Supporting Idea Generation Through Functional Decomposition: An Alternative Framing For Design Heuristics

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This study explored how guided ideation can support concept initiation and development. We conducted a set of in-class activities in a junior-level industrial design studio at a large Midwestern US university with 20 students. Participants generated concepts individually while working on a previously defined problem. They performed a functional decomposition of existing concepts, then used a self-selected function to rapidly generate ideas in three stages over 45 minutes, supported by Design Heuristics cards. Through analysis of eight cases, we found that generated concepts were consistent with the originally defined function. The students' ability to create a range of solutions increased over time, and concepts became more divergent through each of the three stages. Use of Design Heuristics changed, beginning as a tool for divergent concept generation (ideation), moving to a more mechanical transformation of existing concepts (iteration), and concluding with a broader, more evaluative synthetic framing (recomposition). Based on these results, we offer implications for the integration of idea generation methods across multiple stages in design and engineering contexts.

Topics: Design methods and tools, Design for a sustainable life
Keywords: Design methods, Functional decomposition, Design Heuristics, Idea Generation, Problem framing

1 INTRODUCTION

Designers often struggle to create a large number and wide range of concepts (Ullman, Dietterich, & Stauffer, 1988)—a capacity known as divergent thinking (Dym et al. 2006; Eris, 2004). Divergent thinking involves producing multiple or alternative answers from available information; for example, making unexpected combinations and transforming information into unexpected forms (Cropley, 2006). Novice designers often struggle to think in divergent ways, only using convergent or synthetic behavior (Lawson and Dorst, 2009; Yilmaz, Seifert, and Gonzalez, 2010), even when they are asked to consider solutions that are unexpected, a behavior which requires both convergent and divergent thinking. In this paper, we investigate how stages of scaffolded idea generation can support designers in producing more, and more diverse, ideas. We combined two design approaches, functional decomposition (Umeda et al., 1996; Stone & Wood, 1996), which can help identify existing problem spaces, and Design Heuristics (Daly et al., 2012; Yilmaz et al., 2014), a method that guides concept generation and development. The relevant cores of each method, we propose, can be synergistically combined to support designers as they explicitly set constraints, using constrained problem framings to create innovative concepts and expand designers' understanding of the larger solution space.

2 BACKGROUND

Designers are engaged in a constant cycle of abductive reasoning, with definition, synthesis, and evaluation all happening concurrently in design activity (Rittel, 1987). Within this cycle, research on ideation—framed by cognitive psychology and creativity literature—has generally only focused on the initial emergence of ideas. Less work has focused on design activity within a more "natural" ideation-iteration-evaluation-recomposition loop that would be typical of design practice (Christiaans & Dorst, 1992). Design problems are usually open-ended and ill-structured (Cross, 2000; Jonassen, 2000), which requires the designer to engage in extensive structuring to understand and analyze them (Goel & Pirolli, 1989). The term "framing effect" in the design context refers to the fact that designers often respond differently to different descriptions of the same problem (Frisch, 1993; Tversky & Kahneman, 1981). The framing narrows the designer's approach to problem solving and the concepts generated (Shalley, 1991), suggesting that problem framing functions as a source of constraints in ideation. The setting of *productive* constraints has been shown to be vital for divergent thinking, leading to innovative outcomes (Biskjaer & Halskov, 2014; Stokes, 2009). Design problems are ill-structured, requiring task clarification (Pahl & Beitz, 2007) and the setting of sometimes-artificial constraints in order to limit complexity. These productive, sometimes decisive constraints provide bounds for the problem and may be helpful in identifying an initial problem space from which to explore new ideas. In this way, constraints can be an aid to divergent thinking when supported by an ideation method such as Design Heuristics, limiting the space in a productive way to guide perspective taking, allowing for multiple versions of productive constraints to provide multiple lenses on the problem space.

2.1 Design Methods as Cognitive Supports

Jones (1970) proposed an intellectual space for design methods within design activity, making some of the first references towards methods as a way of opening up the "black box" of design, making it accessible, visible, and perhaps most importantly, internally rational. While the notion of establishing and sharing successful design methods is not new (Jones, 1970; Smith, 1998), their codification and dissemination in more structured forms (e.g., Linsey et al., 2011; Martin & Hanington, 2012) is a relatively recent phenomenon. Design practitioners often view these tools as flexible and easily adapted, combined, or altered based on their affordances and "core," however, method developers must also demonstrate the method's appropriateness and effectiveness (Gray, Stolterman, & Siegel, 2014). We focused on two methods in our work and discuss them in the following sections.

2.1.1 Functional Decomposition

The core idea behind functional decomposition is that a given product can be defined by a hierarchical set of functions, which can be thought of as modular and thus replaceable (Umeda et al., 1996; van Eyk 2011). Functional decomposition is a commonly taught approach in many engineering programs (e.g., Booth et al., 2014), and this core idea has been applied in a number of forms. Simon (1996) noted that hierarchies in nature exist, and can evolve over time; thus, functions could describe a way to "see" and understand systems at work. From software engineering, cognitive approaches to decomposition often result in problem reframing, with the goal of an "effective separation of concerns" with "the resulting components…more likely to be reusable than those obtained by more conventional approaches" (Jackson and Jackson, 1995, p. i). The mental exercise of defining a system in a functional way—or what Umeda and Tomiyama (1997) refer to as *functional reasoning*—allows the designer to relate subfunctions to one another in a cascading hierarchy.

Functional decomposition is focused on the cognitive skill of breaking a larger system or product into smaller pieces, which can then be discussed separately. This strategy may serve as a way of explicitly setting bounds on the problem space, identifying necessary functional constraints, and systematically redefining the designer's understanding of the particular design challenge at hand (Stone & Wood, 2000). In early stages of concept generation, where the designer's understanding of the problem is murky and ill-structured, the cognitive skill of functional reasoning can serve as a way of reframing the problem to allow access to a fresh set of creative concepts to move the design process forward.

2.1.2 Design Heuristics

While not commonly integrated into engineering design courses, there are a variety of idea generation tools available (e.g., brainstorming, brainwriting, morphological analysis, Synectics, SCAMPER, TRIZ). These methods vary in their focus, specificity, and usability (Daly, et al., 2012), and while some are derived from actual engineering designs (e.g., TRIZ), none have been empirically validated nor assessed for their impact on ideation in rigorous ways. Design Heuristics has been both systematically derived and extensively validated in scientific studies (Daly et al., 2012; Yilmaz et al., 2014), cataloguing "design strategies" used by designers of various levels of expertise in their ideation approaches. The heuristics were developed from authentic design activity (e.g., Daly et al., 2012; Yilmaz & Seifert, 2011) and existing award-winning products (Yilmaz and Seifert, 2010). The set of 77 heuristics were compiled into a deck of cards, each of which includes the heuristic name, description, abstract visualization, and two examples of products representing this heuristic in use in a design (Figure 1). This design method has been validated in classrooms (e.g., Daly et al., 2012; Kotys-Schwartz et al., 2014; Christian et al., 2012) and professional contexts (Yilmaz et al., 2011; 2014), and has been found to produce more varied and creative concepts.

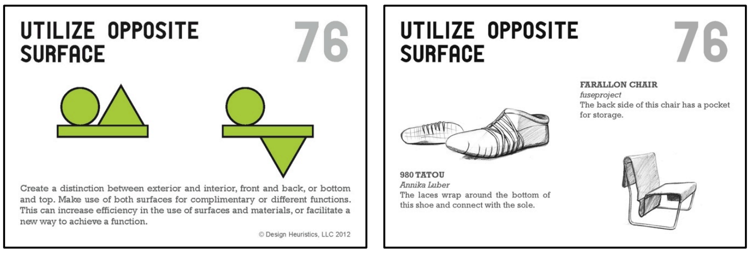

Figure 1. Sample Design Heuristics card (front and back).

Prior studies on ideation with Design Heuristics have focused on initial ideation with the tool (Daly et al., 2012; Kramer et al., 2014; Christian et al., 2012), with no preceding task to assist in framing the design problem, a task that can impact the success of ideation. The present study included (1) functional decomposition to help students frame the problem and also (2) multiple stages of ideation with the Design Heuristics tool, facilitating a cycle of ideation, iteration, evaluation, and recomposition typical of professional design activity (Dorst & Cross, 2001).

3 RESEARCH QUESTIONS

In this study, our goal was to explore the impact of functional decomposition and Design Heuristics through a facilitated design process. This approach was selected for three primary reasons: 1) the potential to build a richer understanding of the role of functional constraints in ideation, particularly in relation to cognitive supports; 2) to contextualize idea generation within a cycle of active iteration, evaluation, and recomposition of concepts; and 3) to examine a complex design process that includes the exploration of the problem space, allowing for documentation of potential barriers or thresholds where designers may need support. This study assessed the following research questions:

1. What functions did students select through functional decomposition, and what specific function did they choose to focus on?
2. How did the students' selected focus on function affect their concept generation at each stage (ideation, iteration, recomposition)?
3. How did the students' use of Design Heuristics affect concept generation at each stage?

4 METHOD

4.1 Participants

Twenty participants in a junior-level industrial design studio at a large research institution participated in the study (6F; 14M). All students were majoring in industrial design, and had been previously organized into five teams of four students each, with three females in T1 (Team 1), no females in T2, and one female each in the remaining three teams. Students worked in teams for a semester-long team project that focused on a "next generation" product line of kitchen products for millennial users.

4.2 Classroom Intervention

The classroom intervention took place in the fourth week of the class, during the initial idea generation stage. Students were previously asked to generate a series of detailed concepts as a group based on the problem space the teams had already identified (e.g., on-the-go eating, food preservation and storage). The study took place as a three-hour period of structured lecture and activities conducted during a regular studio session. The study included a short lecture on concept generation and functional decomposition, followed by two main activities: (1) individual design with four phases, and (2) two additional phases working in intact student teams. For the remainder of this paper, we will focus on the individual portion of the workshop (approximately 45 minutes). In this individual task, students performed a functional decomposition of their team's problem focus, and then used a selected function from this decomposition to generate concepts in three stages: ideation, iteration, and recomposition (Figure 2). These three stages were intended to encourage students to quickly generate (ideation), iterate, and synthesize (recomposition) their concepts in a time-compressed manner. This allowed for the introduction of a more complete design process within a limited period of time.

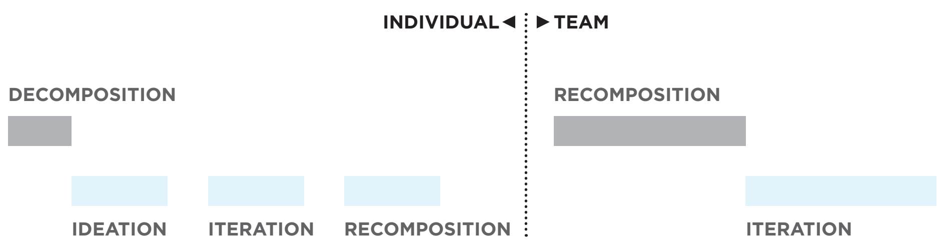

Figure 2. Classroom intervention overview, with focus on individual activities.

After a short explanation of the functional decomposition method with examples, students were given 15 minutes to create a "function tree," including a set of functions that are related in logical and hierarchical ways. Students created structured representations of functions with their interpretation of the team's problem focus at the center and relevant functions surrounding it. Before moving to the next stage, students were asked to select one function to focus on as an explicit concept generation constraint for the remainder of the individual portion of the study.

Students then moved through three 15-minute phases of concept generation—ideation, iteration, and recomposition—using their selected function. They were provided with a different set of five Design Heuristics cards selected at random from the 77 heuristics. After a short instruction on the use of the cards, they first *ideated* using the cards, generating as many concepts as possible. Then, they were encouraged to *iterate* on their ideas using a new random set of five cards. They were instructed to iterate at least once on each initial concept from the ideation phase. Finally, all students received a new random set of five cards for the *recomposition* phase, where they were encouraged to combine or distill their concepts prior to working in their teams. In all stages of the process, students were asked to sketch and label their concepts on paper, and to note on each page any use of the Design Heuristics cards. They were also asked to note when their current concept was based on a prior concept.

4.3 Analysis

Analyses examined all materials produced by students in the individual tasks. Concepts generated in each design stage were counted. They were then organized based on the stages in which they were produced (i.e., ideation, iteration, recomposition), while also noting any Design Heuristics cards the participant indicated using and any previous related concepts. One of the researchers identified the emergent themes of concepts for each set of concepts by stage, identifying how these themes changed or shifted between stages. For example, two concepts depicting alternative ways to divide space into compartments were scored within a single theme, while another using movable dividers to create separate spaces was scored as a separate theme. Following this initial analysis, a second researcher validated the relationships of sketches and the emergent themes identified. Any discrepancies were resolved through discussion. The themes are shown in Table 1.

5 RESULTS

Students' functional decomposition analyses resulted in trees with 4 to 20 functions identified, an average of 9.11 functions (SD = 4.53). Each student selected a single function for use in the design stages. Example functions include compactability, preservation, and customizability. Across design stages (i.e., ideation, iteration, and recomposition), students generated a total of 237 concepts, with an average of 11.85 concepts (SD = 4.06) each. All 20 students generated concepts in the ideation phase (n=133), 17 students generated concepts in the iteration phase (n=82), and only 8 students generated concepts in the recomposition phase (n=22). Thus, our analysis focuses on the 8 complete cases for the remainder of this paper. This subset of the dataset averaged 13.63 concepts (SD = 4.90) per student.

5.1 RQ1. What functions did students select through functional decomposition, and what specific function did they choose to focus on?

Students identified a range of functions through the process of creating a function tree. These functions seemed to be based largely on the problem space the teams as a whole had already identified (Table 1). Each student selected a single function for use in the design process as shown in the table.

We identified two distinct types of functions that students identified in their function trees, which do not necessarily represent functions in the formal sense of functional modeling, but were identified as "functions" by participants: directive and descriptive. *Directive* functions were possibly closest to those indicated by typical functional decomposition methods, identifying a discrete physical component or interaction with a clear action sequence; for example, the directive function "dries food" suggests drying through heating elements, fans, etc. *Descriptive* functions, which may be more aptly described as desired design characteristics, were noticeably more open, with an undeclared or ambiguous action sequence, leading to a more abstract sense of the component or interaction that might be indicated. For instance, the descriptive function "adjustable" suggests a range of interactive elements with specific affordances that may achieve the function (e.g., adjusting bigger or smaller). Four participants' functions were primarily descriptive (compartmentalization, space saving, compactable, adjustable), with an additional two participants' functions that were primarily directive (dries food, circulation). The remaining two participants' functions were more hybrid in nature, with one relating to descriptive qualities at a particular directive use case (cleaning) and the other relating to an descriptive affordance that also indicated a directive attribute (hand held).

5.2 RQ2. How did the function affect concept generation at each stage?

Table 1 describes the number of concepts generated within each design stage as well as a count of the variations in the types of concept generated.

5.2.1 Stage 1: Ideation

In Stage 1, all concepts (n=49) were related to the function that had been selected by the participant. However, the nature of the selected function appeared to alter the kinds of concepts that the participants generated. Participants proposed a range of concepts for each function in this stage (min=3; max=8), with a generally greater range or higher divergence of concepts resulting from the descriptive functions. An extreme case of a directive function, "dries food" (S5) resulted in solutions across four concepts that varied only in their heat source (e.g., element, cover, fan, motion). In contrast, a descriptive function such as "adjustable" (S4) resulted in five different themes of concepts across eight concepts: bigger/smaller (n=3), attaching components to customize product volume (n=1), using texture to cue the user's awareness of adjustability (n=1), customizing compartments within a product (n=2), and an integrated cover for a specific product type, a colander (n=1).

Table 1: Students' designs by function, number of concepts, and number of different themes of concepts generated in each stage. The number of concepts indicating the use of Design Heuristics is provided in square brackets.

	Selected Function	Stage 1: Ideation	Stage 2: Iteration	Stage 3: Recomposition	# of Themes
S1	compartments	**8 TOTAL [DH:3]** 2: dividers 5: compartments 1: product with parts	**6 TOTAL [DH:4]** 2: dividers 1: compartments 2: motion expand/slide 1: attachment	**3 TOTAL [DH:2]** 1: compartments 2: attach together	**6**
S2	space saving	**3 TOTAL [DH:2]** 1: hang in fridge 2: store by stacking	**2 TOTAL [DH:2)** 1: hang in fridge 1: flex cover	**1 TOTAL [DH:1]** 1: flex cover	**3**
S3	compactable	**8 TOTAL [DH:3]** 6: fold/fit inside 1: spin to close 1: cone	**6 TOTAL [DH:3)** 2: rotate/spin 3: bend/compact 1: cups on both sides	**3 TOTAL [DH:2]** 2: fold/twist 1: button to power	**8**
S4	adjustable	**8 TOTAL [DH:5]** 3: make big/small/tall 1: attach components 1: texture to cue interaction 2: customize compartments 1: colander	**8 TOTAL [DH:5)** 3: make big/small/tall 1: attach components 1: texture to cue interaction 2: customize compartments 1: colander	**3 TOTAL [DH:3]** 1: customize by user 1: recyclable 1: adjustable	**8**
S5	dries food	**4 TOTAL [DH:1]** 4: drying mechanism	**4 TOTAL [DH:2)** 3: mechanism altered 1: dry and moisten	**3 TOTAL [DH:2]** 1: multipurpose 2: assemble/configure	**5**
S6	circulation	**4 TOTAL [DH:3]** 2: vent/component 1: motion 1: human power	**2 TOTAL [DH:1]** 2: vent/ component	**2 TOTAL [DH:2]** 1: flatten components 1: toasting	**5**
S7	hand held	**8 TOTAL [DH:2]** 5: handles 3: multifunction pan/pot/plate	**5 TOTAL [DH:2]** 1: handle 4: multifunction pan/pot	**5 TOTAL [DH:4]** 2: multifunction pot/pan 1: pan topper 1: measuring aid 1: multifunction handle	**5**
S8	cleaning	**6 TOTAL [DH:3]** 2: dishwasher space 3: reverse/ flexible/popout 1: drain	**5 TOTAL [DH:3]** 2: dishwasher space 3: reverse/ flexible/popout 1: drain	**2 TOTAL [DH:2]** 1: flexible + dishwasher 1: flexible + nibs	**5**

5.2.2 Stage 2: Iteration

In Stage 2, participants were asked to explicitly iterate on their first set of concepts in a serial or combinatorial manner. Concepts generated in this phase (n=38) departed somewhat from the original function participants had selected, but were still related. S4 and S5 showed the least change in concept themes in this stage, with S5 adding one new concept theme (moisten in addition to dry), while S4 had no change in the number and distribution of concepts and themes. Participants also used this stage as a way to select a promising concept theme, weighing concepts within a particular them more highly in this second stage of concept generation. For instance, S7 created 8 concepts in the first phase, with 5 relating to handles and 3 relating to multifunctional pots/pans/plates; in the iteration phase, S7 created one concept iterating on the handle concepts, but centered the remaining four concepts on multifunctional pots/pans. In other cases, new concepts were formed out of different interpretations of initial concepts, as with S2's stackable sun dryers in the ideation phase reinterpreted without the stacking functionality in the iteration phase, while introducing a flexible, breathable cover.

5.2.3 Stage 3: Recomposition

In Stage 3, participants were asked to combine and synthesize their earlier concepts. Concepts (n=22) were generally resonant with the original function participants had selected, but often departed substantially from the concepts created in the first and second phases. Many concepts resulted from the combination of individual concepts, or more often themes of concepts. For instance, S8 combined concepts that included conservation of dishwasher space and a focus on the product surface properties and flexibility, resulting in a flexible, dishwasher-safe concept. Some students who started with a more directive function ended up expanding their range of concepts, as with S5's introduction of assembly and multipurpose functionality in her final concepts, drawing on but recontextualizing the core food drying technology from her earlier concepts (Figure 3).

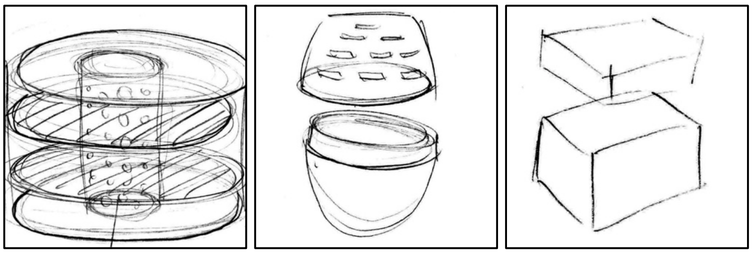

Figure 3. Transformation of S5's concepts across the three stages: from a focus on the heating core at the center (left) to a detachable top that activates the drying function (center) to a dryer that can also function as a storage container (right).

5.3 RQ3. How did the students' use of the Design Heuristics method affect concept generation at each stage?

5.3.1 *Stage 1: Ideation*

In this stage, students indicated their use of Design Heuristics in the majority of concepts (n=44/49). Because many of the cards that participants received modeled specific physical transformations of concepts (e.g., bend, mirror, utilize opposite surface), early uses of Design Heuristics seemed to broaden the characteristics after the concept was completed, to describe one or more elements of the concept. Initial concepts were diverse with regard to what function the design performed rather than the number of different Design Heuristics cards addressed. Most participants used a subset of the five cards they were given, applying it in different ways, with many focusing on the use of a single heuristic across multiple concepts.

5.3.2 *Stage 2: Iteration*

In the iteration stage, the majority of concepts were reported as using Design Heuristics (n=33/38), but the way these heuristics were used was much more evident when tracing the evolution of concepts from the ideation stage. Commonly, these new concepts were direct descendants of ideation concepts, with one key element or approach altered, as in Figure 4 where S3's initial product (folded down to compact) was changed to folding from the side after using the Design Heuristic #18: "change direction of access." The students' use of Design Heuristics in this stage was more synthetic, resulting in the combining of an existing concept with a new feature or altered physical form. Relatively few new concepts, less likely to have used Design Heuristics, were introduced, likely due to the constrained nature of this stage.

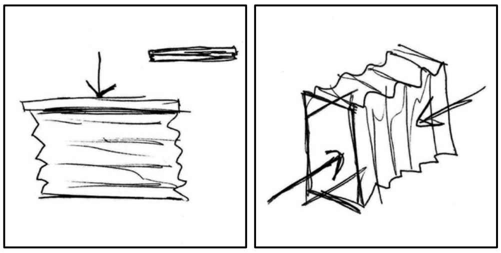

Figure 4. Evolution of concept from ideation to iteration using Design Heuristics. In this example from S3, "fold down" was changed to "fold horizontally' when using #18: "change direction of access."

5.3.3 Stage 3: Recomposition

In the final concept generation stage, participants used Design Heuristics in a fewer number of concepts (n=12/22). Most participants appeared to be focused on synthetic activities (e.g., combining, selecting) rather than explicitly iterative ones. However, participants who did use the Design Heuristics at this stage tended to recontexualize their concepts in interesting ways beyond mere synthesis (e.g., recyclability of materials, human-generated power), pointing towards a recomposition of the concept within a broader problem framing. For instance, S8 created a concept (Figure 5) for a product with a “living” pop-out flexible hinge (using #12: “animate”) in the ideation stage to facilitate placement in a dishwasher. In the iteration stage, he added rubber nibs to further aid in cleaning (using #22: “change surface properties”); and in the recomposition stage, he added similar nibs to flexible parts from another earlier concept, improving grip and discoverability of functionality (using #22: “change surface properties”; #29: “create system”; #73: “use packaging as a functional component”).

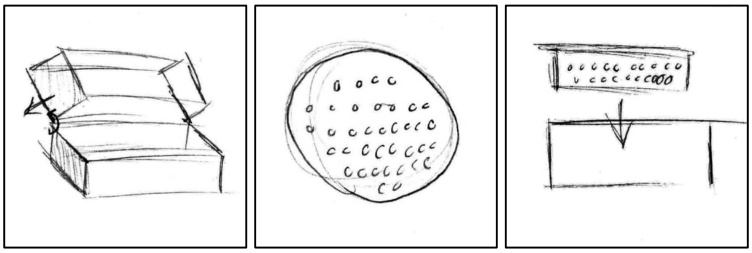

Figure 5. Evolution of one of S8’s concepts from ideation to iteration to recomposition.

In sum, 89 of 109 concepts generated across the three design stages incorporated at least one of the Design Heuristics. This suggests participants found the heuristics applicable to their concepts (as they were evident in the concepts generated in addition to students' reports on the heuristic they used for each concept), and usable with minimal instruction (as only 10 minutes of instruction was provided). The use of Design Heuristics resulted in the generation of a range of concepts, resulting in 3 to 8 different themes of concepts (M=5.6) across the three design phases.

6 DISCUSSION

From our study of design processes across these three stages, we propose that there was a synergistic relationship between students’ use of functional decomposition and Design Heuristics to create design concepts. While functional decomposition has been used in the past to facilitate an understanding of the design problem, including its components and related functions (Umeda & Tomiyama, 1997; van Eck, 2011), this study suggests a value in using a combination of idea generation and framing methods to identify generative design constraints that aid the student in artificially and temporarily limiting the solution space (Cross, 2001; Rittel, 1987; Stokes, 2009; Stone & Wood, 2000). Functional decomposition promotes consideration of the functions of a potential product from multiple perspectives, and on multiple levels. In this study, this initial functional consideration of the product and problem space then allowed the designers to productively generate concepts within a focused design space by using a selected function as an explicit constraint. Even without a full understanding of functions in a technical sense, the students’ idea generation—framed by the decomposition process—was nevertheless generative, and resulted in the creation of diverse concepts.

This study provided a first exposure to both the functional decomposition and Design Heuristics methods, and the instruction was limited. With more experience, students’ use of both methods may reflect different advantages of each method. While this small-scale study does not allow for definitive conclusions, it appears that the qualities of the function selected by students encouraged different forms of divergence, indicating a possible relationship between the function and the corresponding size of the constrained solution space. In particular, we noted that directive functions were often too prescriptive in terms of form, resulting in participants focusing on particular classes of solutions, while more descriptive functions resulted in a broader, more divergent set of solutions.

This study also, for the first time, investigated the use of Design Heuristics across three stages of design. The heuristics appeared to facilitate the generation of a relatively wide range of concepts within a limited framing of the problem, supported by the selection of a product function. Further, this combination of functional decomposition and Design Heuristics across multiple stages of concept generation suggests that pairing these design methods can support idea generation through the development of productive constraints, opening up potentially unconsidered portions of the solution space. This combined process encouraged students to first foreground an understanding of function within the design space, and then later, generate diverse concepts within that constrained space. The study suggests that combining a productive constraint with a generative method appeared to aid the design process by providing a focused search space and methods for identifying possible design solutions. This provides initial support for the notion that pairing methods of constraint identification with idea generation is helpful in promoting diverse design concepts. As a result of this process, participants in the study were able to create designs that differed significantly from their initial concept, and offered a variety of concepts to consider in later stages of the design process.

7 CONCLUSIONS

This small-scale study demonstrates value in studying design processes at multiple points, and using this understanding to design more effective support for the development of ideation flexibility throughout the design process. While past research has focused primarily on functional reasoning (e.g., Umeda & Tomiyama, 1997) at particular junctures in the design process, this study demonstrated that functional constraints impacted idea generation, even with relatively little developed functional reasoning skill on the part of participants. Similarly, it showed that ideation methods like Design Heuristics can be fruitful in intermediate stages of design where concepts are combined and reconsidered. Understanding the capabilities and barriers to success within a more holistic design process could lead to more targeted interventions that increase design expertise.

We have outlined one particular combination of two extant design methods, functional decomposition and Design Heuristics, as experienced by students in an industrial design studio course. These initial results suggest that functional decomposition was an effective tool in fostering systemic thinking on the part of design students, resulting in productive constraints to further aid the generation of innovative concepts. This process did not *determine* the concepts produced during ideation, but the type of function selected did affect the breadth of concepts created. Students also appeared to use Design Heuristics in distinct ways across the three concept generation stages, reflecting their growing understanding of the range of concepts that might exist within a solution space. This resulted in a nuanced application of Design Heuristics for exploratory, iterative, reframing, and synthetic activities.

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