What Problem Are We Solving? Encouraging Idea Generation and Effective Team Communication

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Abstract
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Keywords
Problem framing, Functional decomposition, Design heuristics, Affinity diagramming, Team communication

Disciplines
Art and Design | Critical and Cultural Studies | Industrial and Product Design | Interpersonal and Small Group Communication | Organization Development

Comments
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Abstract: Idea generation has frequently been explored in design education as an exercise of students’ “innate” creativity, and few tools or techniques are offered to scaffold ideation ability. As students develop their design skills, we expect them to demonstrate increasing ideation flexibility—a cognitive and social ability to see a problem from multiple perspectives, and to create more varied concepts within the problem space. In this study, we introduced three tools—functional decomposition, Design Heuristics, and affinity diagramming—to aid students’ ideation in a three-hour workshop. Participants included 20 students in a junior industrial design studio arranged in five pre-existing teams. These participants first decomposed the functions within an existing set of concepts they had generated, then selected a specific function and generated additional concepts using the Design Heuristics ideation method. Finally, teams organized these concepts using affinity diagramming to find patterns and additional concepts. Our findings suggest that this process encouraged students to try multiple ways of examining the existing problem space, resulting in a broadened set of final concepts. More striking, the instructional activities served to foreground differences in team members’ understanding of the problem they were addressing, fostering alignment of their problem statement and aiding in its further development.

Keywords: problem framing; functional decomposition; Design Heuristics; affinity diagramming; team communication
Introduction

The framing of a design problem is a key component of design thinking (Dorst, 2015; Paton & Dorst, 2011). Previous research has addressed the exploration of problem spaces (Cross, 2007; Goel & Pirolli, 1989; Schön, 1990), both through the application of productive constraints (Biskjaer & Halskov, 2014; Stokes, 2009) and the dialectic between problem and solution states (Dorst & Cross, 2001), in which problem framing can make a wicked or ill-structured problem tractable for individual designers and design teams. However, less is known about how designers and design teams develop consensus around problem framings in order to develop potential solutions, particularly early in their design education. While the reflective skills of articulating design decisions and building consensus around those decisions are hallmarks of expert design behavior (Lawson & Dorst, 2009; Nelson & Stolterman, 2012), the pedagogical scaffolds that are needed to effectively teach these skills have not been adequately identified.

Numerous scholars have suggested that sketching offers a unique insight into the creative process (e.g., Goldschmidt, 1997; Goel, 1995; Self & Pei, 2014) by externalizing design cognition in a visual form, forcing the individual designer to document potential design solutions. However, sketching as a method or tool does not necessarily constrain the student’s articulation of the problem space they are working within, and when sketches are externalized and isolated from the individual designer, can often be too ambiguous to build consensus without other forms of communication. When multiple stakeholders are engaged in the design process (as is most often the case), the alignment of problem space and potential solutions—as depicted through sketching and other communication tools used in early concept generation—becomes even more complex, requiring complex patterns of communication in order to reach an understanding among team members (e.g., Cross & Cross, 1996; Nelson & Stolterman, 2012).

The issues of team communication, dialogue, and negotiation are critical in forming an understanding of how design is practiced; however past design research has focused primarily on the relationship of the individual designer to the created artifact. However, Cross and Cross (1996) offer an early example of how team alignment and the roles of designers within the team can affect the ability to build consensus and work efficiently. McPeek and Morthland (2010) focused on the development of communicative patterns that facilitated alignment and understanding within student teams, including a common dialogue and language. In addition to these more general studies of team alignment, and the elements of interaction that facilitate this alignment, some scholars have focused more closely on problem framing and its role in facilitating and sustaining alignment. Stumpf and McDonnell (2002) operationalized Schön’s concept of reflection-on-action between team members as a way to make the frame negotiation process explicit, with team recognition of major shifts in framing as a productive step towards producing aligned concepts. Hey, Joyce, and Beckman (2007) expanded on the idea of frame negotiation as a cycle of frame setting, where students’ individual frames are systematically made explicit, which then raises potential conflicts between individual frames, ultimately leading to the construction of a shared frame.

Reflection-on-action is valuable to externalize and explain the situated design judgments of an individual designer (e.g., Holt, 1997; Schön, 1985) on both the design decision and problem framing levels. But team-based design requires not only externalization, but also negotiation. Nelson and Stolterman (2012) refer to the object of
negotiation as the desiderata—or “that-which-is-desired”—which reinforces the need to understand design intentions in a specific, situated design process. The negotiation of the desiderata, which encompasses the problem framing along with the dimensions of ethics, aesthetics, and reason, is at the core of developing a team design solution. Yet there is little research addressing the mechanics of this alignment process, particularly in relation to ideation and the continued development of a collective understanding of problem framing. So, while we know that designers constantly engage in a dialectic between problem and solution (Dorst & Cross, 2001; Maher & Tang, 2003), it is less clear how this dialectic forges alignment between team members.

Three Design Methods

For this study, we selected three existing, complementary design methods to scaffold the generation of ideas and help students gain an understanding of the problem space. The first method, called functional decomposition (e.g., Booth et al., 2014), encourages the generation of productive constraints. The second method, called Design Heuristics (Daly et al., 2012b; Yilmaz et al., 2014), provides strategies or shortcuts for designers to generate multiple, varied concepts. The third method, affinity diagramming (e.g., Hanington & Martin, 2012; Kawakita, 1975), encourages the sorting and grouping of data to understand potential relationships. The relevant cores of each method, we propose, can be synergistically combined to support designers as they actively and explicitly set design constraints, and then use that constrained problem framing to create innovative concepts.

Functional Decomposition

Functional decomposition is a method commonly used in engineering (e.g., Booth et al., 2014). It describes a product or system by means of its functions, often oriented in a hierarchical way. Thus, when a product is defined in terms of functions, each function can be thought of as modular or replaceable to some degree (van Eyk, 2011), and this decomposition provides insight into how a system works. In order to adequately describe a product or system in terms of its functions, an engineer must have the cognitive skill that Umeda and Tomiyama (1997) refer to as functional reasoning—an ability to understand subfunctions of a product, and to relate them to each other in a logical, hierarchical manner.

A common approach to functional decomposition in the classroom is to begin with an existing product or system and decompose the primary and secondary functions in order to identify the hierarchy of functions present within an extant design (Toh, Miller, & Kremer, 2012). This approach often includes not only conceptual decomposition, as in software engineering (Jackson & Jackson, 1996), but also a physical product dissection in order to encourage students to understand how component functions relate to each other (e.g., Booth, Bhasin, Reid, & Ramani, 2014; Lamancusa & Gardner, 1996). In this study, we focus on conceptual functional decomposition, using the resultant understanding of functions as generative constraints to further develop early concepts (Gray, Yilmaz, Daly, Seifert, & Gonzalez, forthcoming).

Design Heuristics

A variety of idea generation techniques and approaches have been introduced in the engineering and design literature (e.g., SCAMPER, TRIZ, morphological analysis). Design
Heuristics is an evidence-based method for encouraging the production of varied concepts during idea generation (Daly et al., 2012b; Yilmaz et al., 2014). Design heuristics were derived from award-winning products (Yilmaz & Seifert, 2010) and the design activities of expert designers (Daly et al, 2012b; Yilmaz et al., 2010; Yilmaz & Seifert, 2011). The 77 identified heuristics comprise a catalogue of “cognitive shortcuts” that can be used in generative ways to transform or modify design concepts. This method has been extensively validated in studies of ideation in engineering and design classrooms (Christian et al., 2012; Daly et al., 2012a; Kotys-Schwartz et al., 2014; Kramer et al., 2014; Yilmaz et al., 2012). The Design Heuristics are presented on a deck of 77 cards, with each card including a heuristic, a written description, an abstract depiction of the heuristic, and two examples of the heuristic as it is used in consumer products (Figure 1).

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

### Affinity Diagramming

A final method introduced to the students in the study is the use of affinity diagramming (Hanington & Martin, 2012) to create clusterings of potential concepts that support the selection of a final product design direction. This method originated as a way to understand relationships between complex sets of qualitative field data (Kawakita, 1975), and has been widely used in business settings and participatory design to encourage the collaborative grouping of information, with participants distilling this information into themes or clusters that may drive further development or iteration.

### Purpose

In this study, we addressed the gap in research on the team negotiation of problem framing through a situated design project in an industrial design context. We focused on individual and team understandings of problem framing, and how these understandings affected idea generation and selection. While the majority of research on idea generation strategies have focused only on individual or team behaviors, in this study, we address the movement from team to individual processes and back to team through the process stages of problem framing, idea generation, and recomposition of concepts using the following research questions:

1. What individual and team problem framings did students rely on when performing their functional decomposition?
2. How did the students’ selected focal function and resulting concepts relate to their individual and team problem framing?
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3. How did the scaffold of three design methods influence the nature of divergence in concept generation and sorting relative to initial and revised problem framing?

Method

Participants
Twenty students (6 female and 14 male) in a single junior-level undergraduate industrial design course at a large Midwestern U.S. university participated in the study. These students were organized into five teams of four students at the beginning of the semester, and all teams engaged in an industry-sponsored semester-long project on the development of innovative kitchen products related to rising food costs, the future of food, or the unique needs of millennials.

Classroom Intervention and Problem Statement Evolution
The study took place as a workshop held during a three-hour class session (Figure 2), during the fourth week of the semester. The workshop included a set of activities to facilitate the generation of divergent concepts through three methods: individual functional decomposition of existing concepts, individual concept generation using Design Heuristics, and affinity diagramming in teams. In preparation for these activities, each team was asked to produce ten detailed concepts related to a previously defined problem, and these team-generated concepts informed the individual functional decomposition noted in Figure 2.

Data Collection
Beyond the specific intervention, classroom activities supporting individual and team problem framing throughout the semester were used as a secondary data source. In this study, we drew upon three separate groups of problem statements created by each team during the classroom intervention: 1) an initial set of problem statements completed individually by each team member in the first week of the semester, resulting in a total of 18 potential problem statements from three starting statements, forming iterative “ladders” of related statements; 2) a team problem statement supported by the initial
research created in the third week of the semester; and 3) the final team problem statement included in the end-of-semester process book.

The concept data from the classroom intervention include: 1) team-generated concepts immediately prior to the intervention; 2) individual concepts generated across three sequential 15-minute stages (ideation, iteration, recomposition); 3) team clustering of individual concepts, which includes the composition of concepts and cluster names; and 4) the final concepts generated by each team at the conclusion of the intervention. These primary data sources are contextualized within the problem statements generated before and after the intervention, including the relationship of generated ideas to the final design at the conclusion of the semester.

**Analysis**

Data were analyzed using several strategies focusing on the longitudinal development of a problem statement within each team, and the relationship of that problem statement to the concepts each team member created and then clustered with other team members’ concepts. We first identified emergent themes from the team-generated concepts prior to the intervention, relating these concepts to the previously defined problem statement. In isolation, we then analyzed the labeled clusters of concepts identified by each team, including the composition of concepts from individual team members. These clusters were then related to the initial problem statements generated by individual team members in the first week of the semester, and the correspondence of final concepts generated by the team to the problem statement the team had generated collaboratively. Finally, these clusters and problem statements were compared to the completed design at the end of the semester. All comparisons were initially made by the lead researcher, and then were confirmed and altered where necessary by a second researcher familiar with the classroom intervention until agreement was reached.

**Results**

In the classroom intervention, five teams of students generated a total of 237 concepts across the three design stages (i.e., ideation, iteration, and recomposition), with an average of 11.8 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). The number of sketches varied somewhat by team, with the lowest averaging 9.5 sketches (SD=5.2) per team member in Team 1 (T1) and the highest average of 14.5 sketches (SD=4.2) in T2.

All teams generated concepts in the final stage following the clustering activity, with an average of 4.0 concepts (SD=2.3) each. The affinity diagramming activity resulted in an average of 5.6 clusters (SD=2.4; min=3; max=9), with each cluster including an average of 6.8 concepts (SD=4.6; min=3; max=26). Out of the 237 total concepts students generated, 189 were organized into labeled clusters; 3 concepts were not organized into a cluster; the remaining 45 concepts did not appear to be represented in team activity (M=2.4; SD=2.26). A summary of the team problem statement, individual functions selected by team members to direct their ideation, team clusters, and final concepts are included in Table 1.
<table>
<thead>
<tr>
<th>Team</th>
<th>Initial Team Problem Statement</th>
<th>Individual Functions After Functional Decomposition</th>
<th>Team Concept Clusters After Affinity Diagramming</th>
<th>Team End-of-Semester Problem Statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>System-based solution to improve upon portion control, food preservation, &amp; waste</td>
<td>Compartmentalization Ease of Access Space saving (N/A)</td>
<td>Accessibility (n=4) Adjustable Dividers (n=5) Exterior Adjustability/Space Saving (n=8) Interior Adjustability (n=12)</td>
<td>How can we create a system that discourages millennials from throwing away food at home?</td>
</tr>
<tr>
<td>2</td>
<td>...this system will work towards saving space, minimizing waste, maintaining taste &amp; nutrients, &amp; decrease amount of time.</td>
<td>Compactable Hold Adjustable Fold Down</td>
<td>FFB (n=4) FFP (n=6) FPT (n=3) Inset stackable (n=3) Lid (n=4) Misc. (n=7) Sliding lids (n=5) Stackable (n=8) Strainers (n=2)</td>
<td>How could we create a system that encourages millennials to connect with one another while preparing a meal?</td>
</tr>
<tr>
<td>3</td>
<td>The proposed dehydration solution will be combined with a microwave and/or convection oven to provide faster access to dehydrated produce, accommodating a busy lifestyle.</td>
<td>Collapsible Dries food Air circulation (N/A)</td>
<td>On-the-go (n=26) Preparation (n=10) Preservation (n=7)</td>
<td>Facilitate an emotional connection with a food preservation system that encourages healthy and personalized snacking experience.</td>
</tr>
<tr>
<td>4</td>
<td>Generate products that increase convenience, support and encourage the principles of a healthy lifestyle, and tie in a community facet within the preparation and consumption of meals.</td>
<td>Be held Covering of base Intuitive use Unique experience</td>
<td>Attachments (n=11) Coverings (n=9) Handles (n=9) Serving (n=6) Storage (n=3)</td>
<td>How could we compose an engaging interaction specifically adapted to the eating habits of the dynamic millennial lifestyle?</td>
</tr>
<tr>
<td>5</td>
<td>Develop a system, which will re-invent the perception of 'on the go eating' that conforms to the lifestyles &amp; eating habits of health-conscious millennials.</td>
<td>Give user experience Emotional Cleaning Versatility</td>
<td>Customizable Container (n=3) Lid (n=6) Other (n=4) Flexible Cleaning Mechanisms (n=5) Storage Mechanisms (n=7) Experience Consumption (n=6) Storage (n=6)</td>
<td>Promote an experience that accommodates eating habits which reflect the diverse lifestyles of the out and about millennial.</td>
</tr>
</tbody>
</table>

Based on the initial summary and descriptive statistics of all five teams, we selected two contrasting cases from this intervention, representing diversity in the number of generated concepts and the apparent degree of alignment among team members around a central problem framing.
Team One: Divergence Through Multiple Interpretations of the Problem Space

Team One (T1) included one male and three female students. In previous problem framing activities, they had generated a wide range of potential problem framings, first in laddering exercises performed individually (18 framings per team member), and then later in a collaborative one-page summary document drawing on several themes based on the individual laddering exercises. These concepts were primarily combining elements rather than selecting or synthesizing. The resulting problem statement was broad, with the team focusing on a “system-based solution to improve upon portion control, food preservation, & waste.”

Initial Concepts

Prior to the classroom intervention, T1 created 10 concepts in a collaborative manner, working within the problem framing that had previously been set. The team’s concepts primarily addressed issues involving extending or enhancing existing functions within an existing refrigerator or freezer system (e.g., shelves, drawers). As shown in Figure 3, the concept drawings were developed as relatively detailed marker comps, including callouts and arrows to indicate movement. Eight of the 10 concepts dealt directly with organizing or making food in the refrigerator/freezer more accessible, with the remaining two concepts targeting space-saving elsewhere in the kitchen. Although all of the concepts addressed the overall problem framing, they lacked any sign of integration, and instead were viewed as separate entities.

![Figure 3](image)

Figure 3  A sample of T1 initial concepts, generated prior to the classroom intervention.

Individual Decomposition and Ideation

During the functional decomposition stage, each team member produced a function tree based on their understanding of the concepts and problem space that had previously been defined. It appears that Participant 1 (P1) recognized opportunities outside of the refrigerator (Figure 4, top) because her function tree focused on the temporal context of use, with elements of the problem statement embedded in each function. In contrast, P3 focused on an area less defined by the problem statement: namely, storage (Figure 4, bottom).
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![Diagram](image.png)

Figure 4  Comparison of P1 (top) and P3 (bottom) function trees.

When ideating using their individual understanding of the problem framing, team members took different approaches to divergence within the problem space based on their selected function. P1 focused on compartments that functioned in and out of the refrigerator by exploring mechanisms shared between containers to save space and provide a degree of adjustability. P3 focused on reducing common issues a user might encounter when storing food in a refrigerator. Both participants used Design Heuristics extensively in all of the phases where they generated concepts, frequently beginning with a concept relatively similar to one of the ten team concepts, and then refining or reworking that concept using a Design Heuristics card as a modifier (Figure 5). For instance, several of the team concepts included items being “attached” in some way to each other or to the wall of the refrigerator or freezer space. P1 used these concepts as a starting point, identifying a storage form that could expand or contract to fit the contents (using heuristic #32: “expand or collapse”), and connecting containers together with suction cups (using heuristic #13: “apply existing mechanism in a new way”).
In total, the four team members produced 38 concepts, 28 of which indicated use of one or more Design Heuristics. The concepts were widely varied within the originally defined problem space. P1 focused on the function of “compartmentalization,” and generated concepts relating to compartments, dividers, and other forms of expansion/contraction or attachment to other container elements. P2 did not provide a function tree, but her concepts related primarily to compression, crushing, and bending container forms to fit tight spaces. P3 focused on the function “ease-of-access,” creating mechanisms that slid out or attached to fridge in some way, with unrelated container concepts that had soft edges or soft/hard ribs to promote flexibility. Finally, P4 focused on the function “space saving,” and produced concepts that worked in and out of the refrigerator, including stackable components, flexible covers, and hanging jars.

**Team Affinity Diagramming**

During the affinity diagramming phase, the team members worked together to sort their concepts into groups or clusters. Unlike the previous individual phases, the process of sorting the concepts generated by all of the team members encouraged externalization of the rationale for the concepts, and discussion of how they related to the concepts of other team members. T1 struggled to identify commonalities between their concepts, generating several possible groups before finalizing four categories (Table 2).

Some of the indecision in relation to the cluster names is visible in the final affinity diagram (Figure 6). The cluster titled “transfer” has no concepts assigned to it, whereas the “adjustable” cluster is linked to the external and internal adjustability clusters. These two clusters represented the most alignment among team members, with all participants creating concepts in one or both clusters. However, the other clusters were comprised of concepts created by only one or two team members. Interestingly, when considering phase of production (i.e., ideation, iteration, recomposition), only the interior and external adjustability clusters included concepts from the final recomposition phase.
Table 2  Summary of T1 clusters.

<table>
<thead>
<tr>
<th>Cluster Name (# using Design Heuristics)</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Space saving/ Exterior adjustability (n=6)</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Interior adjustability (n=10)</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Adjustable dividers (n=4)</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Accessibility (n=4)</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Unassigned (n=4)</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>9</td>
</tr>
</tbody>
</table>

Figure 6  T1 affinity diagram.

Final Concepts
Following the clustering of individual team members’ concepts, students were directed to “recompose” concepts from the clusters to form new concepts they could move forward with as a team. T1 created two different concepts (Figure 7): a band to hold silverware in the refrigerator (left) and a microwaveable container that could keep a compartment of food cold while heating the other compartment’s contents.

Figure 7  T1 final concepts, generated by all team members.
Interestingly, neither of these concepts appears to have a direct origin in the individual team members’ concepts. Instead, they provided a new set of framings within the overall problem space. Arguably, these concepts do not fit within the three broad categories identified in the original problem statement (i.e., portion control, food preservation, waste); however, they make sense as a progression of the storage concepts explored by P3 and the containers designed for multiple stages of use by P1. While the team did not appear to come to consensus on their problem statement in this intervention, the variety of concepts generated by the team members encouraged an in-depth conversation about desirable problem framings. The final project presented by this team at the conclusion of the semester was present, in initial form, in the intervention, with significant resemblance to the refrigerator slider concept produced by P3. This concept (Figure 5, bottom), while later valued, was not included in any of the clusters produced by the team, indicating a lack of fit within the clusters or a lack of alignment around this concept at this stage of the team’s work.

**Team Five: Divergence Through Intentional Segmentation of the Problem Space**

Team Five (T5) included three male students and one female student. As with T1, they had generated a wide range of potential problem framings through laddering exercises and a collaboratively created summary document. Unlike T1, however, the resulting problem framing was more narrow and purposeful, with a relatively exclusive focus on “on-the-go” eating. This statement unified the team’s ideation efforts in terms of context (e.g., eating while on the move) and target outcomes (e.g., healthy eating).

**Initial Concepts**

Unlike T1, T5 took a very different approach to the initial concept generation phase. As demonstrated by T5’s initial ten sketches (Figure 8) generated prior to the classroom intervention, the concepts dealt with the storage of food while focused on a particular facet unique to the subject (e.g., the experience from eating out of a container). A wide range of graphic styles and approaches were used, representing multiple team members’ contributions. This variety is in contrast to the homogenous visual style from T1, likely indicating a single author for all sketches. This early approach to engaging variety across all team members appears to have enabled the team to cover large portions of the target problem framing.

*Figure 8  A sample of T5 initial concepts, generated prior to the classroom intervention.*
Individual Decomposition and Ideation

During the decomposition stage, T5’s alignment as a group became more visible. Because of the clear and unified problem statement, with all team members engaged in addressing the topic of "on-the-go" eating, the function trees were considerably more consistent across team members (Figure 9). In particular, all trees branched from a unified “on-the-go” problem, a stark contrast to the variation seen in T1. From this point, however, T5 took on a “divide and conquer” approach by systematically addressing a range of behaviors implicit in eating while on the move, with each team member selecting a complementary perspective. In doing so, the team used the function trees to select functions and explore the problem space in a divergent manner, addressing the need for cleaning, versatility, portability, and experience. Overall, the team’s evident early alignment positioned them to blend resulting concepts, with multiple perspectives working towards the same ultimate goal.

While T5 members were aligned around their problem framing, their individual perspectives and selected functions allowed them to take different approaches to diverge on the concepts they had already created. P18 was focused on the emotional experience of product use, while P19 addressed common issues that might appear when cleaning containers. Both of these participants used Design Heuristics extensively in all of the stages in which they generated concepts, often modifying concepts generated in the first idea generation stage in later stages (Figure 10). For instance, the combination of containers with multiple compartments or elements were a common theme in the initial concepts. P18 started in this general space, first creating a bowl that could be flipped to serve, with the lid functioning as a plate. In a later iteration phase, P18 refined this concept further using heuristic #50 (“provide sensory feedback”) to add the functionality of a scale to the plate. Similarly, P19 used Design Heuristics to transform initial hunches about potential cleaning issues into new concepts. P19 started by identifying a product that could easily...
bend to fit into a dishwasher rack, with a flexible middle portion. Later in the idea generation session, this participant modified this “bendable” concept to include a more accessible lock that could be clicked (heuristic #50: “provide sensory feedback”) by moving a clasp (heuristic #2: “motion”). All participants in T5 exhibited similar transformations of concepts, with several visible threads of concept iteration using Design Heuristics.

![Concepts](image)

Figure 10  Sample concepts generated by P18 and P19 which exemplify use of Design Heuristics in generating concepts. One of P18’s concept sequences includes a “flip and serve” bowl (top left), which is then modified with heuristic #50 (“provide sensory feedback”) to include a display of the weight of the food (top right). P19’s concepts also show a similar iterative development, with a bendable container that bends to fit more easily into the dishwasher (bottom left). This concept was extended using heuristic #2 (“motion”) and #50 (“provide sensory feedback”) to include a quick release clasp and snap for washing (bottom right).

In total, the four team members produced 46 concepts, 38 of which indicated use of one or more Design Heuristics. The concepts were widely varied within the originally defined problem space, but all strongly related to the selected function. P17 focused on the function “user experience,” experimenting with unique container forms, attachments, and ways of stacking or collapsing elements, focusing on portability and user friendliness. P18 focused on emotional qualities by attempting to impart an emotion in the course of using the product, relying on transformations of objects through rolling or orientation shifts to provide a memorable user experience. P19 addressed cleaning as his function, experimenting with different materials and mechanisms to ease the process of cleaning. And finally, P20 focused on the versatility, exploring a variety of inserts or additions to increase configurations or capabilities without altering the core container.

**Team Affinity Diagramming**

T5 then worked together to sort their concepts into clusters. Because the team members were already aligned in their overall problem framing, they began by reiterating an explicit problem statement, writing it next to their eventual affinity diagram (Figure 11). This statement appeared to guide the clusters they would develop:

“Design a solution that provides users w/ a system that is customizable, gives affordances for flexibility & storage, and provides users w/ an experience.”
Unlike any other team, T5 created nested clusters, with three top-level clusters of “flexible,” “customizable,” and “experience” (Table 3).

Table 3  Summary of T5 clusters.

<table>
<thead>
<tr>
<th>Cluster Name (# using Design Heuristics)</th>
<th>P17</th>
<th>P18</th>
<th>P19</th>
<th>P20</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexible</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Storage mechanisms (n=5)</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Cleaning mechanisms (n=5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Customizable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Container (n=2)</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Lid (n=6)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>Other (n=4)</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td>4</td>
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<tr>
<td>Experience</td>
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<td></td>
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<tr>
<td>Consumption (n=5)</td>
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<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Storage (n=5)</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Unassigned (n=6)</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>9</td>
</tr>
</tbody>
</table>

Within each of these clusters, sub-clusters were created to further distinguish among concepts. It is notable that all of the top-level clusters included concepts from all team members, with most of the gaps in sub-clusters among team members resulting from the explicit functions each member uniquely pursued. Only the “customizable” cluster included concepts from the recomposition phase of the idea generation exercise.

Figure 11  T5 affinity diagram.
Final Concepts

After clustering the team members’ concepts, T5 used the newly defined problem statement to “recompose” concepts from the clusters. Unlike any other team, T5 team members generated concepts in the recomposition stage individually (Figure 12). They drew upon their conversations as a team, but retained their individual understanding of the “next steps” for developing their problem space. This strategy not only resulted in a greater variety of concepts than in other groups, but also a larger quantity of total concepts, with an additional nine concepts in this phase alone.

Final concepts varied widely in T5, with many drawing on multiple concepts from the team (Figure 12). In general, it appeared that the team members found it easier to recompose these concepts because the elements were significantly more interchangeable than those of T1. This is likely due to the complementary set of functions the team members chose, and their joint understanding of how these perspectives fit together, as demonstrated in their refined problem statement. The team’s final product design at the end of the semester blended a number of the concept approaches explored in this classroom intervention, resulting in a hybrid, compartmentalized water bottle and snack container (similar to the second concept by P20 above).
Discussion

These two cases illustrate different ways in which functional decomposition, Design Heuristics, and affinity diagramming can encourage team alignment and divergent concept generation. T1 created an exceptionally broad and multi-faceted problem space, and a lack of explicit alignment among the team members in relation to that problem space. This appeared to lead to the development of several isolated clusters of concepts, and provoked a broader discussion about where the team wanted to focus moving forward. These isolated clusters were based on different interpretations of the team’s problem statement which, when broken down to the functional level, resulted in clusters of concepts that were not complementary. Due to this lack of conceptual alignment and divergence at the problem level (rather than concept level, as in T5), the affinity diagramming activity encouraged externalization of team members’ assumptions about what the problem space should include, and which interpretation they were willing to proceed with in the next stages of concept development. In contrast, T5 agreed on a more narrowly stated problem framing, and team members were generally aligned around what kinds of concepts would address their chosen space. As a result, rather than team members creating isolated clusters of concepts, T5 participants selected functions representing complementary aspects of the overall problem framing (e.g., user experience, emotion, cleaning, versatility). They diverged in their perspective on the design problem—choosing elements to foreground and background—but not so completely that their approaches were in conflict.

These differences in team alignment surrounding the understanding of a shared problem space—and by extension, a singular desiderata—underscores the importance of scaffolding activities that encourage team communication. As we will discuss in more detail below, only through aligned problem frames does convergent or divergent activity become clear to the team at large; and, without this realization, the dialectic movement between problem and solution (Dorst & Cross, 2001) can lead to frustration and tension among team members rather than productive engagement.

Alignment of Problem Frames

In the early problem exploration process, the majority of individual and team problem statements were quite broad, representing or defining spaces that did not narrow the complexity of the overarching client problems. This breadth, particularly in the team problem statements, seemed to stem from the variety of individual framings that existed among the team members. Then, when creating the group statement, multiple framings were combined rather than selected or synthesized. The resulting problem space was too large due to this union of multiple frames, and further complicated through the engagement of multiple stakeholders (i.e., team members). The result was a series of misunderstandings among team members about what constraints within that space were appropriate or desirable (e.g., “frame conflict;” Hey, Joyce, & Beckman, 2007). While the concepts that teams brought to class the day of the intervention represented a first step towards consolidating the problem space, these concepts were not sufficient to align the team’s differing frames. Instead, articulation of the constraints and features of the problem space—or bringing the tacit understandings of the team members into explicit
communicative acts—was required (McPeek & Morthland, 2010; Stumpf & McDonnell, 2002).

**Relationships of Divergent and Convergent Behaviors**

Success in idea generation and development relies on both divergent and convergent thinking (Cropley, 2006; Dym et al., 2006; Yilmaz & Daly, 2014); however, students generally need more support to generate divergent concepts, particularly in academic environments that may not value play or speculation. In this study, divergent idea generation was supported through individual use of Design Heuristics, and was critical in creating a space for teams to effectively converge on ideas later in the design process. While students in these groups went about diverging ideas in different ways—the first team in a more chaotic, ad hoc way, and the second team in a more systematic way—the result was the same: a move towards convergence based on their team’s breadth of divergence, individually and collectively. The group clusters reified this divergence, leading to a conversation that helped to identify individual understandings of the problem space, and which convergent paths might be most beneficial.

![Figure 13](image)

**Figure 13** *Dialectic of Divergence and Convergence (DDC) Model, illustrating the shaping of the problem space boundaries through individual and group activities.*

**Idea Generation to Stimulate a Dialectic Movement Between Divergence and Convergence**

Numerous methods exist that have the potential to scaffold divergent or convergent thinking (e.g., Hanington & Martin, 2012), but this study suggests a need to focus on the dialectic between these two modes of exploration. In particular, the relationships between divergent/convergent behavior through situated methods use and the impact of the broader problem framing are poorly understood, even when using empirically validated tools such as Design Heuristics. In this study, we have shown how the setting of decisive and generative constraints, supported by functional decomposition, Design Heuristics, and
What Problem Are We Solving?

Affinity diagramming in an instructional intervention, can encourage both types of thinking and exploring, and movement between these modes of design.

This study suggests that the multiple scaffolded “shifts” in problem framing and structured ideation are productive to the development of design expertise, especially in relation to practicing a expert-like dialectic movement between problem and solution. As seen in Figure 13, the students were guided through multiple framings of the design problem, drawing on both team and individual understandings of the problem space over time, resulting in a dialectic of divergence and convergence (DDC). The framing that students developed through individual work and team concepts prior to the classroom intervention was used to structure individual idea generation, followed by team evaluation and clustering of the resultant concepts. While additional exploration is needed to validate which DDC approaches may be most valuable in specific instructional settings or for classes of design problems, it appears that multiple shifts between team and individual work, and between individual and team framings, resulted in increased team alignment and productive idea generation in this study. Of course, our analysis drew from a relatively small sample in a single context, and may not be directly generalizable to a larger design education population. In addition, specific aspects of the present study, such as the order of method presentation, and which methods were carried out individually and in teams, should be studied in future research. Future studies may include permutations of the order of methods and individual or group work to validate particularly generative sequences using the DDC model.

Conclusion

We have demonstrated one set of methods that encourages the dialectic movement between problem framing and solution generation. The DDC model we have presented has some similarities with techniques in individual and team research that take advantage of differential strengths in individual and group processes, such as the Delphi method (see Pahl, Beitz, Felhusen, & Grote, 2007 for a review relevant to design). The process of working through the DDC appeared to be productive, both for teams that already enjoyed team alignment, and for teams that needed to challenge and verbalize their latent assumptions regarding the target problem space. Individuals were first encouraged to narrow from their initial framing to a specific function through the generation of a functional decomposition tree, selecting a function that would serve as a decisive constraint. Following this convergent behavior, participants were then able to generate ideas within a narrowed, yet purposefully divergent space using Design Heuristics. Finally, the team affinity diagramming activity encouraged individuals within the team to relate their concepts to those produced by other team members, a primarily convergent activity. This final step required a rapid dialectic movement between individual concepts and the broader goals of the team project, including problem statements, problem framings, and observed synergies between individual concepts. The results of this study have a number of implications for design educators, including: (1) additional ways to conceive of team alignment early in the design process, which impacts motivation and, eventually, the success of the design team; (2) the need for a series of robust design methods or other empirically-validated tools for guiding the design process between divergence and convergence stages; and (3) the value of responding to the “right” question as a team by
proposing solutions directly addressing the target problem in idea generation, which is contextualized through a shared awareness of the problem framing being utilized.

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References


