each product unique.

To further understand the mental processes during concept generation, we used a think-aloud protocol technique with 12 industrial designers and 36 engineers with varying expertise levels. We asked each participant to generate concepts for a novel design task, and observed how they naturally created concepts and transformed ideas[8]. Even though we did not instruct the participants on heuristic use, we found evidence for 60 different Design Heuristics in the concepts created for the design task. The diversity of the resulting pool of concepts generated supports the claim that Design Heuristics can be used to generate varied concepts. Furthermore, the repeated evidence of the same heuristics used by different designers on a variety of design tasks suggests that the set of heuristics has the potential to be universally applicable to product design[30].

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 component multifunctional
42. Make components attachable or detachable
43. Make product resuable 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. Descriptive Titles for the 77 Design Heuristics

These studies culminated in an accumulated collection of 77 Design Heuristics. For the current study, each heuristic is presented in the form of a card, which includes a title, a descriptive action prompt, an abstract image, and two product examples. On the front of the card, the action prompt provides specific instructions on how to modify an existing idea, or gives features to build a new idea. The abstract image is intended to supplement the action prompt by representing it visually. On the back of the card, the first product example comes from a variety of consumer products, while the second one offers an example from a consistent object (seat or chair). This is to show that the heuristics apply to a wide range of products and that every heuristic can be applied to the same product category. The entire set of Design Heuristics is shown in Figure 1, and a sample card is shown in Figure 2.

Figure 2. Heuristic Card Example: Utilize opposite surface

We conducted implementation studies to assess the effectiveness of Design Heuristics in engineering classrooms and with professional designers in their own setting[24,31,32]. These studies have shown evidence of students' and experts' success in ideation as a result of Design Heuristic card use. However, our previous studies have not been designed to test for the variety of ways that Design Heuristics can be used during ideation. Our hypothesis is that the application of a heuristic provides a specific way to 1) generate new ideas from scratch and 2) to transform existing ideas into new solutions. The present study thus explored how students use Design Heuristics both as a generative and a transformative tool.

**Research Methods**

This study included data collected in two different sections of an introductory engineering design course. In the first section, we taught Design Heuristics as a tool for concept generation. In the second section, Design Heuristics were introduced as a tool for the transformation of existing ideas. Our experimental approach and analysis was guided by the following research questions:

- How are Design Heuristics used as a *generative* tool to concept generation in an introductory engineering course?
- How are Design Heuristics used as a *transformative* tool to concept generation in an introductory engineering course?

Our study was not comparative; instead, our goal was to identify how using the heuristics in these two different scenarios guided the ideation processes of engineering students, and how the method of heuristic use was reflected in the design outcomes.

## Participants

We collected data from two sections of a single introductory engineering course at a large Midwestern university. This semester-long course introduces engineering students to design processes through a team design project. The projects in each section were different. We selected protocols from five participants from each section based on the variety in their ideas and the impact of heuristics in their creation. For section A, we chose three males and two females. For section B, all five participants were female because this section was predominantly female. Also, the section was subdivided into different design projects, so the number of students working on the same design task further limited our participant selection.

## Data Collection

Data for each section of the introductory engineering course were collected during a regularly scheduled class session that took place about one third of the way into the course, after students had completed lessons about foundational technical knowledge related to the design project. The structure of the Design Heuristics training was the same for each section, and included an introduction to concept generation, an explanation of Design Heuristics along with group practice, and finally, individual concept generation using a small subset of Design Heuristic cards. Time spent on each activity, design task description, and concept generation prior to the training are discussed below.

## Design Heuristics Training

Both sections received the same training presentation at the beginning of the session. The presentation started with an introduction to concept generation, where we explained how a typical design process is affected by concept generation. We stressed the value of divergent thinking, discussed the challenges designers face, and emphasized that the point of the lesson was to combat those challenges. Next, we introduced the concept of a design heuristic, gave background explaining the development of the Design Heuristics set, and showed examples. After showing the front and back of one card, we then showed the front of a second card and asked the students to practice by applying that heuristic to designing a chair. We asked them to practice this with two cards, and then asked the students to share their ideas with the group. We then concluded the training by allowing students to ask questions regarding the use of Design Heuristics.

After distributing randomized subsets of cards to each student, we gave them approximately five minutes to examine them before starting the design task. Each student in section A received a subset of 12 cards and each student in section B received a subset of 10 cards. This difference was due to class size and number of cards available. During the 25 minute task, students were asked to draw their concepts on separate papers. After the task, we gave each student a stack of labels on which they described each concept in detail and identified which Design Heuristics were helpful in developing the concept. Finally, students were asked to complete a short questionnaire evaluating their performance on the task.

Section A

To implement Design Heuristics as a generative approach, it was important that the participants had technical knowledge about the design task, but had not yet spent time considering, researching, or otherwise generating ideas about potential solutions to the task. Thus, we introduced a new design task to the students after the instruction on Design Heuristic use. This novel design task was to develop concepts for a solar-powered cooking device. Specific instructions were to utilize sunlight for heating and cooking food while emphasizing portability, inexpensive materials, and practical user interaction. Additional technical information about the scientific principles of directing and capturing sunlight was provided to the students 10 minutes into the task.

Section B

To implement Design Heuristics as a transformative method, we used the course project as the design task. This task was to develop a composting system to enable access to urban agriculture. Specifically, they were instructed to focus on durable, low cost, and innovative devices that maximize the use of reclaimed or re-used materials readily available in an urban setting. Safety, appearance, and storage were identified as important criteria. The students had spent one week learning necessary technical knowledge for this task, had identified the design problem, and done market research. The students had spent approximately 20 minutes formulating initial concepts prior to the training session. We asked the students to draw these initial concepts and fill out the same labels before coming to the workshop.

## Results

The case studies of five participants from each section focus on the concepts generated during the ideation session. For each concept, we identified evidence of Design Heuristics from that participant's subset of cards. Since we are interested in seeing how the cards that were provided affect the design outcomes, additional heuristics that may exist in the concepts generated were not investigated. The concepts generated by each participant have been redrawn for clarity in the figures presented below.

Section A: Generation

Here, we present the various concepts generated by five participants. Each participant generated a different number of concepts and used a different number of heuristics. As part of the analysis, we examined both the total number of times each heuristic was evident in each concept, as well as the number of different heuristics that the participant used throughout all of their concepts. Figure 3 shows the variation in heuristic use and the number of concepts. For example, Participant A4 generated four concepts, used eight different heuristics, and applied at least one of them multiple times. On the other hand, Participant A5 generated eight concepts, but used only two different heuristics, each of them, once. In previous studies[31], we observed that engineers generated three to four concepts on average during the time given. Therefore, participants A3 and A5 generated a relatively large number of concepts, while participant A2 generated a relatively small number.

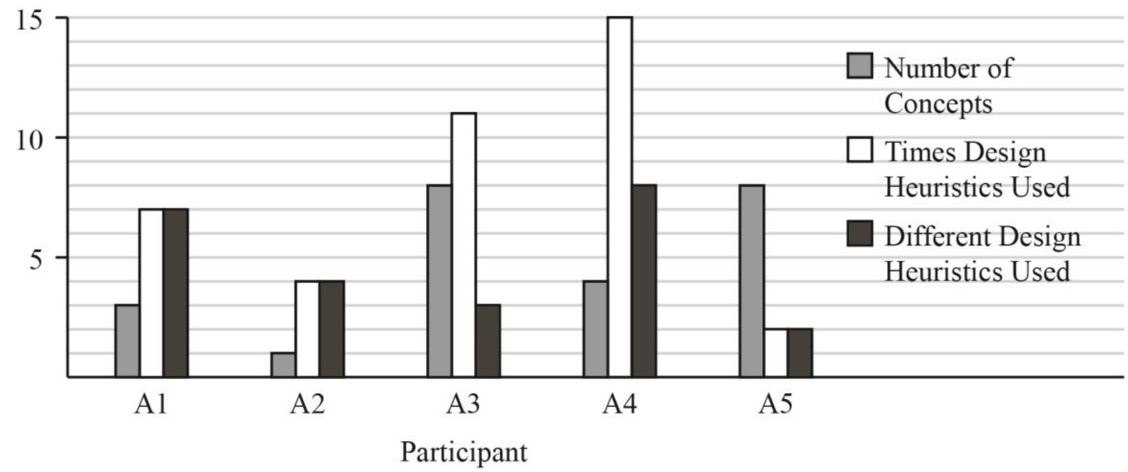


Figure 3: Concept and Heuristic use breakdown for Section A

The following paragraphs and images describe and show the concepts generated by each participant. The italicized numbers next to each concept denote the order in which they were generated, and the circled numbers represent the heuristics that were used to develop them. Arrows represent heuristic application used to transform one concept into another.

Participant A1 generated three different concepts, each with evidence of multiple Design Heuristics. For example, in concept 1, he combined *Adjust function through movement*, *Layer*, and *Telescope* to generate a concept that stacks multiple adjustable magnifying lenses to concentrate the light. In concept 2, he used *Expand or collapse* and *Flatten* to design a cooking surface that can open up to collect and concentrate light. Lastly, in concept 3, he combined *Twist* and *Convert 2-D to 3-D* to create a solar concentrator shaped like a spiral and made of sheet metal. Relative to others, this participant generated an average number of concepts, but applied a large number of different heuristics and used each only once.

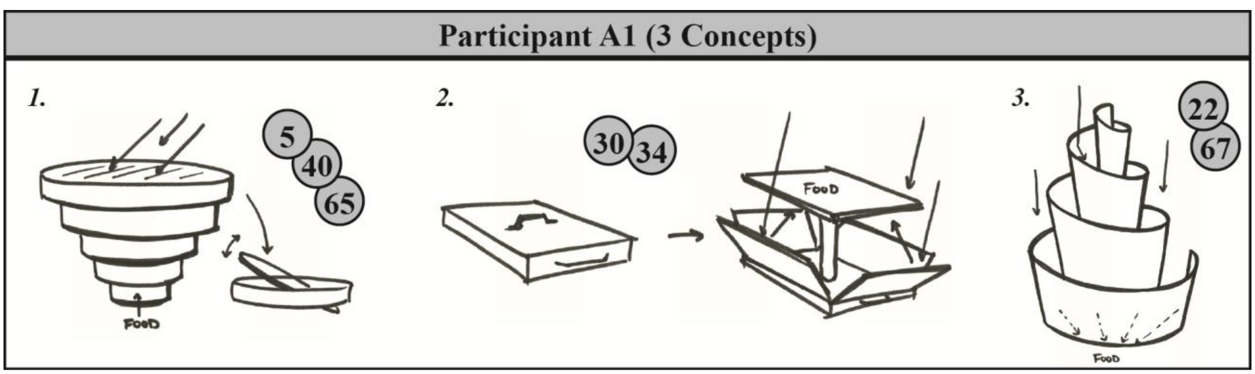


Figure 4: Concepts generated by Participant A1

Participant A2 was unique in that he only generated one concept. However, the concept was highly-detailed, and showed evidence of using four different heuristics. This participant used *Change direction of access*, *Change flexibility*, *Cover or remove joints*, and *Utilize opposite surface* to develop a concept he called the “Sun Bud” – a device with flower-like petals that could charge solar panels when closed, then reflect light toward a central cooking surface when open.

**Participant A2 (1 Concept)**

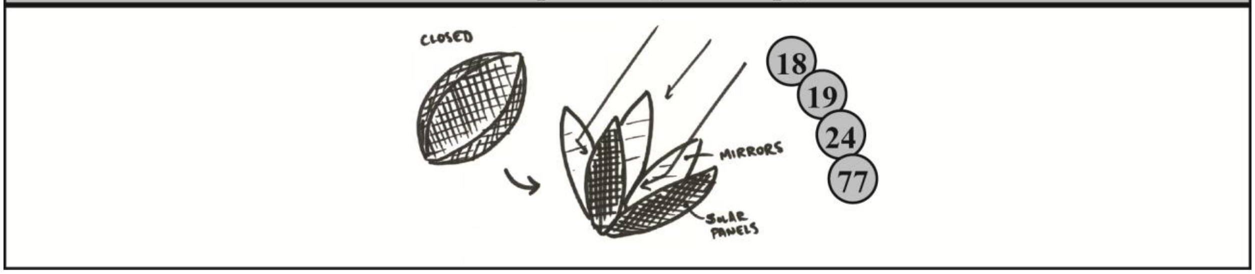


Figure 5: Concept generated by Participant A2

Participant A3 used only three different heuristics from her set of 12, but applied them repeatedly to generate concepts. She used different combinations of *Adjust function through movement*, *Animate*, and *Distinguish functions visually* to create five of her eight concepts. The other three showed no evidence of heuristic use. *Adjust function through movement* was evident in all five heuristic-driven concepts, facilitating the development of solar oven designs that could turn to face the sun, adjust height for the user, or rotate food for even heating. Concepts 2, 7, and 8 combined *Animate* with *Distinguish functions visually* to add a playful element while maintaining functional clarity.

**Participant A3 (8 Concepts)**

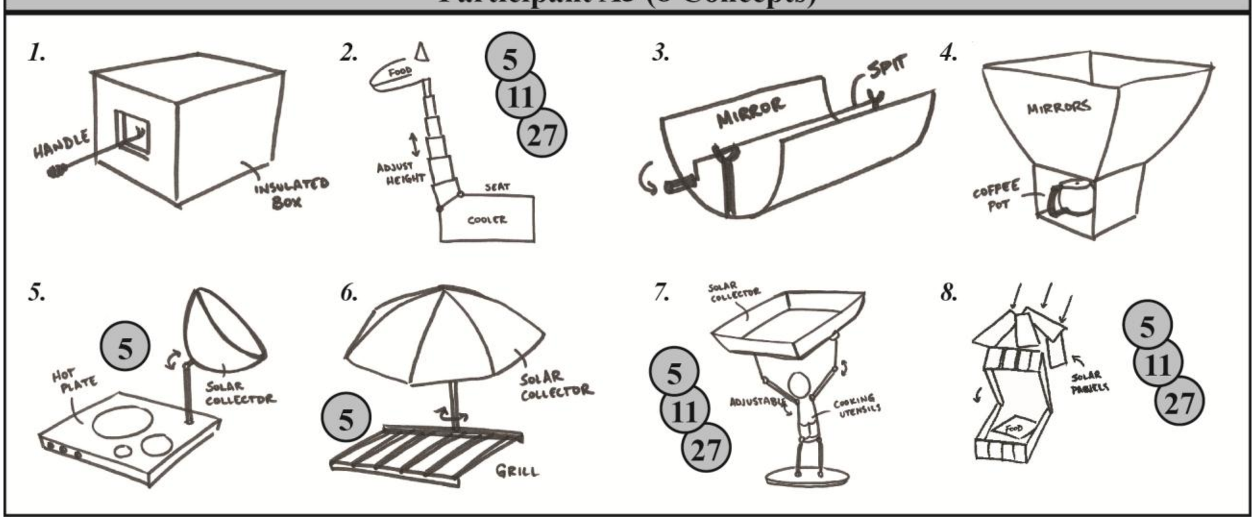


Figure 6: Concepts generated by Participant A3

Participant A4 used the most heuristics out of the five cases, totaling 15 applications of eight different heuristics. He developed four different concepts, tending to focus on products that could transform for storage or had additional functionality. For example, his first concept was designed to be a cooler with fold-out solar panels and legs, using the heuristics *Convert for second function*, *Extend surface*, and *Separate parts*.

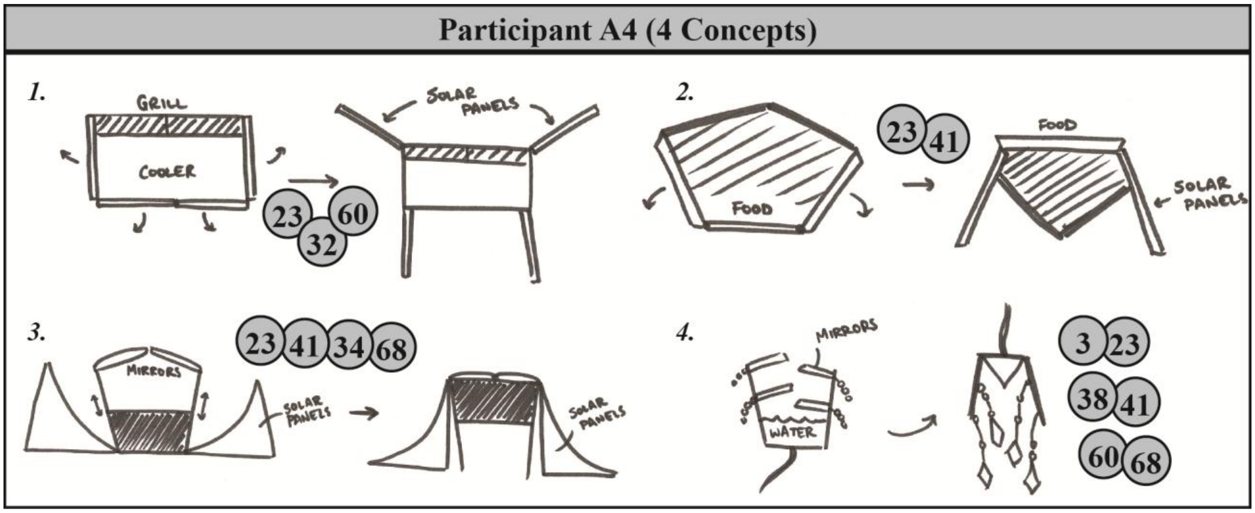


Figure 7: Concepts generated by Participant A4

Similar to A3, Participant A5 generated eight different concepts. However, she only applied the Design Heuristics two times, meaning that six concepts were developed without the use of the cards. She used *Rotate* to add a rotating spit to a black pot (concept 6 to concept 7), and separately used *Use common base to hold multiple components* to create a series of adjustable mirrors that all attached to the central cooking surface (concept 3).

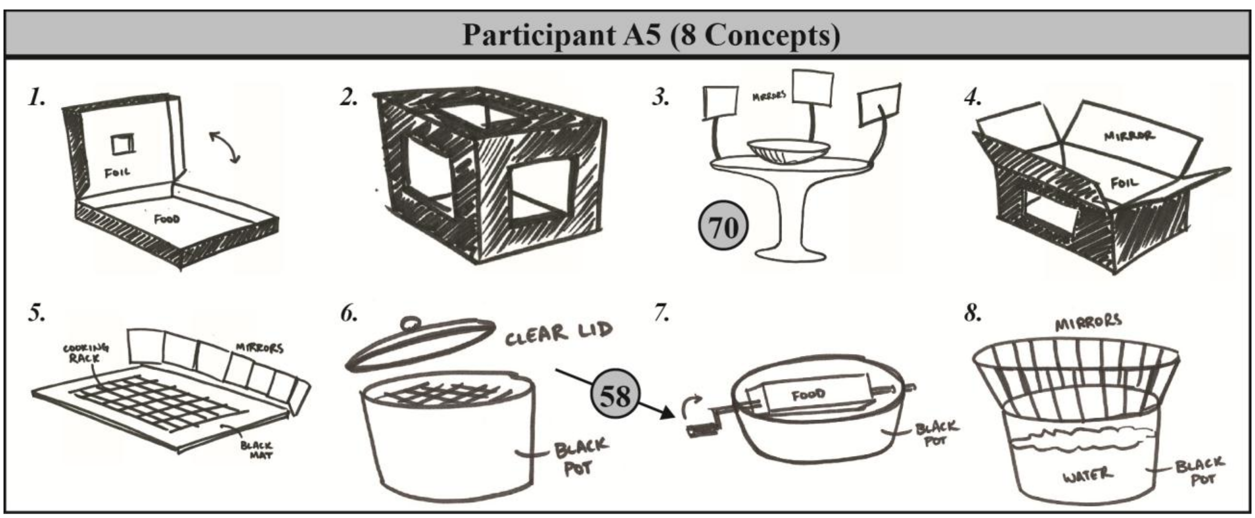


Figure 8: Concepts generated by Participant A5

Section B: Transformation
To analyze the five participants in section B, we identified each concept generated after the Design Heuristic training and the heuristics used in its development. We also compared the new concepts with those generated by the students before the workshop. Figure 9 shows the number of concepts before and after training. In addition, it shows a breakdown of transformative heuristic use (what we taught) and generative heuristic use. For example, participant B1 generated four concepts using Design Heuristics after training, three of which were transformations of previously generated concepts, while one had no strong similarities to any of the concepts she had generated before the training.

In total, the five participants generated 20 new concepts. Of these, 17 were transformations of concepts the participants had previously generated, while the other three appeared to be unrelated to any previous concepts. Fifteen of the 17 transformation concepts were driven by Design Heuristics that were provided in the session. All of the concepts that were not transformations showed evidence of generative design heuristic influence.

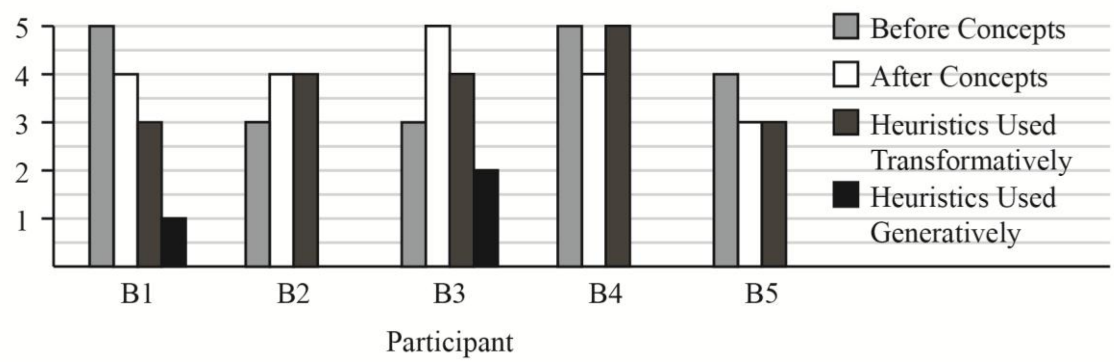


Figure 9: Concept and Heuristic use breakdown for Section B

The paragraphs and images below describe and show the concepts generated by each participant before and after training on Design Heuristics. Arrows represent heuristic applications to transform one concept into another.

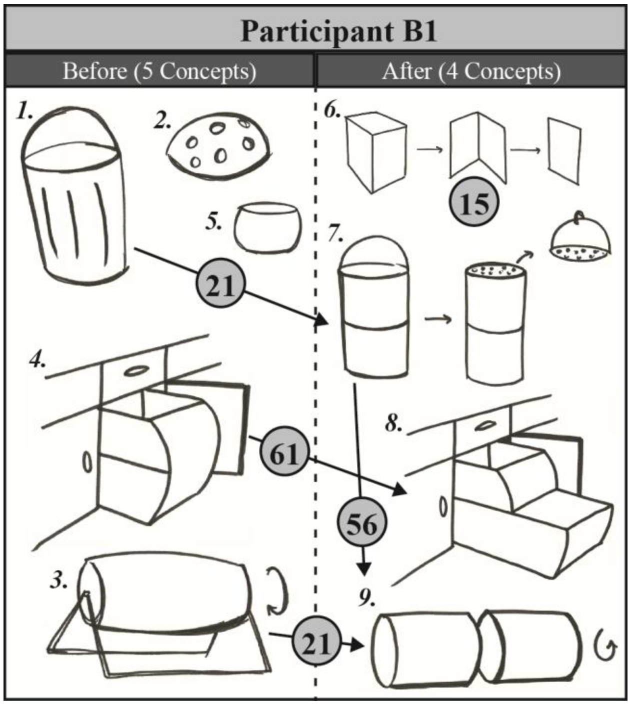


Figure 10: Concepts generated by Participant B1

Participant B1 had five previous concepts, and designed four concepts after training. She used *Compartmentalize* to take her idea of a trash can (concept 1) and separate it into two compartments for different stages of composting (concept 7). Then, using *Reverse direction or change angle*, she turned these two compartments on their side so that they could be rolled to mix the compost (concept 9). Her fourth concept was a cabinet with two compartments. To improve accessibility to both compartments, she applied *Slide components* to create concept 8. Using the heuristic card suggestion, she used *Bend* to generate concept 6, an idea for a collapsible composter that can lay flat for storage when not in use.

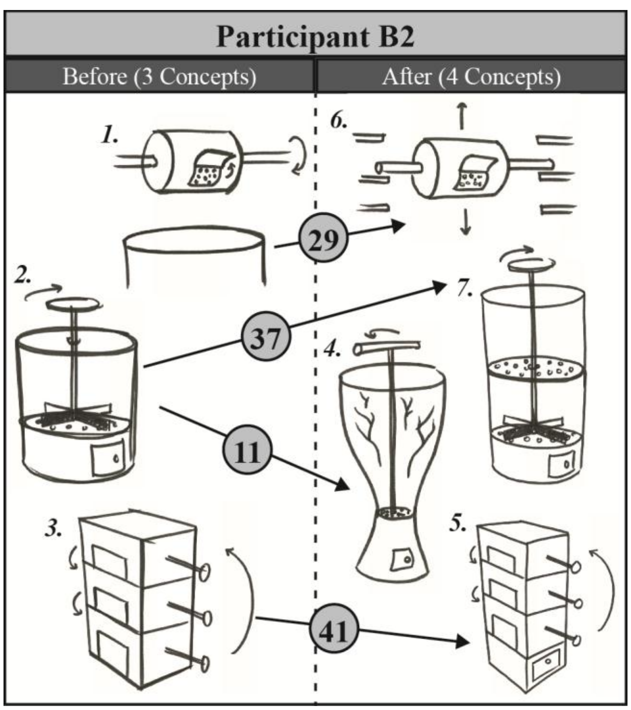


Figure 11: Concepts generated by Participant B2

Participant B2 had three previous concepts and four new concepts. The first previous concept, a rotating barrel that releases soil through a sifter to a catch basin, was transformed using *Elevate or lower* by adding a rack to mount the barrel at different levels (concept 6). She claimed this would allow the user to better customize the product to their needs. Concept 2 was modified to create new concepts in two different ways: First, she used *Animate* to add curves, a wooden turning handle, and colors to imitate a tree (concept 4). Second, she used *Impose hierarchy on functions* to add levels within the main chamber (concept 7), claiming that the compost "can't get to [the] next level unless composted enough." To concept 3, she applied the heuristic *Make component multifunctional* by adding a fourth compartment at the bottom of the stack that could store tools (concept 5).

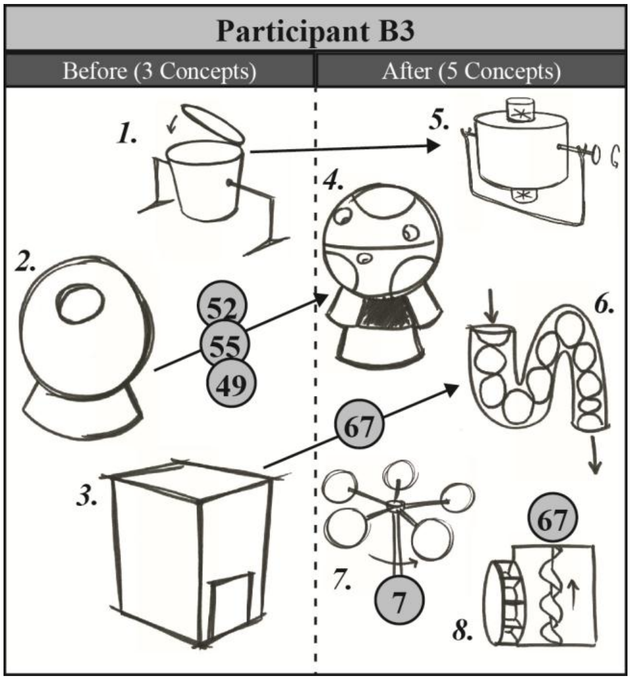

Figure 12: Concepts generated by Participant B3

Participant B3 had three previous concepts and five new concepts. In the first transformation, she added blenders to help mix the compost (concept 1 to concept 5). In the second transformation, she used the heuristics *Provide sensory feedback*, *Reduce material*, and *Repurpose packaging* to add handholds, allow the user to track temperature and oxygen levels, and provide a stable base, respectively (concept 2 to concept 4). In the third transformation, she used *Twist* to explore the possibilities of reducing odor (concept 3 to concept 6). She took a simple rectangular trash can, made it into an s-curve, and then added a long plastic liner that could be twisted to separate sections and isolate the smell. Concepts 7 and 8 were generated from heuristics, but showed no similarities with the before concepts. This suggests some novel concept generation occurred with the heuristics despite instructional efforts.

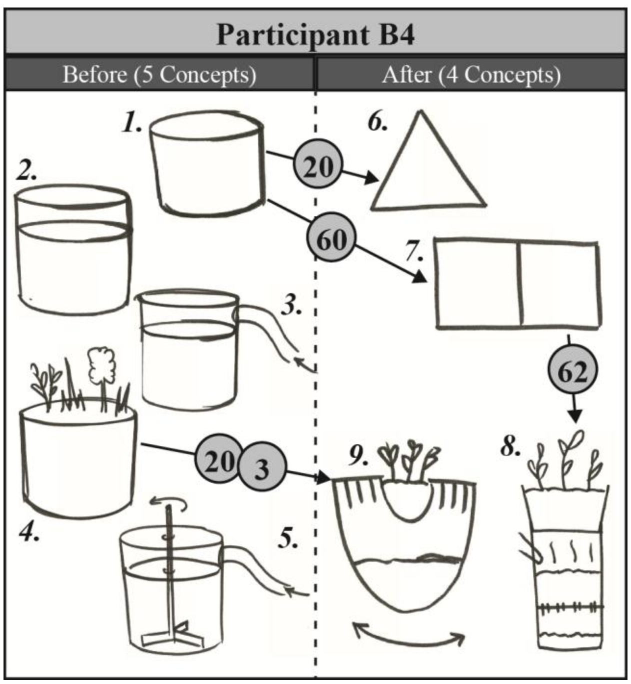

Figure 13: Concepts generated by Participant B4

Participant B4 had five previous concepts and four new concepts. The previous concepts were done iteratively, in that each concept built on the previous. The new concepts after training were all transformations of previous concepts. This participant also generated a concept that came from the synthesis of two ideas: First, she separated a chamber into compartments (concept 7) using the card *Separate*. Then, she stacked the compartments (concept 8), using *Stack*. Finally, she combined the result with concept 4 that incorporated a garden on the top surface.

Participant B5 had four previous concepts and three new concepts. She used no heuristics in her first transformation, adding wheels, a handle, and a sweeper to concept 1 to make a more functional alternative (concept 5). She then applied *Use alternative energy source* to change the input energy source from concept 2, thereby creating concept 6. Finally, she combined *Create system* and *Repeat* to turn her stackable worm bins (concept 4) into a hierarchical system with legs and a garden on top (concept 7).

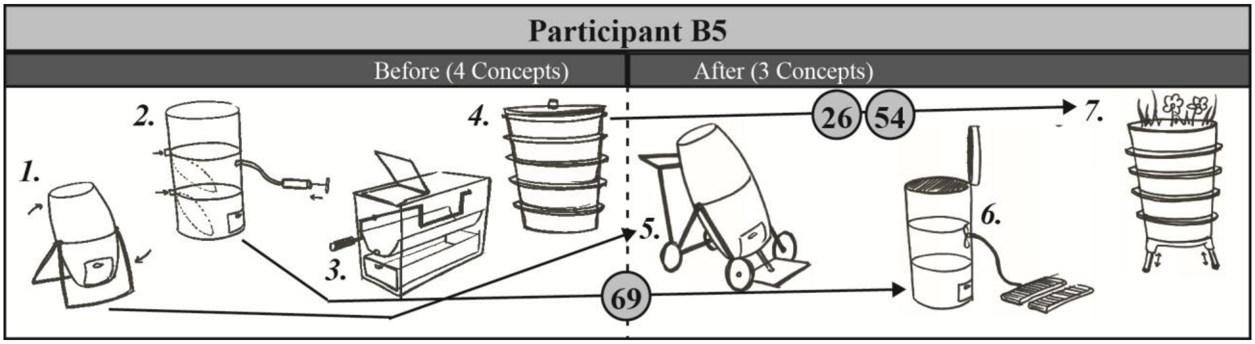

Figure 14: Concepts generated by Participant B5

**Discussion**

Students in both sections of the introductory engineering course used Design Heuristics effectively, and in primarily different ways: both generative and transformative applications were observed. The case studies analyzed for this paper revealed details related to the ways students applied Design Heuristics using both methods. Our observations are consistent with the hypothesis that training in Design Heuristics supported the generation of novel design possibilities, and the confirmation and extension of existing design ideas.

While we directed the use of heuristics in each section to be either generative or transformative, students applied the heuristics using both approaches in both sections. However, students were much more likely to use transformation in the section where they had already developed some existing concepts. For example, participant A5 took a black pot and added different components, such as a clear lid (concept 6), a rotating spit (concept 7), and an array of mirrors (concept 8), using transformations on new concepts. Participant B3 used heuristics to generate two novel, different concepts that did not have any connection to her previous concepts. Thus, participants in both sections exhibited an ability to apply the heuristics in either way. This shows that heuristics can be applied in both ways to both novel and existing concepts depending on the individual's preference or design process.

In both the generative and transformative applications of the Design Heuristics, students used the prompts to elaborate, or further specify, their design ideas. We did not observe a distinction in the level of elaboration between the generative and transformative approaches in the two sessions. Students commented that the heuristic prompts facilitated their consideration of all aspects of the project. For example, participant B3 used multiple heuristics to elaborate on the details of her spherical composter (concepts 2 and 4). In her description of concept 4, she wrote "…added features: indented handles for rolling, multiple doors, can be split in half and fit inside itself, has a base with a ramp…" All of these were additions to concept 2, inspired by Design

Heuristics. In section B, heuristics occasionally appeared to serve a role in confirming existing ideas (using heuristics to validate that an idea was good). But more often, the heuristics seemed to encourage students to push a particular concept further, or further elaborate it. In two of the twenty "after" concepts, there was no evidence of heuristic use, but these concepts were still transformations of "before" concepts. Students who had already been working on concepts for their design task tended to limit their exploration to transformations of ideas they had already generated.

Students also commented that the Design Heuristics made them more aware of the aspects of a concept they should consider or could change. Participant B2 said "It made me think more about features of the design, rather than being so stuck on the task." Thus, students used the heuristics to inspire novel ideas for the task, but also used the heuristics to transform planned product components. For example, participant A1 used heuristics to elaborate on the portability of his second concept, and participant B3 used *Twist* to elaborate on the inner workings of a previous concept (concepts 3 and 6).

Despite the success in concept generation observed in these studies, certain aspects of design fixation were still evident in both sections. Participant A2 generated only one concept. On the other hand, participants A3 and A5 generated eight concepts each, though many were similar to one another. For example, the way participant A5 made small transformations to the basic black pot resulted in three separate concepts that were very similar.

In section B, we observed design fixation in the development of the participants' "before training" concepts, and in the scope of transformations when applying Design Heuristics. Many of the participants' "before" concepts were close repeats of existing concepts found in existing urban composters. In fact, when asked to describe the concept origin of their "before" concepts, participant B1 identified sources such as "picture on the internet", "article", "movie", and "another teammate". When applying Design Heuristics to transform their "before" concepts, participants often made minor tweaks rather than larger changes. For example, participant B2 took her first concept (a rotating barrel that filters soil) and applied the heuristic *Elevate or lower* to allow the user to change how high it would rest. This may be explained by the way the heuristics are presented; for example, participant B1 used *Compartmentalize* to add a single compartment division to her first "before" concept. Without developing this notion or pushing beyond the most obvious application, the heuristic could be "rotely" applied, resulting in relatively small transformations. To combat this effect, it is possible that deeper discussion of heuristic transformations may be necessary to encourage students to more fully explore the potential solution space.

Considering the use of Design Heuristics by students in these cases, it seems that the transformative applications of heuristics corresponded more closely to an incremental type of innovation[33]. However, as Abernathy proposed, more radical forms of innovation are possible, and the generative applications of heuristics may lead to more innovation. Students who applied heuristics to generate new ideas from scratch seemed to have larger differences in their set of concept ideas, while students who applied heuristics transformatively seemed to make smaller, iterative improvements. This finding in our case study suggests further implications for how educators might use Design Heuristics in the classrooms. Specifically, pushing students in the initial idea phase by using Design Heuristics may provide a larger payoff in innovation than applying heuristics to known designs.

This paper presents a qualitative analysis of ten cases of student engineers in two different sections of a course. The goal of qualitative work is transferability, thus our study was not designed to generalize, but to understand the ways Design Heuristics can influence solutions created during idea generation. The results of this work will be used as a foundation for future, larger-scale research, as well as to further develop our recommendations for the use of Design Heuristics in engineering education.

## Conclusion

This study suggests that Design Heuristics are effective in idea generation for both novel designs, and for transforming existing designs. Students applying the heuristics tended to elaborate more, and create more diverse sets of concepts. Also, the heuristics played a role in encouraging students about their ideas and pushing them to continue exploring, revealing design possibilities even for students who felt “stuck” in their process.

From our findings in section B, we see evidence that preliminary, unguided, and non-exhaustive concept generation may foster unwanted design fixation. On the other hand, structured concept generation in section A, where we encouraged diverse and creative ideas with the use of heuristics, appeared to reduce some fixation. Therefore, we propose that an effective procedure would be to start concept generation with Design Heuristics framed as a generative method, and then return to these initial concepts using heuristics to transform, modify, and improve them. Of course, this recommendation requires additional testing and empirical verification.

The size of transformations (i.e., the change produced in moving from one concept to the next) when applying heuristics directly is often quite small, suggesting that it may take multiple heuristics, applied repeatedly and together, to lead designers away from their initial ideas. This research suggests we can improve our strategies to limit fixation during the early stages of the design process, which is an important observation given the difficultly previous researchers had in reducing the impact of fixation[13,34].


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