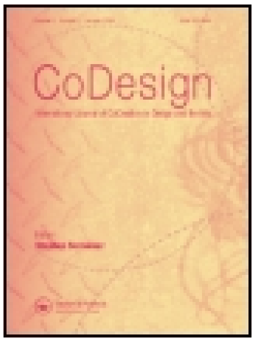

CoDesign

International Journal of CoCreation in Design and the Arts

ISSN: 1571-0882 (Print) 1745-3755 (Online) Journal homepage: http://www.tandfonline.com/loi/ncdn20

Usability tests of ideation flexibility tools with engineering design practitioners

Seda McKilligan, Kathryn W. Jablokow, Shanna R. Daly & Eli M. Silk

CODESIGN, 2017
https://doi.org/10.1080/15710882.2017.1325909

Usability tests of ideation flexibility tools with engineering design practitioners

Seda McKilligan[a], Kathryn W. Jablokow[b], Shanna R. Daly[c] and Eli M. Silk[d]

[a]Industrial Design, College of Design, Iowa State University, Ames, IA, USA; [b]Engineering Design & Mechanical Engineering, Penn State University, Malvern, PA, USA; [c]Mechanical Engineering, University of Michigan, Ann Arbor, MI, USA; [d]Graduate School of Education, Rutgers University, New Brunswick, NJ, USA

ABSTRACT

In an engineering context, ideation flexibility is defined as an engineer's ability to move between his or her preferred and non-preferred ways of generating ideas as required by the current task. In this study, the usability of three specific tools for enhancing the ideation flexibility of engineers—the Problem Framing Guide, Design Heuristics and Cognitive Style-Based Teaming—was investigated with design practitioners in a real-world setting. The performance and perceptions of 16 professionals were analysed as they explored design problems and solutions using these tools in a 3-h workshop. Study outcomes show that all three tools have value in design ideation, with room for improvement in terms of structured instructions for their use. Additionally, results suggest that cognitive style does not influence an individual's performance with or perceptions of these tools, which supports their value and validity for a general practitioner audience.

ARTICLE HISTORY
Received 24 January 2017
Accepted 28 April 2017

KEYWORDS
Conceptual design; design cognition; design tools; ideation flexibility; usability testing

1. Introduction

The increasing complexity of unsolved technical problems makes successful engineering ideation essential to human progress and survival. Early phases of design, including the generation of potential solutions, have a significant impact on design product cost (Pahl and Beitz 1996; Römer et al. 2001), thus a need exists to research and develop empirically based tools to support ideation in engineering (Adams et al. 2011; Dym et al. 2006; Sheppard et al. 2009; Smith et al. 2005). Three existing tools based on theory and research—the Problem Framing Profile, Design Heuristics (DH) and Cognitive Style-Based Teaming—are proposed to support ideation flexibility, which is defined as the ability to generate ideas across a spectrum of thinking from radical to incremental solutions (Helm et al. 2016; Yilmaz et al. 2014)

The development of successful tools relies on understanding 'would-be' users (Nielsen 1993). In the case of ideation flexibility tools for engineers, this means engineering students, educators and practitioners. We engaged one group of potential users, practitioners from an engineering firm, in an early 'usability test' (Dumas and Redish 1993; Rubin 1994) to

CONTACT Seda McKilligan seda@iastate.edu

evaluate the tools and the ways they are taught. Usability testing is an established practice in user-centred design, defined as a systematic way of observing actual users applying and interacting with an artefact and collecting information about specific ways in which the artefact is easy or difficult for them to use (Dumas and Redish 1993). Usability studies inform design iteration (Gould 1988), so our primary research goal was to understand how engineering design practitioners interfaced with the ideation flexibility tools and the effectiveness of the tools in enhancing ideation flexibility, both of which will guide their further iteration and development. An important criterion of a usability test is the early establishment of goals for the test. Our goals in this usability study were as follows.

(1) Assess the value, ease and effectiveness of implementing our ideation tools with practitioners;
(2) Collect practitioner data to compare and combine with data collected in engineering classrooms;
(3) Gain insights into how our tools can be made more practical for industrial settings.

2. Design ideation

The primary goal of early ideation is to generate promising concepts to pursue; a large quantity and diversity of ideas often represents success in terms of the idea generation process, where the goal is to generate many promising solutions from which to choose and then pursue through the design process (Brophy 2001; Liu, Bligh, and Chakrabarti 2003). One measure of diversity is the degree to which a solution would cause a shift to the current paradigm (Abernathy and Utterback 1978), with incremental solutions improving on existing solutions for which infrastructure and processes have already been established, and radical solutions representing tangentially new concepts for which greater technical and market uncertainties exist. Ideas can be mapped on this continuum from incremental to radical, with no greater or lesser value attached to any particular position overall (Kirton 2011). Diversity in ideation is supported through the generation of a range of ideas that span the incremental to radical change continuum.

An individual's cognitive style—one's stable, characteristic cognitive preference for managing structure—impacts the types of solutions he or she will generate (Jablokow and Kirton 2009; Kirton 2011). Cognitive style can be measured using the Kirton Adaption–Innovation inventory or KAI® (Kirton 2011) and ranges along a continuum from highly adaptive to highly innovative, with individuals who are more adaptive preferring more structure, thus generating ideas that fit existing paradigms, and individuals who are more innovative preferring less structure, thus feeling more at ease generating ideas that break existing paradigms. KAI total scores fall between 32 and 160 based on the KAIs 32-item structure; each item receives a value of 1–5 points depending on the user's response. For large general populations and across cultures, distributions of KAI total scores form normal curves with observed means close to 95 (SD = 17) and observed ranges within (43–149). In general, lower KAI scores correspond to more adaptive cognitive styles, while higher KAI scores correspond to more innovative cognitive styles. Individuals can generate ideas that are not in alignment with their cognitive style using coping behaviours; ideation tools can

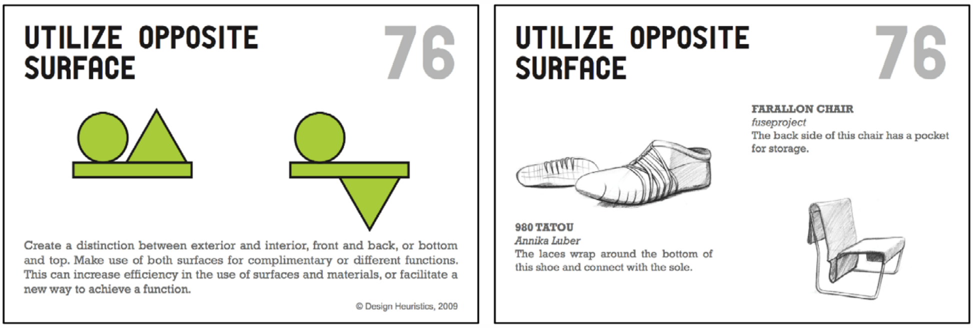

Figure 1. Heuristic Card Example: Utilise opposite surface.

facilitate these coping behaviours. The tools we developed were based on three factors to facilitate coping—ie the way a problem is framed, the DH used and the characteristics of co-designers on the team.

Problem framing includes the way a problem is stated, word choices and the boundaries described. A design problem defined using neutral (non-leading) instructions results in individuals relying on their habitual strategies (O'Hara and Sternberg 2001), while changing the problem instructions can impact these habits. Explicit instructions can enable individuals to break out of their natural responses in favour of different strategies to better address particular situations (Silk et al. 2014a, 2014b). Thus, different descriptions of the same problem can yield different solutions (Tversky and Kahneman 1981).

Many design tools exist to guide idea generation; one such tool is DH (Seifert et al. 2015; Yilmaz et al. 2016a, 2016b). The DH ideation tool provides cognitive prompts that guide designers in their explorations of possible design solutions during ideation (Gray et al. 2015; Kramer et al. 2015; Yilmaz et al. 2015, 2016a, 2016b). Each prompt is represented on a card (Figure 1); the front includes a descriptive title, action prompt and an abstract image depicting the heuristic; the back includes two product examples. Previous work with the DH has shown that they support designers in generating creative, diverse and practical ideas during concept generation and development (Daly et al. 2012; Kramer et al. 2014; Yilmaz et al. 2013; Yilmaz et al., 'comp. of des. app'. 2013).

Team members' ideation styles and approaches can impact the ideas a designer generates. Group ideation sessions are often promoted as important vehicles for the development of creative ideas (Sutton and Hargadon 1996), especially when the team is diverse (Page 2007). While there are mixed recommendations with regards to what types of diversity are best for innovation, cognitive diversity can allow teams to explore solutions they would not have explored otherwise (Paulus 2000). With regards to cognitive style, the just-noticeable-difference (JND) between individuals for KAI is 10 points (Kirton 2011). This means that individuals are unlikely to notice cognitive style differences when ideating with someone with a KAI score that is within 10 points of their own score (in either direction), while with larger gaps, individuals are more likely to realise their teammates are using a different approach and generating different types of ideas.

3. Usability study design

User-centred design (UCD) is a broad term used to describe design processes in which end-users influence how a design takes shape (Abras, Maloney-Krichmar, and Preece. 2004; Corry, Frick, and Hansen 1997; Dumas and Redish 1993; Norman 1988). Within this context, usability testing refers to a critical step in the user-centred design process in which designers can explore, refine and validate ideas based on how users engage with a prototype (Dumas and Redish 1993; Nielsen 1993). Usability testing has roots in classical experimental methodology (Rubin 1994); the general process entails: (1) define specific goals for the test; (2) recruit real users as participants; (3) have the participants engage in real tasks; (4) observe and record what participants do and say; and (5) analyse the data, diagnose problems and recommend changes (Dumas and Redish 1993).

In this paper, we report on the usability testing of three specific tools designed to enhance ideation flexibility; this testing occurred in the context of a workshop conducted with engineering practitioners at a manufacturing firm that specialises in printing and converting of flexible packaging materials for food, medical and industrial products. At the time of this study, company personnel were in the process of changing the engineering culture in the firm and investigating opportunities that would help them bring more ‘innovative’ solutions to their ongoing challenges. To help them address these challenges, we proposed a 3-h workshop with a focus on tools to support ideation to investigate how engineering practitioners used and perceived these tools in their search for ideas.

3.1. Step 1 (define goals)

Our usability test research goals included:

- How do industry practitioners use and perceive the ideation flexibility tools?
- What revisions do the usability tests suggest for the ideation flexibility tools for practitioners and what are the implications for design educators?

3.2. Step 2 (recruit real users)

Sixteen professionals from the same company participated in the full 3-h workshop in which the ideation flexibility tools were introduced. At the time of this study, company personnel were in the process of changing the engineering culture in the firm and investigating opportunities that would help them bring more innovative solutions to their ongoing challenges. As part of this process, they brought together a selective group of employees who were involved in new product development and the innovation process. Table 1 presents their respective positions/job titles, departments, domains of expertise, degree levels and demographic data (age, gender).

3.3. Step 3 (define real tasks)

Three design problems were constructed to serve as contexts for participants to use with the ideation flexibility tools. These problems were developed iteratively in collaboration with the technical director of the company, who was also responsible for innovation

Table 1. Demographics of the workshop participants involved in the study.

Current position	Department	Domain of expertise (Degree)	Age	Gender
VP Operations	Management	Engineering (BS)	53	M
Director of Technology	Technical	Engineering (BS)	37	M
Technical Director	Technical	Engineering (MS)	58	M
Technical Director	Technical	Engineering (MS)	45	M
Technical/Systems Manager	Technical	Industrial Technology (BS)	30	M
Technical Manager	Technical	Engineering (MS)	52	M
Applications Manager	Technical	Engineering (MS)	54	M
Senior Applications Dev. Engineer	Technical	Science (BS)	62	M
Applications Development Engineer	Technical	Engineering (BS)	37	M
Product Development Engineer	Technical	Engineering (BS)	25	F
Product Development Engineer	Technical	Engineering (BS)	28	M
Technical Specialist	Technical	Engineering (BS)	27	F
Technical Specialist	Technical	Engineering (BS)	34	M
Corporate Purchasing Manager	Purchasing	Business (BS)	60	F
Logistics Manager	Purchasing	Business (MS)	43	M
Corporate Procurement	Purchasing	Education (BS)	27	F

Table 2. Design problem statements (neutrally framed).

Design problem	Problem statement
Problem 1	Most granola bars are in wrappers, which are packaged with cold seal adhesive. The package shape and function are almost the same as a candy bar wrapper. Your design challenge is to create a package that would allow the consumer to eat a portion of the product and then reclose the package for later consumption
Problem 2	Many frozen food products are packaged in a carton or a box. Some of the reasons to stay in boxes include: (1) having particular machinery that cannot produce the more valued side gussets, (2) production speed when working with bag in box and (3) lower cost. Design a packaging solution for frozen food that will incorporate flexible packaging without hiding the package within a carton. Consider solutions that will focus on fill process, shelf appeal and cube utilisation and additional conveniences the packaging could provide to the consumer
Problem 3	Consumers want convenience in packaging both in terms of the size and the access to the product. Some products are needed for cars, bags, offices, or simply while travelling. Today's society is rushed in constant motion. Many people value time more than money. These individuals don't desire to take a bigger package and break it up to smaller packages that can be safely transferable. Design a packaging solution that will allow for compartmentalising with easy separation and access. Consider solutions that can be stackable on the shelf

management. A key factor in this construction was the relevance of each design problem to the company's product line. The great advantage of a co-designed problem is that it is 'situated' (i.e. relevant to the organisation) and easily accepted as an applicable problem. Once the design problem context was determined, the problem statements were structured in a neutral framing (Silk et al. 2014b), meaning they encouraged individuals to generate ideas using their natural, preferred cognitive approaches. Neutrally framed problem statements include the problem context, need and goals for ideation, but they are stated in basic form, without additional constraints or criteria (Table 2). Each problem statement ended with the following instructions: 'Develop solutions for the problems provided. Be sure to write each solution on a different piece of paper, and use drawings to sketch your ideas. It's important that you do your best and continue working for the full time of the activity'.

3.4. Step 4 (gather data)

Data collection occurred before, during and after the workshop. One week before the workshop, participants were asked to complete an online survey, which included questions on demographic information and each participant's role and experience in the company. They were also asked to complete the KAI (Kirton 1976).

At the beginning of the workshop, we provided background on our research and discussed best practices for ideation. We then tasked participants to generate ideas according to their natural preferences to establish a benchmark for natural ideation behaviours. Participants were given ten minutes to generate design solutions for Design Problem 1 (framed neutrally) and record them on idea sheets with sketches and written descriptions. A brief discussion followed, with questions on different approaches to problem-solving and whether it was challenging to come up with creative ideas in general.

Afterwards, we introduced Problem Framing Profile with instructions on how adaptively and innovatively framed problems might be used to direct practitioners to generate diverse solutions. After illustrating the framing of a sample design problem in three different ways (neutrally framed, adaptively framed and innovatively framed), participants were asked to re-frame Design Problem 1 four times—two versions using an adaptive framing and two versions using an innovative framing—and record these statements on a framing sheet. They were given 10 minutes for this session; then we engaged them in a discussion on how framings lead them to different types of ideas.

The other two tools were subsequently taught in the same manner, including the activity and discussion time. While prior research has established that the DH 77 Cards tool supports divergence (the process of generating alternative concepts) in idea generation (Author, Year), our goal here was to explore if and how the tool influenced practitioners' ideation flexibility, where ideation flexibility refers to the process of generating solutions based on one's preferred and non-preferred ways of generating ideas as required by the current task. Each participant was provided with the same subset of 10 randomly chosen cards from the 77 Cards deck and asked to use them to generate ideas for Design Problem 2 on idea sheets. The discussion after the activity focused on how participants used the 77 Cards and the types of ideas they generated with them.

Using the final tool—Cognitive Style-Based Teaming—eight dyads were formed based on participants' KAI scores: four heterogeneous and four homogeneous. The homogeneous dyads were constructed with cognitive style gaps between 0 and 6 points, whereas the gaps for the heterogeneous dyads ranged from 18 to 46 points. Participants did not know their KAI scores or whether they were paired with someone with a similar or a different cognitive style. The dyads were asked to generate concepts to Design Problem 3 as a team but to record their solutions individually on their idea sheet and to identify who originated each idea and how much each person contributed. The discussion after this session focused on characterising team interactions, any conflicts experienced and their resolution. The usability test aim was to determine how pairing participants with others of different or similar cognitive styles impacted their ideation flexibility.

After all three tools were introduced, participants discussed the workshop as a whole. Following the workshop, a post-workshop survey was distributed to the participants with questions on each ideation flexibility tool. Figure 2 represents the entire usability study sequence, from the pre-workshop survey to this final post-workshop survey.

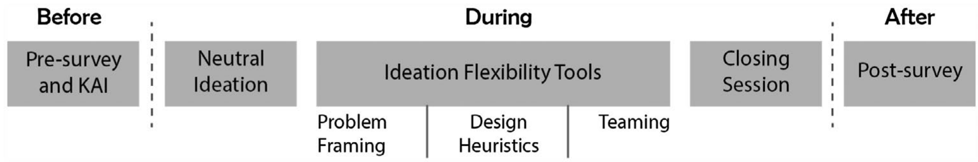

Figure 2. Usability study sequence.

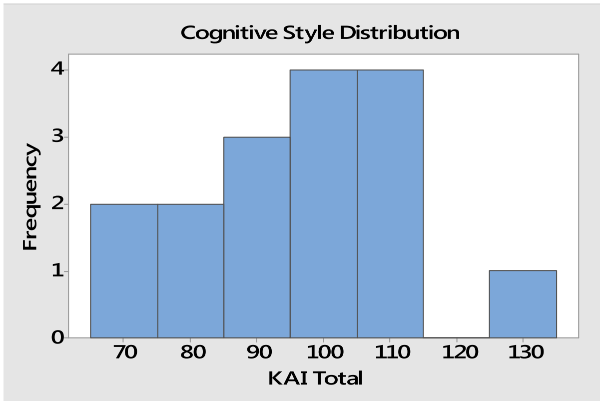

Figure 3. Participants' KAI total scores.

3.5. Step 5 (analyse data)

Our analysis of the data was primarily qualitative and descriptive due to the small number of participants; any quantitative analyses were used descriptively to contribute to our understanding of the participants' performance using the ideation flexibility tools and their perceptions of the tools. With regards to performance, we looked for patterns in how participants used the tools, challenges they had as they tried to apply them to their ideation processes and characteristics of the generated concepts. For performance on neutral ideation, DH and Cognitive Style-Based Teaming, we compared the number of concepts generated and the relationship of the number of concepts to cognitive style. We analysed perceptions of the tools by looking for patterns in the discussions and computing descriptive statistics of questions in the post-workshop survey. All quantitative analyses were performed with standard linear techniques using Minitab® and SPSS® software.

4. Usability test results

The results of our study include baseline data on the KAI make-up of the group, as well as performance in the neutral ideation session. Then, we present the practitioners' performance and perceptions about each of the three ideation flexibility tools. We conclude with a summary across all three tools.

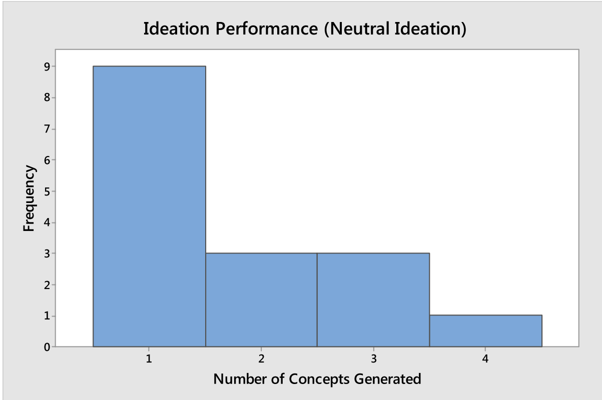

Figure 4. Performance for neutral ideation.

4.1. KAI distribution

The KAI distribution for the participants shown in Figure 3 has a mean and standard deviation (M = 95.81, SD = 15.93) close to those of the general population norms identified by Kirton and others (Kirton 2011). The KAI range for the participants was 60 points (70–130), representing wide diversity in cognitive style across the 16 participants.

4.2. Neutral ideation session

During neutral ideation, participants generated between 1 and 4 concepts (M = 1.75, SD = 1) (Figure 4); the majority of the participants (9 of 16) generated only one idea. Most participants used multiple viewpoints to describe their concepts; some participants used more arrows and described how the package would be opened, with text embedded in the concepts. Overall, the concepts focused on familiar sealing mechanisms and referred to manufacturing techniques with which the participants felt comfortable. From this neutral ideation session, it was evident that participants were not exploring a diversity in solutions.

4.3. Ideation flexibility tool: problem framing profile

4.3.1. Performance using problem framing

Using the Problem Framing Profile, 13 of the 16 participants were able to frame the given problem adaptively, while 15 participants were able to frame it innovatively. In each case, participants reframed the problem statements through the addition of specifications, some of which tightened or refined the underlying structure of the problem definition (ie more adaptive specifications), while others removed or loosened the structure of the problem definition (ie more innovative specifications). Methodologically, the first author reviewed all the participants' framing responses and identified a set of suggested codes for both more adaptive and more innovative specifications. The remaining authors then reviewed and validated these codes and their assignment to the participants' responses; the full team discussed any discrepancies in this coding until consensus was reached.

Table 3. Commonly used specifications for adaptively framed problem statements.

Original design problem (Problem 1): Most granola bars are in wrappers, which are packaged with cold seal adhesive. The package shape and function are almost the same as a candy bar wrapper. Your design challenge is to create a package that would allow the consumer to eat a portion of the product and then reclose the package for later consumption

Specification code	Frequency	Example adaptive re-framings of the problem
Change manufacturing technique	8	Develop and add features to a cold seal HFFS packaging material that will enable the package to be reclosed
Use existing tools/technologies/equipment	6	Create a package that will allow the consumer to eat a portion of the product and reseal it for later consumption. The package must run on existing equipment with minimal line upgrade and the product size may be altered
Emphasise freshness	5	Studies have shown consumers tend to graze or consume the granola bar over several hours or perhaps next day. Create a means of reclose that would maintain freshness
Emphasise cost	4	Must provide a minimum 1.5/in initial seal strength and not cost more than 20% beyond current packaging cost
Emphasise consumer interaction/experience	3	Wrappers are difficult to open without tearing apart the entire package. How can the consumer open the package with less force and without destroying the entire package?
Use the same content size	3	Must be a flexible package using the existing size bar (with same weight and dimensions)

Table 4. Commonly used specifications for innovatively framed problem statements.

Original design problem (Problem 1): Most granola bars are in wrappers which are packaged with cold seal adhesive. The package shape and function are almost the same as a candy bar wrapper. Your design challenge is to create a package that would allow the consumer to eat a portion of the product and then reclose the package for later consumption

Specification code	Frequency	Example innovative re-framings of the problem
Emphasise consumer interaction / experience	8	Create a granola package that recloses for future use that a child can easily open without destroying the outer wrapper
Remove the limitations (cost, content size, material, manufacturing processes)	7	No cost constraints; no packaging equipment constraints; food format change okay
Increased product life	1	Create a granola package that recloses for future use that enhances the product flavour or life of the product
Change the package style	1	Change in package style; zip hard; seal with zip under material top seal to provide re-closeability.
Introduce new technology	1	Even if certain technology does not exist today (eg 'marsupial' polymer film), frame the idea/solution/concept as if certain properties can be meshed together

Specifications that focus on paradigm-preserving ideas are keys to reframing problems adaptively; of the 23 adaptively framed problem statements created, 18 of the reframed problems included one new specification added to the original problem statement, 4 included two new specifications and 1 included three new specifications. These specification codes and their frequency are shown in Table 3; almost half of the added specifications (14 of 29) focused on manufacturing or tooling in some way, while the remainder highlighted various product features.

Specifications that focus on loosening constraints to encourage paradigm-modifying ideas are keys to reframing problems innovatively. Of the 27 problem statements generated by participants, 9 of these statements were broader and more general than the original statement, resulting in statements like 'Create a package that allows a consumer to open and reclose at will'. The other 18 statements (Table 4) pushed towards innovative solutions

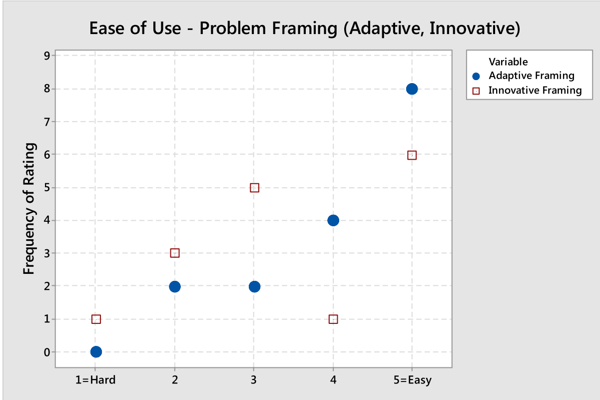

Figure 5. Perceived ease of framing overall.

Table 5. KAI homogeneous groups.

Group Number	KAI range	Number of participants
1	70–79	2
2	80–89	5
3	90–99	4
4	110–119	4
5	120–130	1

through specifications that removed or loosened constraints, directed ideas to be outside of the normal approach and/or focused on the larger consumer experience.

4.3.2. Perceptions of problem framing

Most participants recognised that the Problem Framing Profile demonstrated how problem specifications could be used to change one's approach to a problem. Some participants struggled to apply the tool, and rated it as hard or somewhat hard to use (Figure 5), while others were able to readily apply the tool. On average, participants reported that developing adaptively framed problem statements was easier than creating innovatively framed problem statements (M_A = 4.13, SD = 1.08 vs. M_I = 3.5, SD = 1.37). Participants reported struggling to remove constraints to align with an innovative frame and still have an effective problem statement. When the participants' perceptions of problem framing were organised by homogeneous KAI groups (see Table 5 and Figure 6), we found that perceptions of the ease of framing were similar for three of the five groups (Groups 2, 4 and 5), with the most adaptive group (Group 1) and the middle group (Group 3) reporting the greatest differences in perceived ease of adaptive and innovative problem framings, respectively.

Table 6 includes comments from the post-workshop survey that add depth to the ways in which participants' perceptions of the ease of applying adaptive versus innovative problem framing varied within the group. One can see that the more adaptive struggled to develop innovatively framed statements, and even a participant with a more innovative cognitive style also struggled in the same way.

On the post-workshop survey, we asked participants about the effectiveness of the Problem Framing Profile as an ideation flexibility tool. The mean score was a 3.3 (SD = 1.0); however, we did not have participants use their framed problem statements to generate ideas, so their perceptions were only based on the act of reframing the problem. Table 7

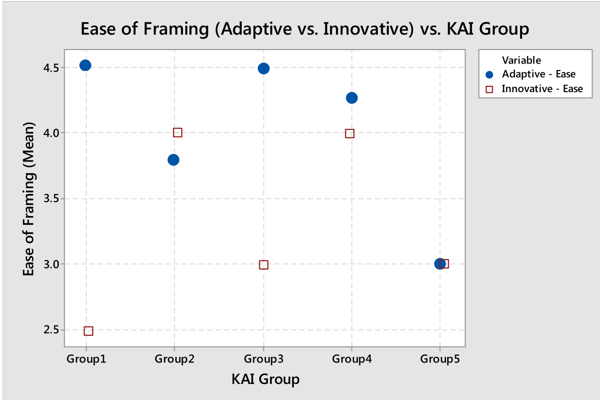

Figure 6. Perceived ease of framing vs. KAI group.

Table 6. Examples of participants' responses to ease of use of problem framing.

Participant ID	KAI score	Participant's response
P12	70	'I have a very adaptive personality, so I am always looking for the constraints/parameters of every problem I must solve. So the innovative framing was difficult to come up with for the exercise'
P13	111	'The innovative mode provided a true out of the box concept that allowed greater design freedom'
P19	112	'I think I kept pulling towards adaptive, it was hard to leave an open ended problem without constraints'

Table 7. Examples of participants' responses to the effectiveness of the problem framing method.

Participant ID	KAI score	Participant's response
P10	88	'Framing showed a methodical approach to looking at a problem, allowed me to open or close frame of reference based on needs of the task. I think this area would require more education to someone new to thinking about ideation systematically'
P13	111	'Framing was an eye-opening concept comparing adaptive vs. innovative styles. I believe that individuals in a technical position tend to get trapped in the adaptive mode, stuck with the constraints of equipment, cost, etc., which truly restrict ideas. We need to push the envelope where possible removing those constraints allows for truly innovative thinking and out of the box ideas'

provides two quotes from the post-workshop survey; specifically describing more support needed in how to reframe the problem.

4.4. Ideation flexibility tool: DH

4.4.1. Performance using DH

Fifteen of the 16 participants were able to use the DH tool to generate at least one solution (range: 1–4; $M = 2.4$; SD = 1.1). Across the 35 concepts generated with the tool, heuristics were used 58 times, either alone or in combination. On average, three different heuristics were used by each participant across all of their ideas (range: 0–6; SD = 1.5). Only four participants repeated the same heuristic from one concept to another, whereas most participants tried to apply different heuristics for each concept. All of the cards were used at least once, with Reconfigure and Repeat used most often.

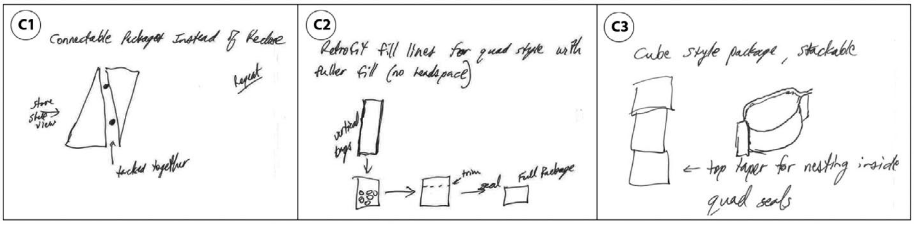

Figure 7. Participant 19's use of heuristics for each concept—C1: repeat; C2: reconfigure; C3: nest.

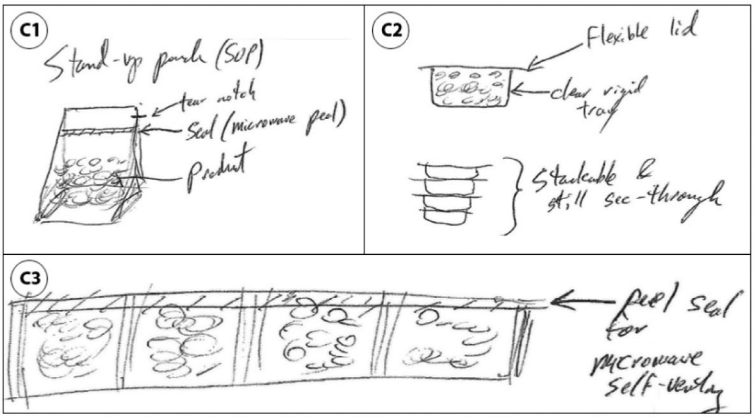

Figure 8. Participant 17's use of heuristics for each concept—C1: mimic natural mechanisms + reconfigure; C2 and C3: mimic natural mechanisms + reconfigure + repeat.

Participants' approaches to using the cards varied, as illustrated in Figures 7 and 8. While some participants preferred to use one heuristic per concept or added one heuristic with each new concept in a systematic way, others experimented with as many as six heuristics in various combinations. Participant 19 (KAI = 112) (Figure 7) created connectable packages (C1) instead of re-closeable ones by repeating the same component twice. C2 focuses on reconfiguring multiple vertical bags to allow for smaller space use on the shelf, while C3 uses the nesting heuristic to stack and nest individual packages to stabilise them in transferring and storing.

Participant 17's (KAI = 82) C1 suggests a clear package with a tear notch on the top and steam venting as the natural mechanism for microwave cooking (Figure 8). C2 repeats the same clear tray multiple times in a stackable manner, which allows for mobility in different ways, while C3 iterates on the second concept in the way the stacked packs are now aligned next to each other with a peel seal.

Across the participants, it seemed the DH tool allowed them to explore new ideas, but they were exploring new ideas in a way consistent with their cognitive style. Overall, participants seemed to be less concerned about how the designs would be manufactured, where the opening(s) of the packaging would be located, and which kind(s) of materials would be appropriate, suggesting that the tool allowed them to explore more freely, perhaps in a slightly paradigm-modifying way overall.

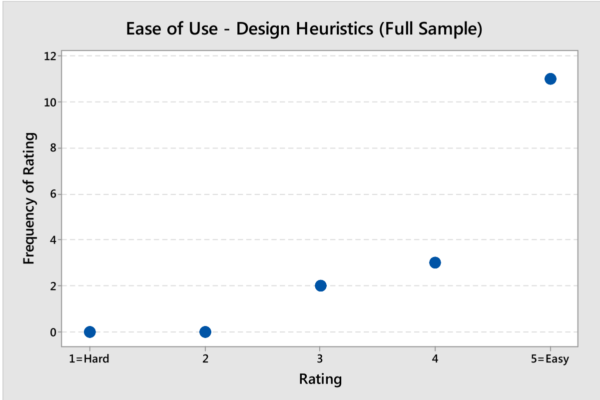

Figure 9. Perceived ease of DH overall.

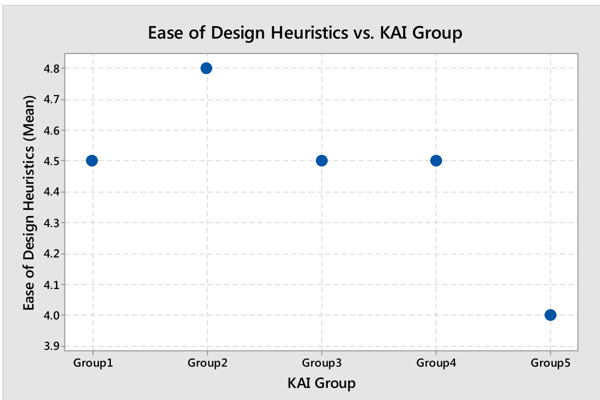

Figure 10. Perceived ease of DH vs. KAI group.

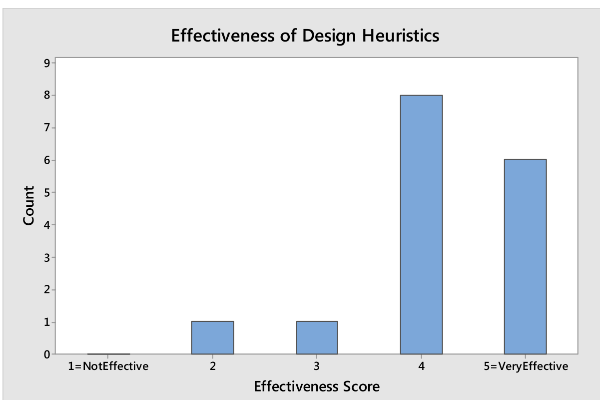

Figure 11. Perceived effectiveness overall (DH).

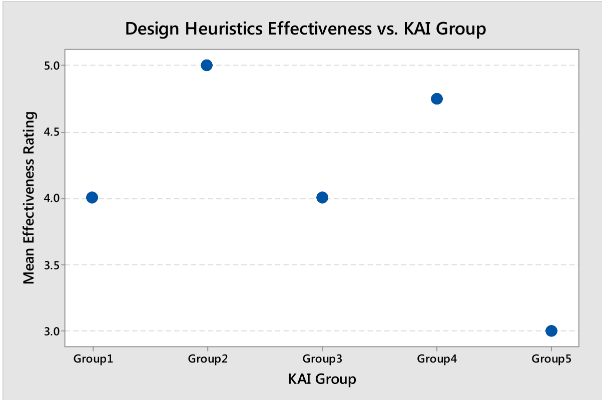

Figure 12. Perceived effectiveness vs. KAI group.

Table 8. Examples of participants' responses to the effectiveness of Design Heuristics.

Participant ID	KAI score	Participant's response
P17	82	'The flashcards were great tools. Very effective in triggering ideas that would not have come on their own'
P19	112	'Loved this exercise. Our past methods were to purchase other samples and we used those samples as the "outside influences". This process was much more beneficial because it does not funnel the thoughts to past packaging ideas. The abstract sides of the cards have basic shapes that are common to packaging, and were easy to use'
P4	88	'This was like a jump start to the brain storming process'

4.4.2. Perceptions of the DH

On average, participants reported that using DH was relatively easy with $M_{DH} = 4.56$, SD = 0.73 (Figure 9). When the participants' perceptions of DH were organised by homogeneous KAI groups (see Figure 10), no particular patterns emerged.

Participants felt the DH was an effective tool to support their ideation, with a mean for effectiveness of 4.2 (SD = 0.83) (Figure 11). Effectiveness rating according to KAI score (Figure 12) did not show an overall trend, but the most innovative cognitive style group rated the tool the least effective, perhaps suggesting they felt that they already knew how to explore diverse ideas.

Open-ended comments about the Design Heuristics (Table 8) demonstrated that participants felt the tool was a good 'jump start' to ideation that helped them remove cognitive barriers that would limit 'out of the box' concepts, suggesting that they encouraged paradigm-modifying ideas. It is important to note that the workshop participants knew that the tools were developed by the authors, which might have affected their perceptions and their responses on the survey, potentially leading to acquiescence bias. However, we did explicitly encourage the participants to provide their frank feedback about the tools (including any negative feedback), so we could use their critiques to improve the tools. Samples of open-ended responses are shown in Table 8.

Table 9. Team compositions.

Team number	Team member 1 (KAI)	Team member 2 (KAI)	Team type Homogeneous (< 10 point KAI gap) Heterogeneous (>10 point KAI gap)	KAI Gap	Concepts generated per team
Team 1	P7 (95)	P21 (95)	Homogeneous (HO)	0	4
Team 2	P13 (111)	P18 (111)	Homogeneous (HO)	0	3
Team 3	P11 (97)	P20 (99)	Homogeneous (HO)	2	5
Team 4	P8 (88)	P17 (82)	Homogeneous (HO)	6	4
Team 5	P10 (88)	P12 (70)	Heterogeneous (HT)	18	2
Team 6	P4 (88)	P19 (112)	Heterogeneous (HT)	24	5
Team 7	P14 (73)	P15 (110)	Heterogeneous (HT)	27	1
Team 8	P2 (84)	P16 (130)	Heterogeneous (HT)	46	4

The shading indicates the separation of homogeneous groups from heterogeneous ones.

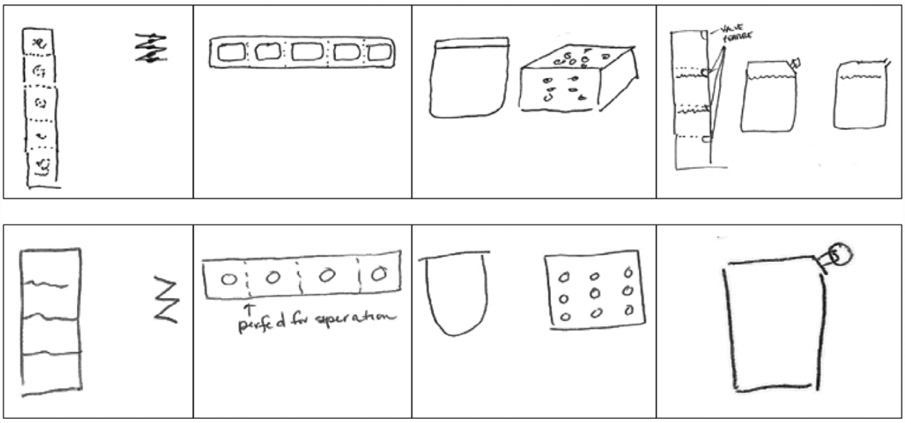

Figure 13. Concepts generated by the two members of HO Team 1 (P7—top row; P21—bottom row).

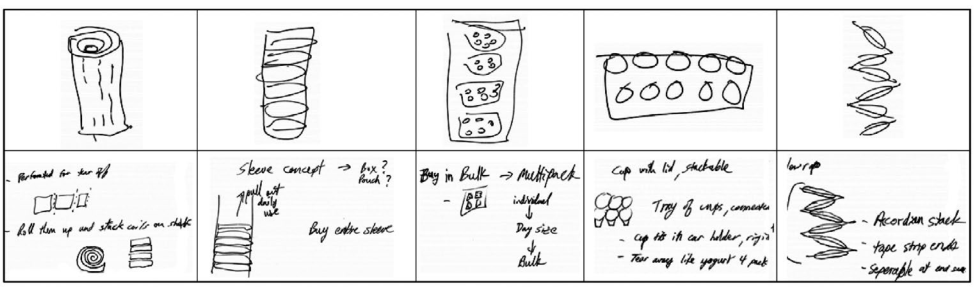

Figure 14. Concepts generated by the two members of HT Team 6 (P4—top row; P19—bottom row).

4.5. Ideation flexibility tool: cognitive style-based ideation teaming

4.5.1. Performance using cognitive style-based teaming

All 16 participants in the 8 two-person teams (See Table 9 for team composition) were able to generate ideas based on their team conversations. The number of concepts generated by each *team* ranged from 1 to 5, with an overall mean of 3.5 (SD = 1.37).

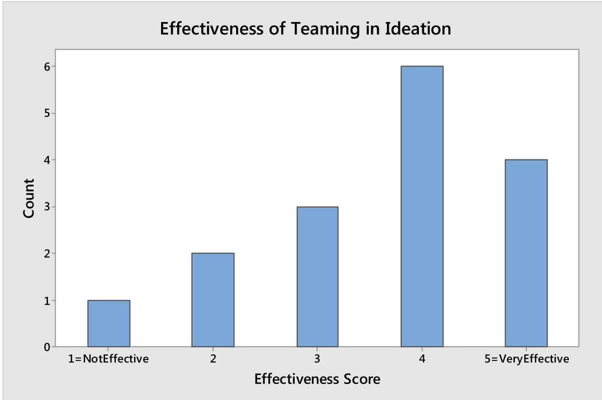

Figure 15. Perceived effectiveness of teaming.

The members of Team 1 had identical KAI scores (95), and the ways in which they described their concepts on their individual idea sheets were very similar in terms of functionality, appearance and user interfacing (Figure 13). As expected from A-I theory, they were (as more adaptive thinkers) concerned with the feasibility of their ideas and how they could be manufactured. Similar solutions were also observed between members of the other homogeneous teams. Members of Team 2, who had more innovative KAI scores, generated less familiar solutions to those already existing in the market compared to the other homogeneous teams.

For the heterogeneous teams, both members of Team 5 had more adaptive KAI scores (88 and 70). Even though the team was heterogeneous, and the team members likely noticed some differences in ideation approaches, their ideas were familiar solutions already existing in the market. The cognitive gap between the members of Team 6 was 24 points, which is considered noticeable; however, they appear to have developed effective coping behaviours that allowed them to generate 5 concepts—the most generated by any heterogeneous team. On the other hand, even though the sketches generated by these participants resembled each other, the amount of detail provided was very different (see Figure 14). Participant 19 (KAI = 112) was more elaborate in describing his concepts, using both the visual and verbal information. He also showed confidence in explaining how the concepts would function with multiple views, which emphasised their unique features more clearly than Participant 4 (KAI = 88). This is the opposite of what one would expect according to KAI theory (Kirton 2011). The situation was similar for Team 8, where there is a cognitive gap of 46 points between the team members. Participant 16 (KAI = 130) included features in his concepts that his teammate P2 (KAI = 84) did not, such as a top that also serves as a plate or incorporating a mixing bag within the package.

4.5.2. Perceptions of cognitive style-based ideation teaming

Participants rated the effectiveness of their teams as an ideation flexibility method with a mean of 3.63 (SD = 0.30) (Figure 15). We did not ask the participants about the ease of teaming in this session since they often use team structures in their routine activities.

When participants were asked about conflicts they experienced in team ideation, five out of eight participants in the heterogeneous teams referred to conflicts related to

Table 10. Examples of participants' responses related to communication issues within the teams.

Participant ID	KAI score	Participant's response
P12	70	'We kept coming up with more and more ideas, or more refinements on each idea so it was hard to know when we had something we felt was good enough to put on paper'
P14	73	'Found it challenging to focus partner into specific attributes'
P19	112	'The one idea that my partner presented it took a while for me to understand it. He had to describe it 3 times and even at the end I did not feel it was a good idea'

Table 11. Examples of participants' responses related to solving conflicts within the heterogeneous teams.

Participant ID	KAI score	Participant's response
P12	70	'We came up with multiple ideas per problem; obviously those could be whittled down in a later phase of design'
P10	88	'We quickly solved this by taking the best parts from our individual ideas and brainstorming a new concept based on the underlying principles of our original designs'
P19	112	'Continued to ask questions and then eventually moved on to other thoughts/ideas'

Table 12. Examples of participants' responses related to solving conflicts within the homogeneous teams.

Participant ID	KAI score	Participant's response
P17	82	'We tried to take a step back and relook at what we were considering to see if we could make it better'
P8	88	'I just let him continue with his thoughts and interjected as needed, then he let me express my ideas and he interjected'
P7	95	'Discussing specifics on ideas and merits for each facet of the idea. Talking calmly, rationally and with logical thought/path tends to work well with other technical brethren'

communication (see Table 10). Homogeneous teams reported fewer conflicts overall and commented on other aspects of working together instead—all in alignment with A-I theory. For example, P8 (KAI = 88) remarked: 'Partner was quick to start solving the problem, and I was more analyzing what was being requested', while Participant P17 (KAI = 82) remarked: 'We did not have many conflicts, but an issue was we fast tracked the idea and may have missed some key points on the way'. Participants were also asked to comment on how they resolved any conflicts within their teams. Members of heterogeneous teams claimed that they either solved them by combining ideas or by moving on to other ideas (see Table 11). In contrast, members of homogeneous teams tried to establish consensus or took turns in bringing up new ideas (Table 12).

5. Discussion

Our primary goal with this research was to study ideation flexibility among practicing engineers and the ways in which the tools we introduced to them supported (or hindered) this flexibility. Our usability results with these practicing engineers revealed strengths and weaknesses of each of our prototype tools, all of which suggest that further studies are needed to sort out the relative usability of these methods for individuals of different cognitive styles. The relationships between both KAI and performance and perception are not clear from our small usability sample. Distinct patterns of ideation behaviour have been characterised for homogeneous style groups under general circumstances (Helm et al. 2017; Jablokow et al. 2015), but little is known about how specific ideation tools enhance or disturb those characteristic patterns in the context of design. Additionally, across the three tools, it was evident that stand-alone supporting materials that guide designers through the tools would be helpful.

Participants recognised that the way the problem was framed had a strong potential to impact the type of ideas generated, but some struggled to rewrite the statements according to the framework. Participants were more successful writing the problem statements in adaptive ways, because they could add multiple constraints. However, it was not clear how to loosen the constraints and maintain the integrity of the problem, or how to add constraints that would be considered innovative constraints. Iterations to the Problem Framing Profile tool need to enable users to see more opportunities for how to revise problems. One route might be to provide a list of replaceable constraints that can be added or taken away; another option could be to develop a computer tool that rewrites a problem in multiple ways.

The Design Heuristics tool was user-friendly. Participants reported that the tool was easy to interpret and apply to generating design ideas. However, with regards to performance, participants seemed to apply the tool in a way in which they were already comfortable; those with more adaptive cognitive styles applied the tool more incrementally, and those with more innovative cognitive styles applied the tool more radically. Across participants, they perceived the tool as pushing slightly towards radical, 'out of the box' ideas. The next version of the tool, 'Design Heuristics for Incremental and Radical Ideas', will focus on helping those with innovative cognitive styles to apply the tool incrementally and those with adaptive cognitive styles to apply the tool radically. The tool will likely include examples of how each prompt can be applied both incrementally and radically, and supplemental materials will emphasise that creativity exists in both types of changes.

Participants had both successful and challenging experiences while using the Cognitive Style-Based Teaming tool. Some teams readily noticed their similarities in style, while others were not aware until the discussion time when we shared information about cognitive style and allowed participants to discover their scores. The next iteration of this tool will provide strategies for teams based on whether they are homogeneous or heterogeneous with regards to how to work together and the types of solutions they can generate together.

Regarding limitations, the small sample size for this study limits our ability to generalise, even though are not intended to generalise, but instead offer important insights about ways the design can be modified to better suit the user. Additionally, the ordering of the usability tests could have impacted performance and perception of subsequent usability tests. Due to the limited timeline for the entire workshop, participants were only given ten minutes to practice with the tools we introduced. Our future work will include additional studies with both practitioners and novice designers (students) on the refined ideation flexibility tools, and the ordering of the usability tests will be varied.

6. Conclusions

The aims of this usability study were satisfied both from the perspective of answering our original research questions and in introducing new directions for investigation that will lead to a better understanding of ideation tools, their outcomes and the performance and perceptions of those applying them. Usability testing is a critical step in the design process in which input from prospective users is used to investigate new products and provide feedback on how that product might be improved. These goals are just as applicable to design tools as they are to the products that result from those tools, making it important to leverage usability studies in our development of the three ideation flexibility tools—the Problem Framing Profile, the Design Heuristics and Cognitive Style-Based Teaming.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported by the National Science Foundation through Research in Engineering Education (REE) [grant #1264715], [grant #1265018], and [grant #1264551].

References

Abernathy, W. J., and J. M. Utterback. 1978. "Patterns of Industrial Innovation." *Technology Review* 80 (7): 40–47.

Abras, C., D., Maloney-Krichmar, and J. Preece. 2004. "User-centered Design." In *Encyclopedia of Human-computer Interaction*, edited by W. Bainbridge, 445–456. Thousand Oaks, CA: Sage.

Adams, R. S., D. Evangelou, L. English, A. D. Figueiredo, N. Mousoulides, A. L. Pawley, C. Schiefellite, R. Stevens, M. Svinicki, J. M. Trenor, and D. M. Wilson. 2011. "Multiple Perspectives on Engaging Future Engineers." *Journal of Engineering Education* 100 (1): 48–88.

Brophy, D. R. 2001. "Comparing the Attributes, Activities, and Performance of Divergent, Convergent, and Combination Thinkers." *Creativity Research Journal*, 13 (3–4): 439–455.

Corry, M. D., T. W. Frick, and L. Hansen. 1997. "User-centered Design and Usability Testing of a Web Site: An Illustrative Case Study." *Journal of Educational Technology Research and Development* 45 (4): 65–76.

Daly, S. R., J. L. Christian, S. Yilmaz, C. M. Seifert, and R. Gonzalez. 2012. "Assessing Design Heuristics for Idea Generation in an Introductory Engineering Course." *International Journal of Engineering Education* 28 (2): 1–11.

Dumas, J. S., and J. C. Redish. 1993. *A Practical Guide to Usability Testing*. Norwood, NJ: Ablex Publishing Corporation.

Dym, C. L., A. M. Agogino, O. Eris, D. D. Frey, and L. J. Leifer. 2006. "Engineering Design Thinking, Teaching, and Learning." *Journal of Engineering Education* 34 (1): 65–83.

Gould, J. D. 1988. "How to Design Usable Systems (Excerpt)." In *Readings in Human Computer Interaction: A Multidisciplinary Approach*, edited by R. Baecker and W. Buxton, 93–115. New York: Morgan-Kaufman.

Gray, C. M., C. M. Seifert, S. Yilmaz, S. R. Daly, and R. Gonzalez. 2015. "What is the Context of "Design Thinking"? Design Heuristics as Conceptual Repertoire." *International Journal of Engineering Education* 32 (3B): 1349–1355.

Helm, K. C., D. A. Henderson, K. W. Jablokow, S. R. Daly, S. McKilligan, E. M. Silk, and D. C. Sevier. 2017. "The Idea Mapping Board: A Tool for Assessing Design Concepts and Visualizing a Team's use of the Design Space (Accepted)." International Conference of Engineering Design, Vancouver, BC, Canada, August 21–25.

Helm, K. C., K. W. Jablokow, S. R. Daly, E. M. Silk, S. Yilmaz, and R. Suero. 2016. "Evaluating the Impacts of Different Interventions on Quality in Concept Generation." Paper presented at the Annual Conference of ASEE, New Orleans, LA, June 26–29.

Jablokow, K. W., and M. J. Kirton. 2009. "Problem Solving, Creativity, and the Level-style Distinction." In *Perspectives on the Nature of Intellectual Styles*, edited by L. F. Zhang and R. J. Sternberg, 137–168. New York: Springer.

Jablokow, K. W., W. Teerlink, S. Yilmaz, S. R. Daly, E. Silk, and C. Wehr. 2015. "The Impact Of Teaming and Cognitive Style on Student Perceptions of Design Ideation Outcomes." Paper presented at the Annual Conference of ASEE, Seattle, WA, June 14–17.

Kirton, M. J. 1976. "Adaptors and Innovators: A Description and Measure." *Journal of Applied Psychology* 61 (5): 622–629.

Kirton, M. J. 2011. *Adaption-innovation in the Context of Diversity and Change*. London: Routledge.

Kramer, J., S. R. Daly, S. Yilmaz, and C. M. Seifert. 2014. "A Case-study Analysis of Design Heuristics in an Upper-level Cross-disciplinary Design Course." Paper presented at the Annual Conference of ASEE, Indianapolis, IN, June 16–18.

Kramer, J., S. R. Daly, S. Yilmaz, C. M. Seifert, and R. Gonzalez. 2015. "Investigating the Impact of Design Heuristics on Idea Initiation and Development." *Advances in Engineering Education* 4 (4): 1.

Liu, Y. C., T. Bligh, and A. Chakrabarti. 2003. "Towards an 'Ideal' Approach for Concept Generation." *Design Studies* 24 (4): 341–355.

Nielsen, J. 1993. *Usability Engineering*. San Diego, CA: Academic Press.

Norman, D. A. 1988. *Design of Everyday Things*. New York: Currency Doubleday.

O'Hara, L. A., and R. J. Sternberg. 2001. "It Doesn't Hurt to Ask: Effects of Instructions to Be Creative, Practical, or Analytical on Essay-Writing Performance and Their Interaction With Students' Thinking Styles." *Creativity Research Journal* 13 (2): 197–210.

Page, S. E. 2007. *The Difference: How the Power of Diversity Creates Better Groups, Firms, Schools, and Societies*. Princeton, NJ: Princeton University Press.

Pahl, G., and W. Beitz. 1996. *Engineering Design: A Systematic Approach*. Verlag: Springer.

Paulus, P. B. 2000. "Groups, Teams, and Creativity: The Creative Potential of Idea-generating Groups." *Applied Psychology* 49 (2): 237–262.

Römer, A., M. Pache, G. Weißhahn, U. Lindemann, and W. Hacker. 2001. "Effortsaving Product Representations in Design – Results of a Questionnaire Survey." *Design Studies* 22 (6): 473–491.

Rubin, J. 1994. *Handbook of Usability Testing: How to Plan, Design, and Conduct Effective Tests*. New York: Wiley.

Seifert, C. M., R. Gonzalez, S. Yilmaz, and S. R. Daly. 2015. "Boosting Creativity in Idea Generation Using Design Heuristics." In *Design and Design Thinking: Essentials in the PDMA's New Product Development Series*, 71–86. Hoboken, NJ: Wiley.

Sheppard, S. D., K. Macatangay, A. Colby, and W. Sullivan. 2009. *Educating Engineers: Design for the Future of the Field*. San Francisco, CA: Jossey-Bass.

Silk, E., S. R. Daly, K. W. Jablokow, S. Yilmaz, and M. Rosenberg. 2014a. "Interventions for Ideation: Impact of Framing, Teaming, and Tools on High School Students' Design Fixation." Paper presented at the Annual Meeting of AERA, Philedelphia, PA, April 3–7.

Silk, E., S. R. Daly, K. W. Jablokow, S. Yilmaz, and M. Rosenberg. 2014b. "Using Adaption-innovation Theory to Build a Framework for Constructing Design Problem Statements." Paper presented at the Annual Conference of ASEE, Indianapolis, IN, June 15–18.

Smith, K. A., S. D. Sheppard, D. W. Johnson, and R. T. Johnson. 2005. "Pedagogies of Engagement: Classroom-based Practices." *Journal of Engineering Education* 94 (1): 87–101.

Sutton, R. I., and A. Hargadon. 1996. "Brainstorming Groups in Context: Effectiveness in a Product." *Administrative Science Quarterly* 41 (4): 685–718.

Tversky, A., and D. Kahneman. 1981. "The Framing of Decisions and the Psychology of Choice." *Science* 211 (4481): 453–458.

Yilmaz, S., S. R. Daly, J. L. Christian, C. M. Seifert, and R. Gonzalez. 2013. "Can Experienced Designers Learn from New Tools? A Case Study of Idea Generation in a Professional Engineering Team." *International Journal of Design Creativity and Innovation* 2 (2): 82–96.

Yilmaz, S., S. R. Daly, K. W. Jablokow, E. M. Silk, and M. Rosenberg. 2014. "Investigating Impacts on the Ideation Flexibility of Engineers." Paper presented at the Annual Conference of ASEE, Indianapolis, IN, June 16–18.

Yilmaz, S., S. R. Daly, C. M. Seifert, and R. Gonzalez. 2013. “Comparison of Design Approaches Between Engineers and Industrial Designers.” Proceedings of the 15th International Conference on Engineering and Product Design Education: Design Education - Growing Our Future, International Conference on Engineering and Product Design Education, Dublin, Ireland, September 5–6.

Yilmaz, S., S. R. Daly, C. M. Seifert, and R. Gonzalez. 2015. “How Do Designers Generate New Ideas? Design Heuristics Across Two Disciplines.” *Design Science* 1 (e4): 1–29. doi: 10.1017/dsj.2015.4.

Yilmaz, S., C. M. Seifert, S. R. Daly, and R. Gonzalez. 2016a. “Design Heuristics in Innovative Products.” *Journal of Mechanical Design* 138 (7): 071102. doi:10.1115/1.4032219.

Yilmaz, S., C. M. Seifert, S. R. Daly, and R. Gonzalez. 2016b. “Evidence-based Design Heuristics for Idea Generation.” *Design Studies* 46 (September): 95–124.