Examining the Effect of a Paradigm-Relatedness Problem-Framing Tool on Idea Generation

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Abstract

Considering a wide range of ideas is crucial for engineers as they seek to solve complex problems. Paradigm-relatedness is one dimension on which ideas can range from more *incremental*—ideas that refine and improve existing solutions—to more *radical*—ideas that approach a problem from a new perspective or seemingly unrelated angle. We developed a tool that consists of a set of framing strategies an engineer can apply to a design task to assist in generating ideas that differ from their initial ideas. We created two versions of the tool—one with an incremental set of framing strategies and another with a radical set. We explored whether the framing tool impacted the paradigm-relatedness of ideas generated in conceptual design sessions. Forty-five students attending a summer engineering outreach program participated in the study. Participants were given a problem statement and generated ideas initially without the tool and then with the version of the tool of their choosing. Post hoc, we coded each idea as more incremental or more radical on a four-point scale and examined the change in ideas between the first ideation session and the second. It was found that 73% of the participants chose the framing tool version we would have assigned to them based on our coding of their initial ideas. All of these participants exhibited a shift in the predicted paradigm-relatedness direction, providing support for the overall effectiveness of the tool. However, some participants selected a version of the tool that was not consistent with our intended use of the tool, and this happened more often with the incremental version of the tool. Those participants were inconsistent in shifting their ideas. Case examples were explored to gain insight into the ways in which the tool was effective as well as how it could be improved.

Introduction

Engineering students and practicing engineers are constantly faced with new and complex problems. They must develop creative solutions in order to address the issues before them, and ideation is a critical part of the design process used to realize these solutions. Prior research has shown that both novice and experienced designers are susceptible to what is called "design fixation."[1–3] Design fixation may stem from a designer self-imposing constraints and artificially limiting the solution space, which in turn results in a narrow focus on initial ideas without adequately exploring alternatives.[4] A solution to the issue of design fixation that has been explored is problem framing.[5] Multiple perspectives or "frames" on a problem can support a broader exploration of the solution space. However, often engineers take design problems as given and do not reconsider the problem in different frames. Although some framing is productive and even necessary in all ill-defined problems, novice designers may commit prematurely to a particular frame and be less aware of the implicit assumptions built into that framing.[6] Thus, an opportunity exists to support beginning engineers in understanding that a problem can and should be reframed so that the problem may be viewed in multiple ways.

The initial framing and resulting ideas that a designer generates to solve a design problem may be influenced by that individual's cognitive style. Cognitive style is a stable attitude or way of thinking that reflects how a given individual prefers to interpret and respond to information.[7] Kirton's Adaption–Innovation (A–I) theory posits that some individuals are more adaptive and

prefer more structure, while others are more innovative and prefer less structure. Although individuals may have a preferred problem solving approach, there are always different problem situations or different times within a problem in which there could be a benefit to approaching that problem in a non-preferred way. A person who is able to ideate along a spectrum of design approaches to fit the needs of their given problem has a potential advantage. This ability to shift between one's preferred and non-preferred ways of ideation is what we call *ideation flexibility*.[8] Pushing designers to be more flexible in their design approaches by ideating outside of their preferred approach can potentially help reduce design fixation and make it more likely the designer considers a broader spectrum of ideas.

There are many ways to assess ideas to capture the range of ideas a designer generates.[9,10] One dimension that may be particularly well aligned with covering a broader solution space is paradigm-relatedness.[11] We define paradigm-relatedness as the degree to which an idea works within or breaks from common ways of thinking about a problem.[9] The spectrum of paradigm-relatedness is defined on one end by paradigm-preserving ideas, which are characterized by being more incremental and tend to be associated with a more adaptive ideation approach. On the other end of the spectrum are paradigm-modifying ideas, which are characterized by being more radical and tend to be associated with a more innovative ideation approach. A critical aspect of paradigm-relatedness is that it is a measure of creative *style*, not creative *level*.[11,12] That is, neither end of the paradigm-relatedness spectrum is considered of higher inherent quality than the other. Instead, the different paradigm-relatedness types are simply alternative *ways* in which to approach a problem. As a result, there is value in engineers exploring ideas from across the full paradigm-relatedness spectrum when seeking to increase the diversity of their ideas and their coverage of the solution space.

In our prior work, we have shown how manipulating the wording of a problem statement has the potential to frame a design problem for engineering students, and so may influence the paradigm-relatedness of the ideas that they generate.[13] We observed[14,15] that when provided with a problem statement that has already been framed adaptively, engineering students on average were more likely to generate a greater proportion of paradigm-preserving ideas. Conversely, when provided with a problem statement that has already been framed innovatively, students were more likely to generate a greater proportion of paradigm-modifying ideas. However, the observed effects were not large and were highly variable, as many engineering students made only a subtle shift in the paradigm-relatedness of their ideas, others made no shift at all, and some even made a shift in the opposite direction from what was predicted by the problem framing. In response, we decided to develop a more explicit problem framing approach that involved a more active role for the students. Inspired by the effectiveness of tools for the design process generally[16,17] and for idea generation in particular,[18–20] we developed a problem framing tool. Instead of providing the designer with an already-framed problem statement, the designer would be provided with a neutrally framed problem statement, and then the tool would consist of general framing strategies that the designer could apply to the problem statement. We expected that using this tool-based approach the designers would be more aware of their framing, and so would be better able to utilize the framing to influence their ideation process.

In this study, we explored how to assist prospective engineering students in shifting their ideas along the paradigm-relatedness spectrum. Our work was guided by the following research question: *To what extent does a design problem framing tool shift the paradigm-relatedness of*

users' ideas? We developed a framing tool to help users generate ideas that were either more incremental or more radical. The purpose of this study was to examine the outcomes that result when participants initially generate ideas without the tool and then generate a second set of ideas with the tool. We observed to what extent the tool facilitated participants in generating ideas that differed from their initial ideas in terms of paradigm-relatedness. This study can contribute to our understanding of the types of interventions that may be effective in pushing designers to be more flexible in their ideation approach.

Methods

We conducted a treatment-only research design comparing the paradigm-relatedness of ideas generated by participants across two consecutive ideation sessions. The first ideation session served as a baseline as the participants generated initial ideas without the assistance of a tool. Those ideas were compared with ideas generated to the same design problem in a second ideation session in which the participants used a problem framing tool. There were two different versions of the tool—an incremental tool and a radical tool. With the help of a self-assessment activity, in which the participants evaluated the paradigm-relatedness of their initial ideas, the participants self-selected the version of the tool they used in their second ideation session. They were instructed to select the version of the tool that would encourage them to shift their ideas towards the opposite end of the spectrum from their initial ideas. Thus, the problem framing tool version (incremental or radical) served as a between-subjects factor, even though it was not randomly assigned to participants.

Participants

The participants for the study were high school students attending a summer engineering program hosted at a large Midwestern university. A total of eighty-six students (46 male and 39 female) consented to participate. The participants were randomly assigned to one of two problem contexts. For this initial study we focused on one of the problem contexts, and so a subset of the full sample consisting of 45 students (24 male and 21 female) were included for the present analyses. All participants were between ages 14 and 18 and ranged from having just completed their first year of high school to having just completed their third year of high school.

Materials

Design Problem

The design problem statement challenged students to "Design a way for individuals without lots of skill and experience skiing or snowboarding to transport themselves on snow." The *Snow* problem was adapted from prior design research.[21,22] The problem statement included a short background context, a needs statement, and an ideation goal. The language of the problem statement was carefully crafted to be neutral in the sense of not encouraging either more incremental or more radical ideas. The full problem statement is provided in Appendix A, and a fuller discussion of the reasoning behind the structure of the problem statement can be found in our prior writing.[13]

Table 1. The framing strategies

	Incremental		Radical
A	Limited Budget You have a limited budget for this project. Keep your idea within a tight budget.	Z	Unlimited Budget You have an unlimited budget to complete this project. Don't worry about the cost.
B	Meet Constraints Focus on a key constraint of the problem and be sure to follow it.	Y	Disregard Constraints Pick a key constraint of the problem and disregard it.
C	Already Existing Think about a common solution that already exists and build on that.	X	Unexpected Think about a common solution that already exists and introduce something unexpected.
D	Simple Sometimes the best solutions are the ones that are most easily understood. Keep your solution simple.	W	Underlying Issue Sometimes the best solutions solve an underlying issue instead. Think big picture.
E	Short Term Come up with a solution that can be implemented within the next week.	V	Long Term Come up with a solution that you have a timeframe of several years to implement.
F	Current Technology Generate a solution that only uses technology that currently exists.	U	Future Technology Generate a solution that makes use of technology that has not yet been invented.

Framing Tool

We designed the framing tool based on Kirton's[7] work contrasting more adaptive and more innovative cognitive styles. Kirton[23] observed a number of behaviors that were characteristic of more adaptive thinkers, and contrasted those with behaviors that were characteristic of more innovative thinkers. For example, a more adaptive thinker, "challenges rules rarely, cautiously, when assured of strong support," whereas a more innovative thinker, "often challenges rules, has little respect for past custom."[23] Our conjecture was that if we provided designers with framing strategies that aligned with more adaptive thinking and asked them to apply those framing strategies to a design problem, then they would be likely to generate more incremental, paradigm-preserving ideas. Conversely, if we provided them with framing strategies that aligned with more innovative thinking, then they would be likely to generate more radical, paradigm-

modifying ideas. Returning to the example about challenging rules, we created a corresponding radical framing strategy that tells the designer to pick a key constraint of the problem and disregard it. In theory, this framing strategy would push the designer to generate more radical ideas. Similarly, we created a corresponding incremental framing strategy that tells the designer to focus on a key constraint of the problem and follow it. We conjectured that this framing strategy would push the designer to generate more incremental ideas.

In all, we generated six framing strategies, each of which had an incremental version and a corresponding radical version (**Table 1**). The strategies represented a range of typical constraints and criteria that designers use to frame a problem. Because the participants in the study only had a limited time to work with the framing tool, we decided to provide each participant with only four of the framing strategies. For each version of the tool (incremental and radical), we created three groups of framing strategies, each group having four of the six framing strategies. We put the tools in a bi-fold print format with each framing strategy having its own flap (**Figure 1**). In this format, the participants could have easy access to each of the framing strategies, but could choose to focus on one at a time. The framing strategies were evenly distributed to ensure no single framing strategy was seen more than the others.

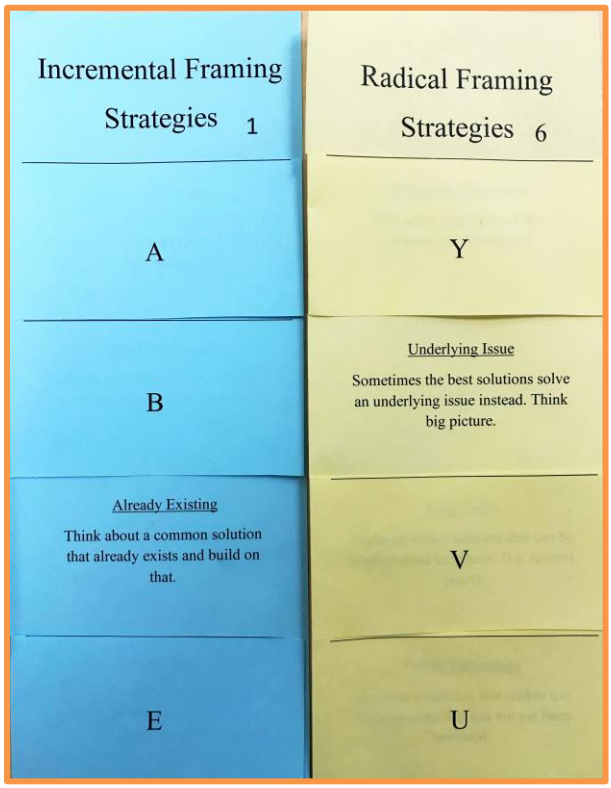

Figure 1. The framing tool

Self-Assessment

To enable the participants to choose the framing tool that would best support their own ideation flexibility, we provided the participants with a worksheet to help them conduct a self-assessment of their neutral ideas (Appendix B). After brief instruction on the difference between incremental (paradigm-preserving) and radical (paradigm-modifying) ideas, participants used the worksheet to rate each of their ideas on a scale from one to four with one being very incremental and four being very radical. They also assessed their ideas as a set with an overall rating. The overall assessment was then used to guide the participant in deciding which tool to use to help them generate ideas that differed from their initial ideas. Participants with an overall rating on the incremental side (1 or 2) were instructed to choose the radical framing tool, and participants with an overall rating on the radical side (3 or 4) were instructed to choose the incremental framing tool.

Procedure

The study included one period lasting roughly 90 minutes in total. Participants were initially given a presentation about the benefits of idea generation in design and best practices in ideation. Participants were told to avoid being too critical of their ideas and to record their ideas using drawings and text for further explanation. They then received the design problem statement. Students were allotted 20 minutes in total to generate ideas. To control for the quantity of ideas, the participants were instructed to generate exactly five ideas, and the time in the ideation session was structured such that the experimenters instructed the participants to move onto their next idea every four minutes. A short reflection survey was given to participants at the conclusion of the ideation session to capture their perceptions of their ideas and the design problem.

After the first ideation session, the notion of incremental and radical ideas was explained to the students using example ideas from a design problem statement not used in this study. Participants were then asked to use the self-assessment worksheet to rate each of their initial ideas and their overall set of ideas. After a short break, the problem framing tool was introduced to the students. The students were asked to select the version of the tool meant to push them in the opposite direction from what the self-assessed overall rating of their initial ideas had indicated. If the overall assessment was more incremental, they were to take the *radical* tool. If the overall assessment was more radical, they were to take the *incremental* tool.

Finally, the participants generated ideas in a second 20-minute session using the same procedure as in the initial ideation session, with the exception being that this time they were to use the framing tool they selected to help them generate ideas. At the end of this second ideation session, students again self-assessed their individual ideas and their overall set of ideas. Participants were also asked to complete a final reflection survey similar to the first, but this time were also asked about their perceptions of the tool.

Data Analysis

To measure the effect of the tool, we utilized a paradigm-relatedness coding scheme to categorize the ideas the students generated. We coded each student's initial ideas from the first ideation session and their ideas from the second session with the framing tool to examine the

change in type of ideas generated. We utilized a 4-category paradigm-relatedness coding scheme from the literature[9,11] that we adapted for the *Snow* problem context (**Table 2**). The four paradigm-relatedness categories paralleled the rating categories on the self-assessment worksheet.

Table 2. Paradigm-relatedness coding categories

	General Category	Snow
1	*Strongly Paradigm Preserving* Solution resembles an already existing, common design	Uses personal transporter on snow that already is (or is very close to) an existing solution Ex: Snowboards, skis, snowmobiles, snowshoes
2	*Somewhat Paradigm Preserving* Solution integrates an uncommon element or relationship	Uses personal transporter on snow that involves paradigm-modifying elements or relationships Ex: An already existing solution that has an interesting element (sled with solar panels)
3	*Somewhat Paradigm Modifying* Solution violates a typical problem assumption	Uses device to actively remove snow/changes the environment Ex: Use salt or a heater to melt snow, snow plow to push snow out of path, make hills less steep, change snow into ice
4	*Strongly Paradigm Modifying* Solution shifts the focus of the problem	a) Shared infrastructure/user does not control device Ex: Community snow plowing, local bus system, tow rope b) Avoids snow entirely Ex: Ski lift, hovering or tunnels in air c) Dissipates need for travel on snow at all Ex: Take classes online, move to where it never snows

The paradigm-relatedness coding scheme was used to code the ideas. The ideas were blinded and randomized so that the coders could not tell from which participant or from which idea generation session the idea came. After individual coding, all disagreements were resolved through discussion.

We calculated an *average idea score* for each participant by taking the mean of the coded category levels for each of their five ideas in each ideation session. We also calculated a *shift score* for each participant by taking the difference between the average idea score for the initial ideation session and the average idea score from the second ideation session using the tool. A positive shift score indicates a shift toward a more radical set of ideas and a negative shift score indicates a shift toward a more incremental set of ideas.

Results

The average idea score for the initial ideation session, the average idea score for the second ideation session, and the shift score for each participant are presented in Appendices C and D. The data are broken apart by whether the participant chose the incremental tool or the radical tool for their second ideation session. Fifteen participants selected the incremental tool and the other thirty participants selected the radical tool.

Ideation Shifts

Of the 45 participants, 36 shifted in the expected direction given the tool they selected (80%). To illustrate the observed shifts across the participants, we created an arrow chart for the participants who chose the incremental tool (**Figure 2**) and an additional arrow chart for the participants who chose the radical tool (**Figure 3**). In the charts, the x-axis indicates the range of idea scores. A line represents each participant with an arrow pointing from that participant's initial average idea score to their average idea score using the tool, so that the length of the line indicates the magnitude of the shift. We colored shifts in the incremental direction blue and shifts in the radical direction yellow. Participants whose average idea score did not change from the initial ideation session to the second ideation session are represented by a gray dot.

Inspecting the figures, we can see that there was a mix of both incremental and radical shifts in the group of participants that chose the incremental tool (**Figure 2**). In contrast, in the group of participants that chose the radical tool, every participant made a radical shift except for one (**Figure 3**). However, that participant's initial average idea score was well into the radical side of the range, and so that participant's choice to select the radical framing tool was not consistent with our intended use of the tool to help designers shift toward generating ideas that differed from their initial ideas. Looking at the data in this way, we can consider 2.5 the midpoint of the idea score range, such that participants whose initial average idea score was less than 2.5 began on the more incremental side and so we would have expected them to select the radical tool. Participants whose initial average idea score was greater than 2.5 began on the more radical side, and so we would have expected these participants to select the incremental tool. Across both framing tools, 33 out of 45 (73%) participants selected a version of the tool that was consistent with our intended use of the tool, and all of those participants did make a shift in the predicted direction. That included 29 of the 30 participants who selected the radical tool, but only 4 of the 15 participants who selected the incremental tool.

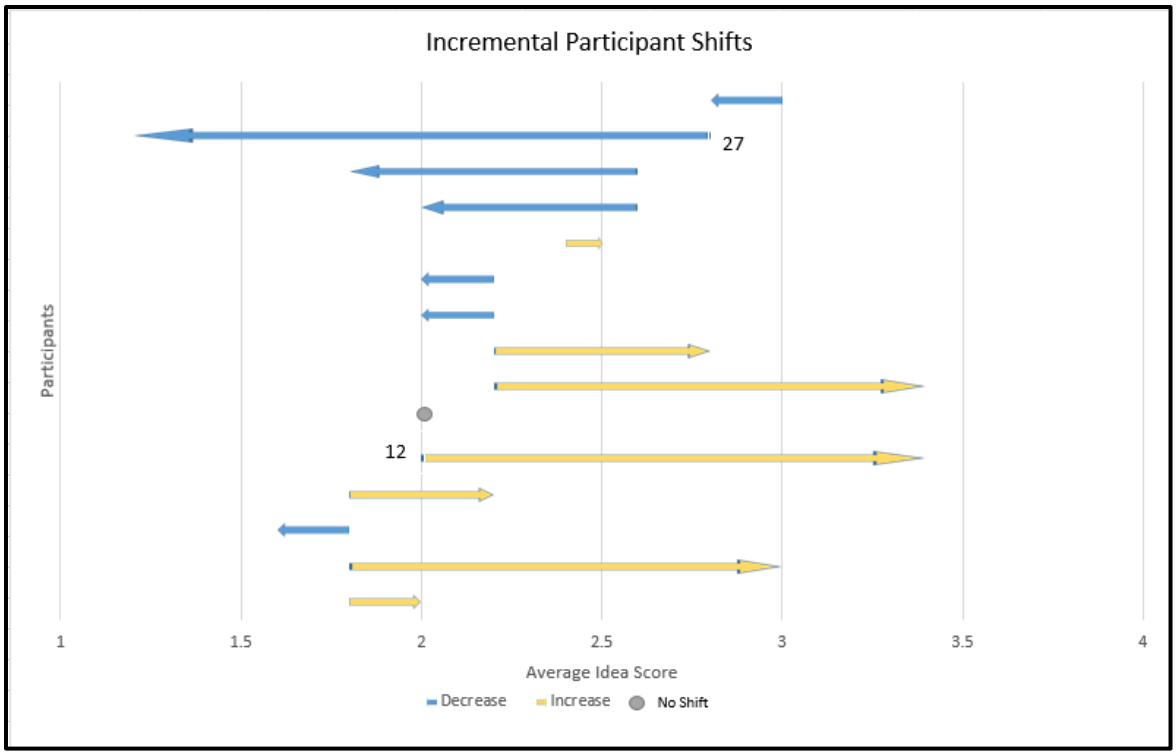

Figure 2. Shift scores of participants using the incremental tool

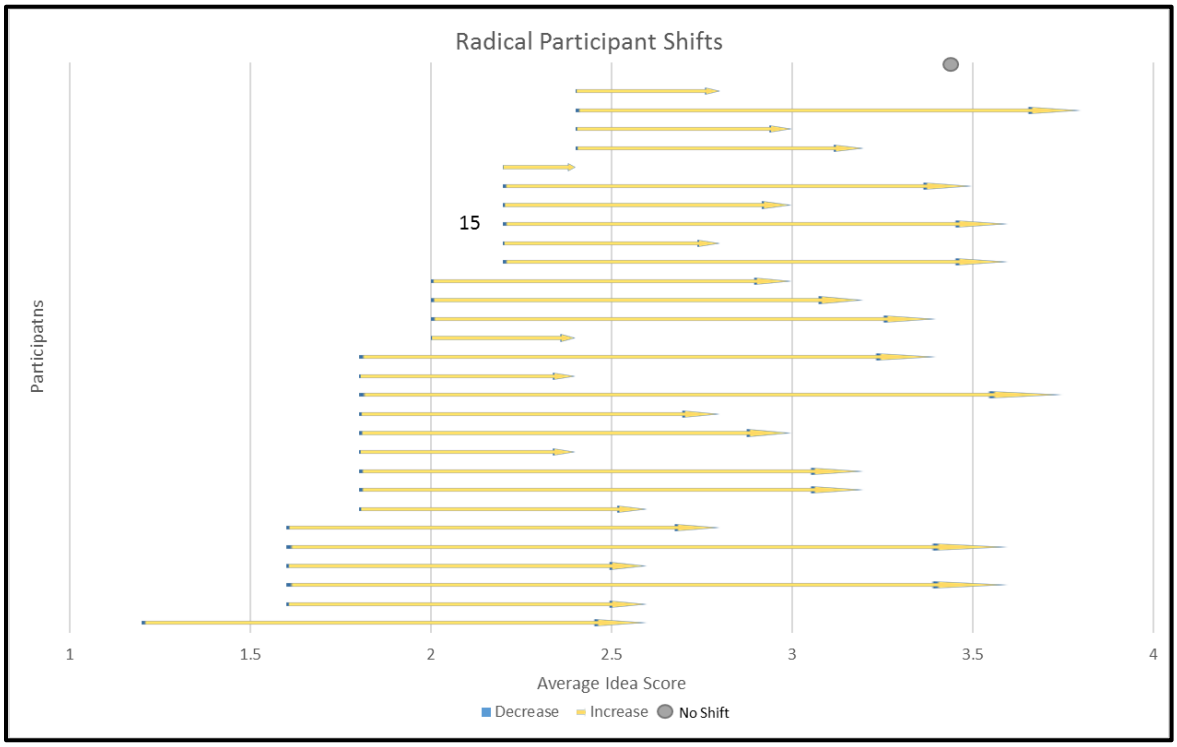

Figure 3. Shift scores of participants using the radical tool

Figure 4 shows the mean idea score across the participants for the two tool types (Incremental and Radical) and the two phases (Neutral and Framed). For the participants that chose the incremental tool, they had a mean idea score of 2.23 (*SD* = 0.37) for the Neutral ideation session, and a mean idea score of 2.31 (*SD* = 0.65) for the Framed ideation session. There was no significant shift observed for the incremental tool group, $t(14) = 0.418$, $p = 0.68$.

For the participants that chose the radical tool, they had a mean idea score of 1.99 (*SD* = 0.40) for the Neutral ideation session, and a mean idea score of 3.06 (*SD* = 0.44) for the Framed ideation session. There was a significant shift towards generating more radical ideas in the radical tool group, $t(29) = 11.451$, $p < 0.001$.

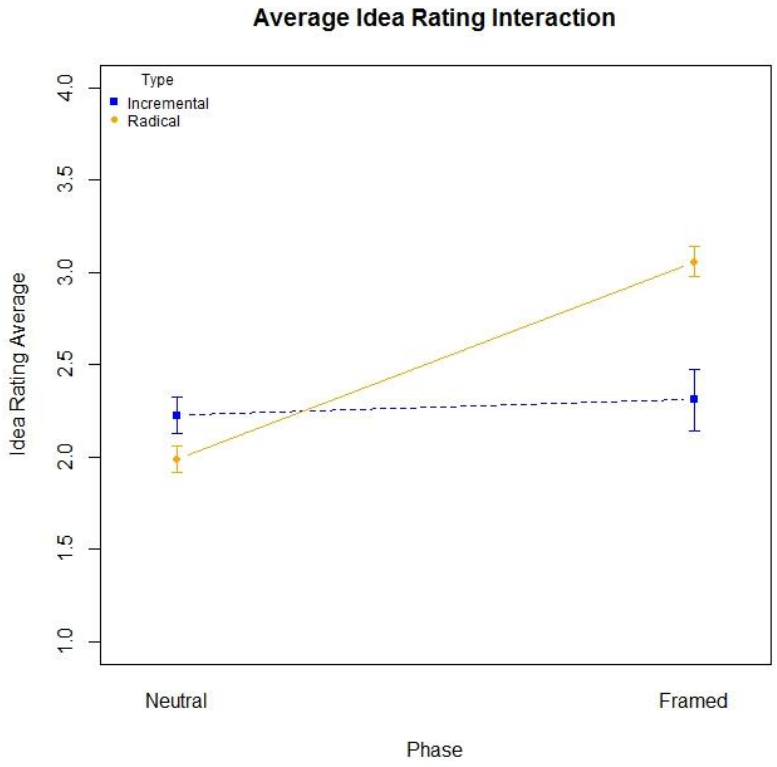

Figure 4. Interaction plot of mean idea score by ideation phase and tool type

Case Examples

We chose to examine two cases in which the tool successfully shifted the ideas of participants, and one case where the shift was not consistent with our expectations of the effect of the tool. We labeled Case 1 as *Expected Adaptive Shift* to represent Participant 27 shifting from having more radical ideas in their initial set to having more incremental ideas in the set generated using the incremental tool. Case 2 was labeled as *Expected Innovative Shift* to represent Participant 15 shifting from having more incremental ideas in their initial set to more radical ideas in the set generated using the radical tool. Case 3 was labeled as *Unexpected Innovative Shift* as Participant

12 selected the incremental tool, but shifted toward having more radical ideas in the second session using the tool, which was opposite of our expectations. For each case, we have included the sketches that the participants drew for each of their ideas. On each sketch, there is a bubble that corresponds to our paradigm-relatedness coding for that idea (see the key in **Figure 5**).

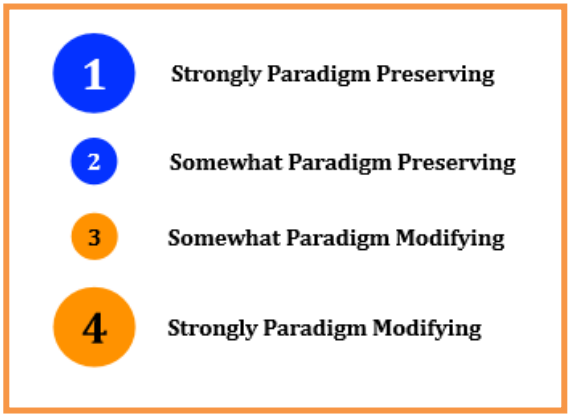

Figure 5. Key for bubble corresponding to paradigm-relatedness coding categories

Case 1: Expected Adaptive Shift

Participant 27 chose and successfully utilized the *incremental* version of the framing tool. Their neutral ideas were overall more paradigm-modifying, resulting in an average idea score of 2.8, while the ideas generated using the tool were overall more paradigm-preserving, resulting in an average idea score of 1.2. This is visually illustrated in **Figure 6**, which shows the sketches from the two sets of ideas generated by Participant 27.

As shown on the left side of **Figure 6**, Participant 27's initial set of ideas all had paradigm-modifying aspects to them. The most strongly paradigm-modifying solutions included a hover board (Idea 2) and a jetpack (Idea 5), both of which defy the constraint of physically having to travel on the snow. But even their ideas coded as paradigm-preserving had elements that are not typically used to travel across the snow, including Idea 3 that utilized a giant snowball, and Idea 4 that utilized a giant fan to propel the device. In contrast, Participant 27's ideas generated with the incremental framing tool were considerably more paradigm-preserving. These ideas are on the right hand side of **Figure 6**. The ideas included snow boots, sleds, snowshoes, snowmobiles, and motor vehicles, which all resembled existing solutions and were representative of a strongly adaptive ideation approach.

Participant 27 used framing strategies F, E, D, B, and F, respectively to generate the five ideas in their second ideation session. The participant reported the *Current Technology (F)* framing strategy to be their favorite because it helped them to generate ideas that integrated current and successful technologies. This was shown through Ideas 1 and 5, which depicted a snowmobile and snow boots, which are both technologies that exist. In the participant's reflection survey, they conveyed that the tool helped them to generate ideas when they were lost.

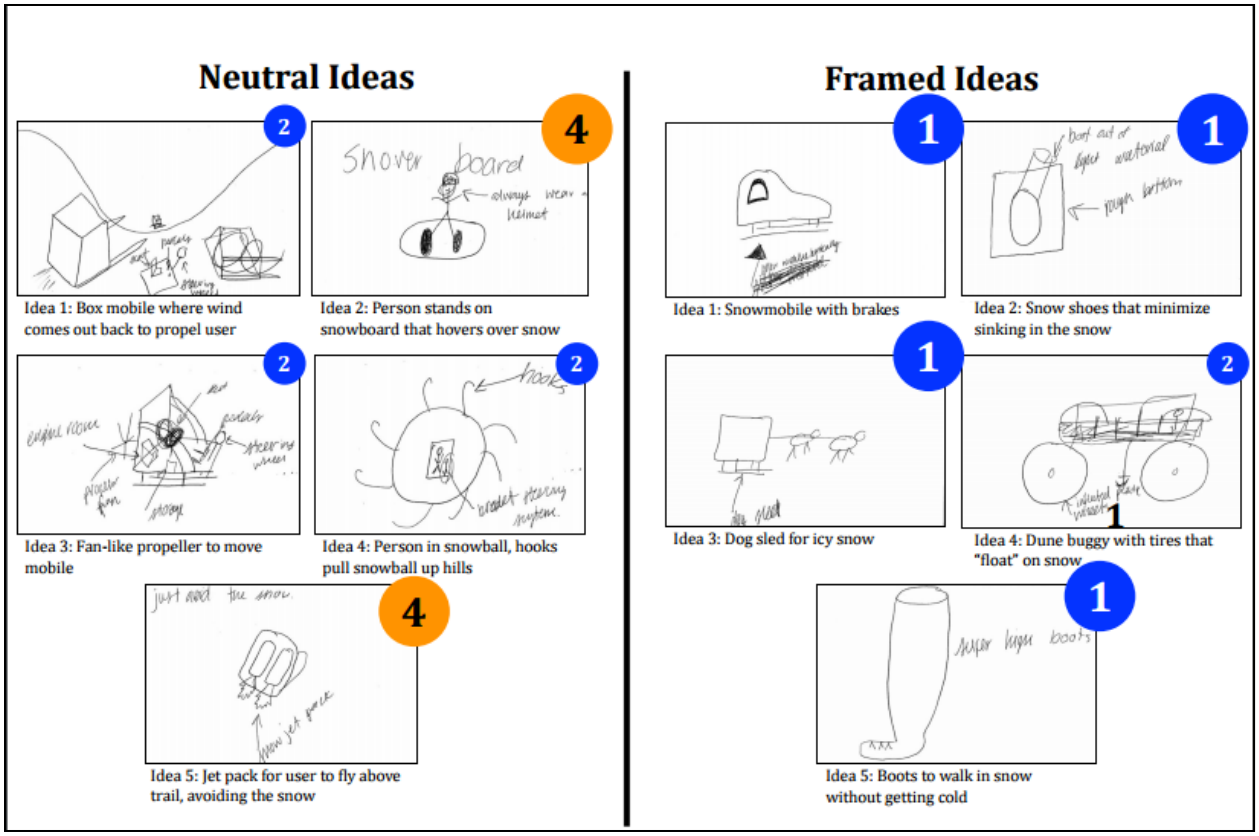

Figure 6. Set of ideas generated by Participant 27 (Case 1)

Case 2: Expected Innovative Shift

Participant 15 chose and successfully utilized the *radical* version of the framing tool. The average idea score of their initial ideas was 1.8, which is on the more paradigm-preserving side. The average idea score generated with the radical tool was 3.2, which indicated a substantial shift toward a more innovative ideation approach. The sketches from Participant 15's two sets of ideas are provided in **Figure 7**.

Participant 15's initial ideas were all coded as paradigm-preserving. Their ideas were based on already existing solutions such as skis and sleds. Even though they made small changes to these already existing solutions, such as adding brakes and arm supports, these changes did not challenge the focus or assumptions of the problem and so were still paradigm-preserving. Participant 15 then selected the *radical* version of the framing tool. In the ideation session using the tool, Participant 15 generated three ideas coded as paradigm-modifying and two coded as paradigm-preserving. Their paradigm-modifying ideas changed the focus and challenged the assumptions of the problem. For example, Idea 2 is hover skis. This challenges the assumption of the problem that the solution requires the individual to travel directly on the snow. For this idea they used frame *Unlimited Budget (Z)*. By removing the budgetary restriction, this framing strategy allowed them to consider ideas that they might have disregarded during the initial ideation session. Another idea that highlights how Participant 15 made use of the radical version of the tool is Idea 4. This idea places escalators on hills. This solution is not an individual

solution and therefore breaks an assumption made within the problem statement. For this idea, Participant 15 reported using the framing strategies *Long Term (V)* and *Disregard Constraints (Y)*. Thus, it was possible for a designer to use multiple framing strategies at one time.

In their reflection responses, Participant 15 indicated that the tool helped them think about ideas that they originally discounted because the ideas didn't seem plausible. Reconsidering ideas that may initially have been excluded is aligned with the intent of the tool, which is to help designers explore areas of the solution space they may have unnecessarily disregarded. When asked in their Neutral session reflection survey what they would tell a co-worker to focus on when solving this problem, Participant 15 reported maneuverability. In their initial ideation session, Participant 15 focused on existing solutions that require a lot of experience to maneuver, such as skis. However, in the ideas they generated with the tool, they solved this problem by getting rid of maneuverability altogether through autonomous skis and shared infrastructure. The framing tool may have facilitated Participant 15's re-framing of the problem in such a way that it was possible to simultaneously keep that criterion in mind while still expanding the possible ways to solve the problem.

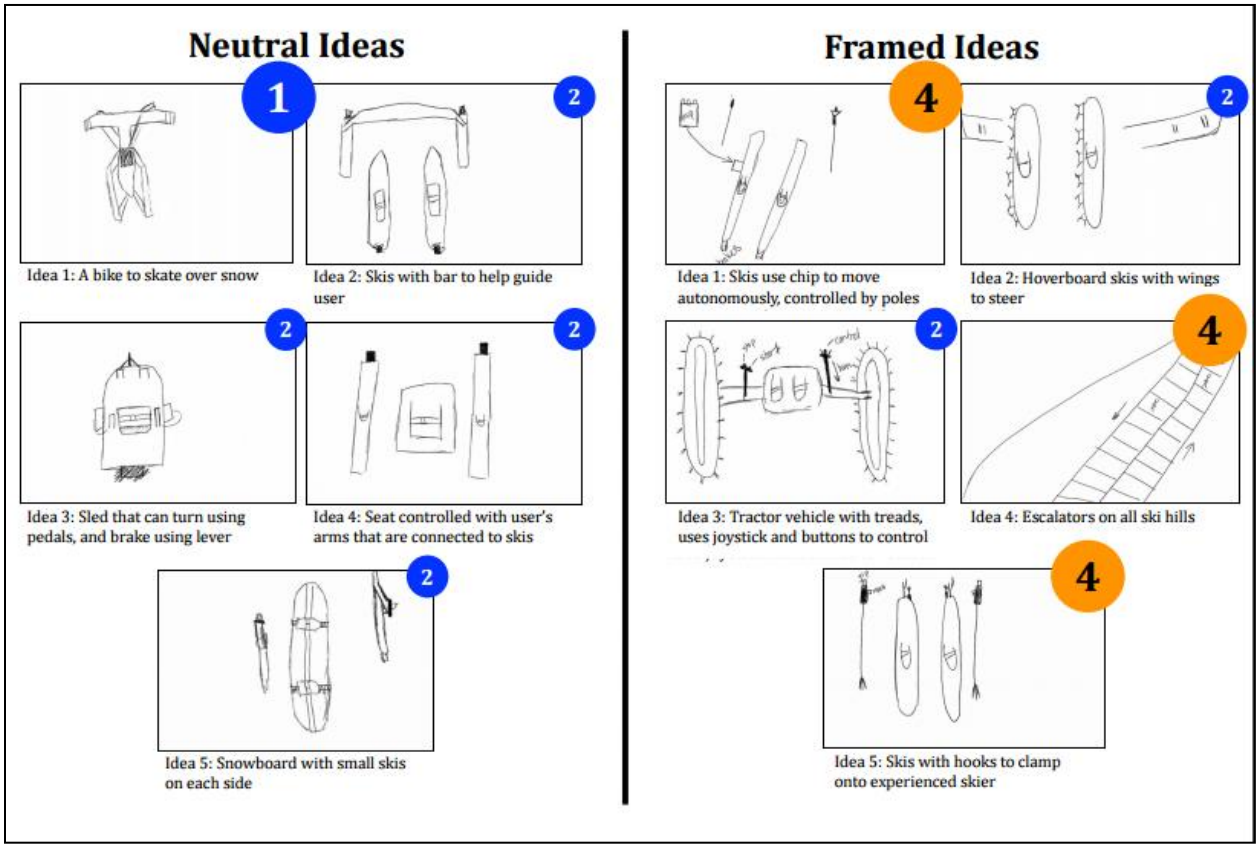

Figure 7. Set of ideas generated by Participant 15 (Case 2)

Case 3: Unsuccessful Adaptive Shift

Participant 12 self-assessed their initial set of ideas as being overall more paradigm-modifying. Consistent with this self-assessment, Participant 12 chose the incremental version of the framing tool. However, in our post-hoc coding of Participant 12's initial ideas we classified the overall set as being somewhat paradigm-preserving with an average idea score of 2.0. Despite the inconsistency between Participant 12's self-assessment and our own coding of the initial ideas, Participant 12 used the incremental tool to generate the second set of ideas, and so we still expected that second set of ideas to be more paradigm-preserving. That was not the case, as the Participant 12 generated more paradigm-modifying ideas in the second session, resulting in an average idea score of 3.4. The substantial innovative shift indicates that the tool was not effective for this participant in the way the tool was intended. The sketches from Participant 12's two sets of ideas are provided in **Figure 8**.

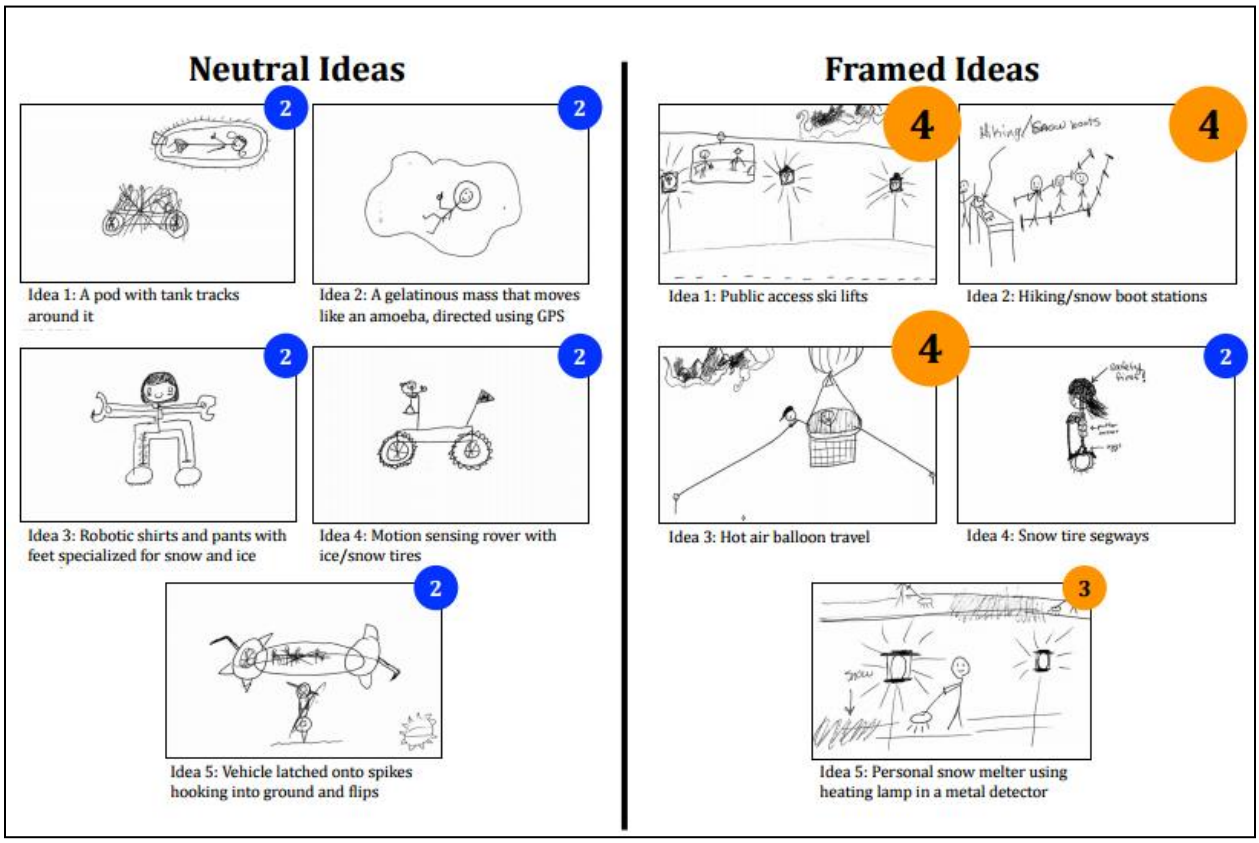

Figure 8. Set of ideas generated by Participant 12 (Case 3)

Participant 12's initial ideas were each coded as somewhat paradigm-preserving. All five of these ideas included uncommon elements and relationships in relation to currently existing solutions for this problem, and so had some aspects of more radical ideas. For example, Idea 2 was a pod with tank tracks. A pod as a traveling device was not a common solution. Despite the unusualness of many of these initial ideas, paradigm-relatedness is distinct from originality[9] and so reflects more whether an idea approaches a problem in a transformational way.[24] None of

Participant 12's initial ideas change the focus of the problem or violate any of the constraints given in the problem statement, so we consider them to be more paradigm-preserving.

As described before, Participant 12 then selected the *incremental* version of the framing tool to use in the second ideation session. The first three ideas generated in this second session were coded as strongly paradigm-modifying. Each of the designs shifted the problem's focus from what was explicitly stated in the problem statement, instead providing solutions that allowed the user to avoid traveling directly on snow and/or to take advantage of shared solutions rather than solutions for individual use only. The other two ideas also had paradigm-modifying aspects to them, including a Segway as an uncommon element for traveling in snow, and a heater that violates the problem assumption that the snow cannot be removed. Overall, Participant 12's set of ideas generated with the incremental version of the tool was not representative of an adaptive ideation approach. On the contrary, despite our expectations of the effect of the tool, Participant 12 took a much more innovative ideation approach using the tool compared to the approach taken in the initial ideation session.

Although our ratings of Participant 12's neutral session ideas were consistently paradigm-preserving, the initial ideas exhibited some of the traits that are associated with radical ideas. When asked in the first reflection survey what she would tell a co-worker who was generating ideas for the same design task, she said to "focus on creative but possible ideas" and "ideas that are not already around". Many of the participant's initial ideas contained elements and relationships that are not typical in existing snow transportation options, which is consistent with her focus on generated ideas that are not already in existence. As mentioned before, although originality and paradigm-relatedness do tend to be associated with each other in empirical studies, they are two distinct aspects of novelty.[9] It is possible that Participant 12 self-assessed her ideas as more radical because she did not differentiate originality and paradigm-relatedness in the evaluation of her initial ideas.

In her reflection survey following the second ideation session, Participant 12 responds that generating ideas with the incremental tool was slightly difficult because she "naturally [leans] towards radical ideas". When asked to rank the tool framing strategies in terms of effectiveness, this participant chose the *Already Existing (C)* strategy as being the most helpful. She also reported that the *Meet Constraints (B)* strategy was the least helpful because she "found this one hardest to follow". Many of the participant's second set of ideas do already exist, such as ski lifts, shoe rental stations, and hot air balloons, so in one sense her ideas were consistent with the *Already Existing (C)* strategy. On the other hand, many of the ideas represented a change in focus from an individual solution to a shared solution and helped users avoid traveling on the snow entirely. So in another sense, the ideas were strongly paradigm-modifying as they reconsidered common assumptions made from the problem statement about how to approach the problem. We suspect that this participant's understanding of the different characteristics that define the spectrum from incremental to radical was not consistent with our own. Her use of the framing strategies in ways that we did not predict suggest that we need to better understand the different interpretations of the strategies in light of understandings about paradigm-relatedness generally. We might then be able to better redesign the tool itself along with the training to use the tool so that it is more likely to be used in ways consistent with its intended use.

Discussion

Summary of Findings

Our data showed that the tool was successful for the majority of participants. Of the 45 participants analyzed, 36 shifted in the direction of the tool they chose (80%). Furthermore, it was found that every student who chose the same version of the tool that we would have chosen for them based on our post-hoc coding also shifted in the direction consistent with version of the tool. Thirty-three participants (73%) took the same tool we would have chosen for them, and all 33 shifted in the expected direction.

We observed differences between the incremental and radical versions of the tool. First, more participants self-selected the radical version—30 participants chose the radical tool compared to 15 that chose the incremental tool. This was not necessarily surprising given that we have consistently found paradigm-modifying ideas to be less common than paradigm-preserving ideas in our prior work.[14,15] Regardless of where participants fell on paradigm-relatedness spectrum for their initial set of ideas, of the 15 participants that selected the incremental tool, only seven were able to make a shift towards more paradigm-preserving ideas on average. Out of the 30 that selected the radical tool, 29 were able to make a shift towards more paradigm-modifying ideas on average. Thus, the participants who selected the radical version of the tool more consistently shifted toward generating a greater proportion of paradigm-modifying ideas. In contrast, less than half of the participants who selected the incremental version of the tool shifted toward generating a greater proportion of paradigm-preserving ideas. This asymmetry in observed selection and effectiveness of the radical version of the tool compared with the incremental version of the tool is worth exploring further.

Finally, by examining three case examples, we found that participants were able to utilize the framing strategies in a variety of ways to influence the ideas they generated. Case 1 illustrated how a strategy of adding to and improving on existing technologies can ground a set of ideas, thus facilitating a more adaptive ideation approach. Case 2 illustrated how the strategies that temporarily remove common constraints such as cost and time can open up the space of solutions that are worth considering, supporting a more innovative ideation approach. Case 3 illustrated how some framing strategies may be applied in unintended ways, such as when a designer has a strong association between originality and paradigm-relatedness. Thus, the framing strategies and the training around the use of the tool may have to better differentiate these related but distinct aspects of ideation in order to facilitate more reliable ideation shifts.

Possible Explanations and Future Work

Our goal in this study was to understand how the tool works and where improvements could be made. We were able to gain insight into each participant's perception of the framing tool from their responses on the reflection surveys. Many of the responses were positive, saying that the tool "gave [the participant] new ways to think about the problems" and that it helped to "discover new ways of creating ideas".

Framing Strategies

From the reflection survey, we were also able to see which framing strategies the participants found to be most and least effective towards their idea generation process. In Case 1, Participant 27 reported the *Current Technology (F)* frame as being most effective in shifting their ideas in the incremental direction. This frame was used more than the others in this participant's idea set, and we can see its effect in the successful shift Participant 27 was able to make. A notable finding was the case of Participant 12 detailed above, in which the participant was able to use a frame from the adaptive tool to generate more radical ideas. The frame was the *Already Existing* frame, which advises participants to generate solutions for the problem that already exist. This was intended to parallel the radical tool's *Unexpected* frame that told participants to add in "something unexpected" to an already existing solution. While the word "unexpected" seems to be widely understood, the idea behind "already existing" solutions may not be as clear. For example, Participant 12 used the *Already Existing* frame to generate a hot air balloon that they ranked as being an incremental idea. While hot air balloons are not common in the context of snow travel, they are an already existing idea for travel in general.

Tool Selection

In order to receive their tool for the Framed ideation session, participants were asked to raise their hands to indicate to the researchers which tool they needed. All participants in a given session were able to see which tools their peers were requesting, creating the possibility of social bias. We potentially see this effect when we consider that 15 of our 45 participants chose the incremental tool for the Framed ideation session when the researchers decided post hoc that only four should have selected the incremental tool.

Additionally, we propose that not fully understanding the difference between radical and incremental ideas could cause a participant to choose an unexpected framing tool. During the ideation sessions, there was a limited time period in which to convey a detailed description of the paradigm-relatedness spectrum. Confusion stemming from the information sessions could cause participants to inaccurately assess their initial ideas and lead them to select the unexpected tool.

Intervention Type

Prior research has focused on how problem framing impacts the paradigm-relatedness of ideas and has typically involved procedural methods that we purposely decided to alter for this study: (1) problem framings were given embedded within a problem description that participants were given, (2) participants were not explicitly told of the framings and were left to infer them from the descriptions, and (3) participants were randomly assigned a frame.[13,22] We chose to perform our study by creating a tool containing the problem frames and asking participants to decide which tool would be best for them to personally generate ideas on the side of the paradigm-relatedness spectrum that they were not naturally inclined to.

These specific design prompts were incorporated in previous research and involved studies analyzing a small number of participants, therefore making it difficult to compare the proportion of participants that were able to make the shift using our tool as opposed to the built-in, randomly assigned problem statements.[8,13] However, our study showed that every participant who

used the tool the researchers would have assigned to them based on their neutrally generated ideas was able to shift in the intended direction of the tool. This suggests that matching the framing to the participant, based on their natural style, yields more promising results, as opposed to the random assignment of frames seen in previous studies.

One feature of previous studies is the modification of problem statements through the inclusion of embedded framing statements. For example, the adaptively framed descriptions encourage designers to improve upon existing designs, and develop solutions that are practical, cost-effective, and immediately workable. Since there is no telling which of these statements may have prompted the largest shift and which may have led a designer astray, it is difficult to adjust the statement to include only the most effective prompts. By having separate frames and asking for feedback in our study, we were able to identify which specific prompting statements were the most effective in pushing our participants to generate ideas that the tool encouraged. This knowledge can aid us in improving the tool for future iterations.

Conclusion

Problem framing can affect how engineers create solutions to challenging problems. This concept was taken and applied to the design of a framing tool prototype. To test our tool, we conducted ideation sessions with pre-engineering students. By examining specific cases from those ideation sessions, we were able to identify causes and patterns in the shifts of the participants' ideas. It was found that when a participant chose the framing tool we would have assigned them based on their first set of neutral ideas, the participant exhibited a shift in the expected paradigm-relatedness direction of their ideas. Furthermore, certain frames on the adaptive framing tool were more difficult to follow than others, thus creating confusion for the participants. Along with the ideation data, we also utilized reflection surveys to understand how the participants utilized the tools.

In a greater context, our study produced evidence supporting the influential relationship between problem framing and paradigm-relatedness. By modifying idea statements, designers and engineers may shift their ideas to develop solutions they do not naturally create. In turn, this will produce a greater range of ideas, thus better serving the problem at hand. Engineers can use this concept, along with the tool, to increase the variety of their ideas generated in both an academic or professional setting. Similarly, instructors could use our tool to help students further explore problem spaces and depart from solutions in which they would naturally gravitate.

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Appendix A – Design Problem Statement

Low-Skill Snow Transporter

Today skis and snowboards are widely used as personal transportation tools on snow. But to be able to use them, a lot of skill and experience are required that a user cannot normally learn within one day. Moreover, skis and snowboards cannot run uphill easily. It would be better if there were other options of personal tools for transportation on snow, which still allowed the user to control direction and braking, but did not require much time to learn how to use.

Context

Design a way for individuals without lots of skill and experience skiing or snowboarding to transport themselves on snow.

Need

Develop solutions for this problem. 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.

Goals

Appendix B – Self-Assessment

Look back at the ideas that you just generated. Rate each idea on a scale from 1 to 4, 1 being "very incremental", 2 being "somewhat incremental", 3 being "somewhat radical", and 4 being "very radical". At the bottom of the page after you have rated each idea, rate your ideas overall as incremental or radical by circling the appropriate label.

Idea #1:	**1** **Very Incremental**	**2** **Somewhat Incremental**	**3** **Somewhat Radical**	**4** **Very Radical**
Idea #2:	**1** **Very Incremental**	**2** **Somewhat Incremental**	**3** **Somewhat Radical**	**4** **Very Radical**
Idea #3:	**1** **Very Incremental**	**2** **Somewhat Incremental**	**3** **Somewhat Radical**	**4** **Very Radical**
Idea #4:	**1** **Very Incremental**	**2** **Somewhat Incremental**	**3** **Somewhat Radical**	**4** **Very Radical**
Idea #5:	**1** **Very Incremental**	**2** **Somewhat Incremental**	**3** **Somewhat Radical**	**4** **Very Radical**

Overall, my ideas are more (circle one):

1 **Very Incremental**	**2** **Somewhat Incremental**	**3** **Somewhat Radical**	**4** **Very Radical**

Appendix C – Incremental Tool Idea Scores

	Average Idea Score		
Participant ID	**Neutral**	**Framed**	**Shift Score**
1	2.2	3.4	+1.2
4	1.8	2.0	+0.2
6	1.8	3.0	+1.2
12	2.0	3.4	+1.4
13	2.4	2.5	+0.1
17	**2.6**	**2.0**	**-0.6**
23	**3.0**	**2.8**	**-0.2**
24	2.2	2.8	+0.6
25	**2.6**	**1.8**	**-0.8**
27	**2.8**	**1.2**	**-1.6**
37	**2.2**	**2.0**	**-0.2**
40	**1.8**	**1.6**	**-0.2**
43	**2.2**	**2.0**	**-0.2**
44	2.0	2.0	0.0
45	1.8	2.2	+0.4

Appendix D – Radical Tool Idea Scores

	Average Idea Score		
Participant ID	**Neutral**	**Framed**	**Shift Score**
2	**1.2**	**2.6**	**+1.4**
3	**1.6**	**2.6**	**+1.0**
5	**1.6**	**3.6**	**+2.0**
7	**1.6**	**2.6**	**+1.0**
8	**1.8**	**2.6**	**+0.8**
9	3.4	3.4	0.0
10	**2.4**	**3.2**	**+0.8**
11	**2.0**	**2.4**	**+0.4**
14	**2.4**	**3.0**	**+0.6**
15	**1.8**	**3.2**	**+1.4**
16	**2.0**	**3.4**	**+1.4**
18	**1.8**	**3.2**	**+1.4**
19	**2.0**	**3.2**	**+1.2**
20	**1.6**	**3.6**	**+2.0**
21	**2.0**	**3.0**	**+1.0**
22	**2.2**	**3.6**	**+1.4**
26	**2.2**	**2.8**	**+0.6**
28	**2.2**	**3.6**	**+1.4**
29	**1.8**	**2.4**	**+0.6**
30	**2.2**	**3.0**	**+0.8**
31	**2.4**	**3.8**	**+1.4**
32	**1.6**	**2.8**	**+1.2**
33	**2.2**	**3.5**	**+1.3**
34	**1.8**	**3.0**	**+1.2**
35	**1.8**	**2.8**	**+1.0**
36	**2.2**	**2.4**	**+0.2**
38	**2.4**	**2.8**	**+0.4**
39	**1.8**	**3.75**	**+1.95**
41	**1.8**	**2.4**	**+0.6**
42	**1.8**	**3.4**	**+1.6**