TEAM IDEATION: A DETAILED INVESTIGATION INTO IDEATION EFFECTIVENESS

A Thesis in
Mechanical Engineering

by
Wesley Teerlink

© 2015 Wesley Teerlink

Submitted in Partial Fulfillment
of the Requirements
for the Degree of
Master of Science

August 2015
The thesis of Wesley Teerlink was reviewed and approved* by the following:

Kathryn W. Jablokow, FASME  
Associate Professor of Mechanical Engineering  
Associate Professor of Engineering Design

Matthew Parkinson  
Associate Professor of Mechanical Engineering  
Associate Professor of Engineering Design

Dan Haworth  
Professor-In-Charge of MNE Graduate Programs  
Professor of Mechanical Engineering

*Signatures are on file in the Graduate School
ABSTRACT

Ideation is a key part of the design process that is often carried out in teams. Cognitive style, the preferred way in which individuals tend to solve problems, plays an important role in team dynamics and perceptions. Differing cognitive styles on a single team allow for increased team potential, but working together can become more difficult. It has been shown previously that working in teams can lead to fewer ideas overall. Previous research leaves many questions as to what the benefits of teaming are and if they are worth the costs. This work makes a detailed analysis of the ideation performance of individuals and teams. The participants’ cognitive styles and perceptions of the experience are also considered. The subjects are 86 university engineering students that participated in two, 20-minute ideation sessions: one individually and the other as two- or three-person teams. All ideas were evaluated for quantity, quality, variety, and novelty.

It was observed that individuals on teams recorded fewer ideas than when working alone. Yet, in general participants indicated that ideation was easier as a team and that they felt more creative. Several known causes of process loss were observed and possible alternate causes are proposed, including conglomeration and evaluation of ideas.
TABLE OF CONTENTS

LIST OF FIGURES ................................................................................................. vi

LIST OF TABLES ..................................................................................................... vii

ACKNOWLEDGEMENTS ......................................................................................... x

Chapter 1 Introduction ......................................................................................... 1

Chapter 2 Background .......................................................................................... 5

  2.1 Ideation as part of the design process ......................................................... 5
  2.2 Cognitive factors ......................................................................................... 6
  2.3 Ideation in teams ......................................................................................... 9
  2.4 Ideation assessment .................................................................................... 12
    2.4.1 Quality .............................................................................................. 16
    2.4.2 Novelty .............................................................................................. 18
    2.4.3 Quantity ............................................................................................ 20
    2.4.4 Variety .............................................................................................. 20
  2.5 Self Assessment .......................................................................................... 21

Chapter 3 Research Methods ............................................................................. 22

  3.1 Research Questions .................................................................................... 22
  3.2 Participants ................................................................................................ 23
  3.3 Data Collection .......................................................................................... 24
  3.4 Idea Evaluation ......................................................................................... 27
    3.4.1 Metric assessment ............................................................................. 27
    3.4.2 Focus on individuals ......................................................................... 35
  3.5 Answering the Research Questions ........................................................... 36

Chapter 4 Results ............................................................................................... 38

  4.1 How is working in a team related to an individual’s perceptions of their ideation? (Research question #1) ............................................................... 39
    4.1.1 Individual perceptions of ideation (session 1) ....................................... 39
    4.1.2 Perceptions of ideation while working in teams (session 2) .............. 41
    4.1.3 Changes of perception from individual to teaming ideation (difference) .... 44
  4.2 How is working in a team related to ideation performance? (Research question #2) ....................................................................................................... 46
    4.2.1 Individual ideation performance ......................................................... 46
    4.2.2 Teaming ideation performance ........................................................... 52
    4.2.3 Changes in performance from individual to teaming ideation ............ 56
  4.3 How is an individual’s cognitive style related to their perceptions of ideation? (Research question #3) ................................................................. 60
    4.3.1 Cognitive style in perceptions of individual ideation ........................... 61
    4.3.2 Cognitive style in perceptions of team ideation ................................... 61
LIST OF FIGURES

Figure 1 Relationship investigated in individual and teamwork .......................................................... 3
Figure 2 Ideation metric descriptions .................................................................................................. 15
Figure 3 Distribution of KAI scores (N=64) compared to large population distribution .................. 24
Figure 4 Example of hierarchical variety tree ..................................................................................... 31
Figure 5 Variety outlier example .......................................................................................................... 33
Figure 6 Session 1 reflection survey responses (N=86) ..................................................................... 40
Figure 7 Session 2 reflection survey responses (N=86) ..................................................................... 42
Figure 8 Perception responses to the "Impact of team" question in session 2 (N=86) ......................... 43
Figure 9 Difference between sessions reflection survey responses (N=86) ....................................... 45
Figure 10 Quantity of ideas generated in session 1 (N=86) ................................................................. 47
Figure 11 Quantity of ideas generated in session 2 (N=86) ................................................................. 52
Figure 12 Difference in number of ideas generated from session 1 to session 2 ............................ 57
Figure 13 Summary of findings from session 1 ..................................................................................... 71
Figure 14 Summary of findings from session 2 ..................................................................................... 72
Figure 15 Summary of findings from the change between sessions .................................................. 73
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>List of ideation metrics used in previous literature</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>Reliability notes for quality metrics</td>
<td>29</td>
</tr>
<tr>
<td>3</td>
<td>Example rarity scores for belonging securer context</td>
<td>35</td>
</tr>
<tr>
<td>4</td>
<td>Classification of correlation strengths</td>
<td>39</td>
</tr>
<tr>
<td>5</td>
<td>Analysis of variance in perceptions of participants who received different problem contexts (Kruskal-Wallis analysis of variance; N=86)</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>$R$-values between perception responses in session 1 (Pearson correlations; N=86)</td>
<td>41</td>
</tr>
<tr>
<td>8</td>
<td>$R$-values between the changes in perception responses (Pearson correlations; N=86)</td>
<td>45</td>
</tr>
<tr>
<td>9</td>
<td>Difference in Means from Session 1 to Session 2 (paired t-tests; N=86)</td>
<td>46</td>
</tr>
<tr>
<td>10</td>
<td>$R$-values between quantity of ideas and other performance metrics in session 1 (Pearson correlations; N=86)</td>
<td>47</td>
</tr>
<tr>
<td>11</td>
<td>$R$-values between all of the quality metrics in session 1 (Pearson correlations; N=86)</td>
<td>49</td>
</tr>
<tr>
<td>12</td>
<td>Mean and standard deviations of quality metrics in session 1</td>
<td>49</td>
</tr>
<tr>
<td>13</td>
<td>Maximum, median, mean, and standard deviations of variety scores in session 1</td>
<td>50</td>
</tr>
<tr>
<td>14</td>
<td>$R$-values between variety score and other performance metrics in session 1 (Pearson correlations; N=86)</td>
<td>50</td>
</tr>
<tr>
<td>15</td>
<td>Maximum, minimum, mean, and standard deviations of rarity scores in session 1</td>
<td>51</td>
</tr>
<tr>
<td>16</td>
<td>$R$-values between rarity score and other performance metrics in session 1 (Pearson correlations; N=86)</td>
<td>51</td>
</tr>
<tr>
<td>17</td>
<td>$R$-values between quantity of ideas and other performance metrics in session 2 (Pearson correlations; N=86)</td>
<td>53</td>
</tr>
<tr>
<td>18</td>
<td>Mean and standard deviations of quality metrics in session 2 (N=86)</td>
<td>53</td>
</tr>
<tr>
<td>19</td>
<td>$R$-values between performance metrics in session 2 (Pearson correlations; N=86)</td>
<td>54</td>
</tr>
<tr>
<td>20</td>
<td>$R$-values between variety score and other performance metrics in session 2 (Pearson correlations; N=86)</td>
<td>54</td>
</tr>
<tr>
<td>21</td>
<td>Maximum, median, mean, and standard deviation of variety scores in session 2</td>
<td>55</td>
</tr>
</tbody>
</table>
Table 22 R-values between rarity scores and other performance metrics (Pearson correlations; N=86) ........................................................................................................................................ 55

Table 23 Maximum, minimum, mean, and standard deviation of rarity scores in session 2 ............ 55

Table 24 R-values between the change in quantity to the change in other performance metrics (Pearson correlations; N=86) ........................................................................................................................................ 57

Table 25 R-values between the change in all of the quality metrics (Pearson Correlations; N=86)..... 58

Table 26 Change in the mean quality metrics from session 1 to session 2 (two-sample paired t-tests; N=86) ........................................................................................................................................ 58

Table 27 R-values between the change in variety scores and the change in the other performance metrics (Pearson correlations; N=86) ........................................................................................................................................ 59

Table 28 Maximum, minimum, mean, and standard deviation of the change in variety scores (N=86).................................................................................................................................................. 59

Table 29 R-values between change in rarity score and change in other performance metrics (Pearson correlations; N=86) ........................................................................................................................................ 60

Table 30 Maximum, minimum, mean, and standard deviation of the change in rarity scores (N=86) 60

Table 31 R-values between perceptions and KAI in session 1 (Pearson correlations; N=61) .............. 61

Table 32 R-values between perceptions and KAI in session 2 (Pearson correlations; N=61) .............. 62

Table 33 R-values between change in perceptions and KAI (Pearson correlations; N=61) .............. 62

Table 34 R-values between quantity and KAI scores in session 1 (Pearson correlations; N=61) ......... 63

Table 35 R-values between variety scores and KAI scores in session 1 (Pearson correlations; N=61) ........................................................................................................................................ 63

Table 36 R-values between quality metrics and KAI scores in session 1 (Pearson correlations; N=61) ........................................................................................................................................ 64

Table 37 R-values between rarity score and KAI scores in session 1 (Pearson correlations; N=61) .... 64

Table 38 R-values between quantity and KAI scores in session 2 (Pearson correlations; N=61) .......... 65

Table 39 R-values between variety scores and KAI scores in session 2 (Pearson correlations; N=61) ........................................................................................................................................ 65

Table 40 R-values between quality metrics and KAI scores in session 2 (Pearson correlations; N=61) ........................................................................................................................................ 65

Table 41 R-values between rarity score and KAI scores in session 2 (Pearson correlations; N=61) .... 66

Table 42 R-values between change in quantity and KAI scores (Pearson correlations; N=61) ............ 66

Table 43 R-values between change in variety scores and KAI scores (Pearson correlations; N=61) .... 66
Table 44 R-values between change in quality metrics and KAI scores (Pearson correlations; N=61) .. 67

Table 45 R-values between change in rarity scores and KAI scores (Pearson correlations; N=61) .... 67

Table 46 R-value between performance metrics and perceptions of ideation in session 1 (Pearson correlations; N=86) ................................................................. 68

Table 47 R-value between performance metrics and perceptions of ideation in session 2 (Pearson correlations; N=86) ................................................................. 69

Table 48 R-value between performance metrics and perceptions of team experience in session 2 (Pearson correlations; N=86) ................................................................. 69

Table 49 R-value between change in performance metrics and change in perceptions of ideation (Pearson correlations; N=86) ................................................................. 70

Table 50 Participant comments about conglomeration ................................................................. 75

Table 51 Participant comments about evaluation during teamwork ............................................. 76

Table 52 Comments from participants who did not feel that teams made ideation easier ............. 77
ACKNOWLEDGEMENTS

I have a lot of people to thank for supporting me in this research. Kathryn Jablokow has been the best academic advisor that anyone could ask for. She has been understanding through difficult times and demanding in a good kind of way to encourage me to do much more than I thought possible. A big thank you goes to Kathryn Jablokow, Seda Yilmaz, Shanna Daly, and Eli Silk for creating this research opportunity and making it so interesting and fun to work together.

Many undergraduate researchers volunteered their time and talents to the progress of this research. They, who are already very busy, made room in their busy schedules to help with difficult and sometimes monotonous tasks. These students have my appreciation and admiration: Kevin Helm, Nick Giltrow, Cavin Israel, Ajia Lui, Rafael Suero, Peiquan (Tabitha) Lin, Valerie Pascoe, Casey Luddy, Justin Roarty, and Nadine Geagea.

Matthew gave me lab space, advice, friendship, and many important opportunities that will help me through my entire career. My parents Karen and Steve Teerlink always helped and encouraged me throughout my education experience. They taught me to love to learn and explore. Last and most importantly is my wife Jamie Teerlink who encouraged, supported, and counseled me in all my work. She also played a big role in designing graphics for this work.
Chapter 1

Introduction

Since the brainstorming method was introduced nearly 60 years ago, generating ideas as teams has been general practice in every industry (Osborn 1957). For example, Job postings often call for “team players”, and school projects are often graded on team participation. People who are able to work effectively in team settings are in high demand. In particular, there is a strong need for engineers to work and ideate effectively in teams (Duderstadt 2008; Bordogna 2003).

How is working in teams different than working alone? In what ways is it better? Is it ever better to simply work alone? This work investigates these questions and in hopes to find answers that will improve the effectiveness of teamwork in professional and educational settings. While teamwork has been thoroughly researched in many difference fields, this work brings together an understanding of ideation effectiveness metrics, cognitive style, and participant perceptions that give a unique holistic perspective on teamwork.

Ideation is a crucial skill used throughout the design process to assist in the problem solving process. As ideation becomes more effective, the likelihood of finding successful problem solutions increases. In engineering, design teams are often used for ideation activities where potential design solutions can be generated and discussed as a group. Often, teaming seems to be the key to solving difficult or complex problems, but at other times, it may feel like a hindrance to our natural creative abilities. Research has shown both positive and negative effects of teamwork on ideation in a variety of settings. In some studies it have been shown that social factors can lead to teams producing fewer ideas than the same number of individuals (Diehl and Stroebe 1987). In others, training participants has been the key to making teams produce higher quality ideas than the same number of individuals (Mumford et al. 2001). While these findings are interesting and useful, they are based on a very narrow view of ideation effectiveness that includes only quantity
or quality. Ideas can have many different attributes: novel, useful, feasible, effective, ingenious, creative, detailed and others. This work brings a more holistic understanding of ideation effectiveness to team research than has been used in previous studies.

Why is there such a wide range of outcomes associated with working in teams? One reason could be that people tend to solve problems in very different ways; everyone thinks differently. So, when two or more people who solve problems in different ways try to work on the same problem together, naturally there are some difficulties. These types of differences can be described as cognitive style differences. The relationships between cognitive style and ideation performance in teams has not been adequately explored in current literature and this work attempts to fill that gap.

Because teamwork is a social activity, it is vital to understand how individuals perceive their team experiences in order to learn what makes teams work well together. How do they feel about the ideas they generated? How do they feel about working in a team? How much do they feel that they contributed? Understanding how engineers perceive individual and team ideation can help inform engineering educators and managers on how to improve engineers’ team ideation.

This thesis presents a detailed analysis of performance and perceptions of ideation, both individually and during teamwork, to better understand how teaming can be effective and under what circumstances it is not. Trends were analyzed in and between ideation performance, perceptions of ideation, and cognitive style as subjects participated in both individual and team ideation activities, (see Figure 1).
First, the relevant literature and background is presented to acquaint the reader with previous research in this field, as well as to describe gaps in the current understanding of team ideation. Next, the methods section details how the data were collected, evaluated, and analyzed. Also a description is given of the volunteer participants in the study, how the study was conducted, and how the ideas generated were individually evaluated for quantity, quality, variety, and novelty. The five research questions are also described. The results are then presented for all of the analyses performed on the data. Each section of the results first reports the analysis of participants working alone, then while they worked in teams, and finally the comparison of the two. The statistically significant results are discussed and selected case studies are presented to
deepen the understanding of the results. The final section contains the conclusions, suggestions for future work, and recommendations to improve team ideation effectiveness.
Chapter 2

Background

The background given here will summarize the pertinent information about ideation as a design process, team ideation, cognitive factors in ideation, self-assessment, and ideation assessment.

2.1 Ideation as part of the design process

Ideation is the process by which new solution ideas are generated. Engineers are constantly required to generate ideas to solve both simple and complex problems. Effective ideation is essential to creative problem solving. Briggs even suggests that the quality of the ideation creates an “upper limit” to the quality of the problem solving since the end design solutions must be selected from amongst the generated idea set (Briggs et al. 1997). Therefore, as the academic and industrial problems get more complex, understanding and improving the quality of ideation among engineers is becoming more important (Duderstadt 2008).

The goal of ideation in design is to expand and explore the design space (Shah, Vargas-Hernandez, and Smith 2003). The design space is the collection of all possible solutions to a design problem. The design space can be a complex multidimensional space with unknown boundaries (Westerlund 2009). Exploring the space through ideation and evaluation helps define the boundaries of possible solutions, as well as dispel fictitious boundaries that unnecessarily constrain the design space.

Ideation is a natural process that must be used to some extent in order to solve even the most basic of problems. When faced with the problem of what to eat for lunch, one must generate
at least one viable idea in order to solve this important problem. In particular, ideation is used frequently in engineering design tasks. Because it is so vital to the success of any problem solving, many methods exist to help increase the effectiveness of the ideation session. Probably the most common is group brainstorming, a method of group ideation where team members are instructed to avoid criticism and attempt to generate as many ideas as possible (Osborn 1957). Brainwriting is a variation on brainstorming that requires the participants to write the ideas down so as to avoid biases (Geschka, Schaude, and Schlicksupp 1976). Other ideation methods include analogical thinking (Perkins 1997), morphological analysis (Allen 1962), lateral thinking (De Bono 1989), and nominal group technique (Van De Ven and Delbecq 1974). Ideation and these methods for augmenting ideation are used throughout the design process to assist in solving problems as they arise. Interestingly, many of these techniques require group participation.

2.2 Cognitive factors

According to Kirton, there are four important cognitive variables involved in problem solving: Level, style, motive, and opportunity. Cognitive level is an individual’s capacity - both potential and manifest – for problem solving. Cognitive level includes intelligence, talent, knowledge, skill, and expertise, among other forms. Cognitive style is the preferred way in which an individual solves problems. Style is independent of level and is very resistant to change; on the other hand, level changes throughout one’s lifetime. Motive is the process that guides and channels your cognitive resources. Opportunity is the source of the problems we solve; individuals differ in if and how they recognize, accept, and manage the opportunities that come to them (Kirton 2011). This work is focused solely on the cognitive style factors in problem solving.

Cognitive style is a that describes the stable properties in an individual’s cognitive functioning when processing information (Ausburn and Ausburn 1978). It can be further defined
as the stable attitudes, preferences, or habitual strategies that determine a person’s perceptions, thinking, and problem solving (Messick 1976). According to Kirton, *cognitive style* is defined as one’s stable, characteristic cognitive preference for seeking and responding to change, including the solution of problems (Kirton 2011; Jablokow and Kirton 2009). Using Kirton’s Adaption-Innovation framework, cognitive style ranges along a continuous spectrum between highly adaptive and highly innovative preferences (Kirton 2011), with mild and moderate degrees of those preferences in between. In general, individuals who are more adaptive prefer more structure (with more of it consensually agreed), while the more innovative prefer less structure (with less concern about consensus). These differences produce distinctive patterns of behavior (described further below), although an individual can (and does) behave in ways that are not preferred; this is called *coping behavior*, which comes at an extra cost to the individual (e.g., stress) (Kirton 2011).

It is important to note the difference between cognitive style and cognitive level. Cognitive style is a bipolar construct (measured on a continuum between two different, but equally valued, extremes). Both adaption and innovation are important styles and individuals along the entire spectrum can make meaningful, creative, contributions to problem solving. Cognitive level is a unipolar construct (measured on a continuum from low to high), and it is independent from cognitive style.

In this study, cognitive style was assessed via the Kirton Adaption–Innovation inventory or KAI® (Kirton 2011). For large general populations and across cultures, the distribution of KAI total scores forms a normal curve within the theoretical range of (32–160), with an observed mean of 95 (s.d. =17) and an observed range of (43–149); lower scores correspond to more adaptive cognitive styles, while higher scores correspond to more innovative styles. Through multiple validation studies, Kirton also identified three sub-scores that correspond to three sub-factors of cognitive style: Sufficiency of Originality (SO), Efficiency (E), and Rule/Group
Conformity (R/G). These sub-factors are also normally distributed within the following theoretical ranges: SO (13–65), E (7–35), and R/G (12–60) (Kirton 2011). In describing each sub-factor below, we consider how it tends to impact ideation, both when working alone or in a team (Jablokow et al. 2015).

**Sufficiency of Originality (SO):** The SO sub-factor highlights differences between individuals in their preferred ways of generating and offering ideas (Kirton 2011). The more adaptive tend to generate more highly detailed ideas that remain more closely connected to the original constraints of a problem, which results in their digging deeper into a particular region of the solution space in ideation. They may offer fewer ideas, not because they are blocked in their ideation, but because they are more careful in filtering their ideas first to make sure they match the problem constraints (Kirton 2011; Jablokow and Kirton 2009). In contrast, more innovative individuals tend to generate ideas that challenge the problem definition and constraints, resulting in solutions that lie at the boundaries of the solution space or connect it with other tangential solution spaces. They may offer more ideas, not because they are more capable or have a greater capacity, but because they spend less time checking their ideas against the constraints of the problem and may even actively push against those constraints (Kirton 2011; Jablokow and Kirton 2009).

**Efficiency (E):** The E sub-factor reflects an individual’s preferred method for managing and organizing ideas in solving problems. The more adaptive prefer to define problems and their solutions carefully, paying closer attention to details and organization, while searching methodically for relevant information and solutions. In contrast, the more innovative often loosen and/or reframe the definition of a problem before they begin to resolve it, paying less attention to detail and taking a seemingly casual approach as they search for and carry out their solutions (Kirton 2011; Jablokow and Kirton 2009).
Rule/Group Conformity (R/G): The R/G sub-factor reflects differences in the ways individuals manage the personal and impersonal structures in which their problem solving occurs. The more adaptive generally see standards, rules, traditions, and instructions (all impersonal structures) as enabling and useful, while the more innovative are more likely to see them as limiting and irritating. When it comes to personal structures (e.g., teams, partnerships), the more adaptive tend to devote more attention to group cohesion, while the more innovative are more likely to “stir up” a group’s internal dynamics (Kirton 2011; Jablokow and Kirton 2009).

In terms of assessment, the internal reliability of KAI is high: 0.84 to 0.89 (mode of 0.87) over samples totaling nearly 3000 subjects from 10 countries (Kirton 2011). Numerous validity studies were completed for KAI, including content validation, factor analysis, and correlational analyses (see (Kirton 2011): pp. 82–84; also Appendix 6, Tables G & J). In an engineering context, for example, Jablokow’s study of graduate engineering students showed wide ranges of KAI scores among systems engineers, software engineers, and information scientists, respectively (Jablokow 2008), and DeFranco et al. (Defranco et al. 2012) reported similar findings among undergraduate engineering students.

2.3 Ideation in teams

Both in education and industrial settings, teaming is used with the intent of attaining better problem solving results. Often people work in teams under the assumption that two together will outperform two apart i.e., that synergy will boost effectiveness. This view, or “myth”, as Plucker calls it (Plucker, Beghetto, and Dow 2004), might be reinforced by the fact that ideation augmenting methods such as brainstorming call for group participation. Whether or not teamwork is beneficial to ideation is debated among scholars. Methods such as brainstorming, brainwriting, and the nominal group technique are based on the assumption that the correct group
environment can foment the free flow of ideas, resulting in better ideation outcomes, e.g., higher quantity of ideas.

In direct opposition to claims regarding the brainstorming method, Diehl and Stroebe show that groups of high school students that worked alone outperformed the groups that worked together, with quantity of ideas as the performance criterion (Diehl and Stroebe 1987). They offer three possible contributors to this productivity loss in groups: production blocking, evaluation apprehension, and free riding. The phenomenon where the quantity of ideas is less in a group than for the same number of individuals working separately in general has been labeled “process loss”, and it has been observed in numerous studies (Paulus et al. 1993; Linsey et al. 2010; Steiner 1972).

While “process loss” has been observed repeatedly, several studies of electronic brainstorming show the opposite result. Electronic brainstorming is a technique where individuals collaborate electronically, working in separate rooms, and it is used to mitigate the social effects on brainstorming. These studies have shown that groups using electronic brainstorming outperform, in terms of quantity, the same number of individuals working alone (Dennis and Gallupe 1993; Valacich, Dennis, and Connolly 1994). These studies show that is some settings there is a group “process gain” instead of a loss by removing some of the social influences of working in a face-to-face group. It appears that “process loss” is a somewhat circumstantial phenomenon; changing the team circumstances can change, or even invert the phenomenon.

Only a few of the many studies investigating team ideation have evaluated ideation quality. Diehl and Stroebe measure originality and feasibility of individual and group ideation though no significant difference in these measures have been found (Diehl and Stroebe 1987). Groups have been shown to generate higher quality ideas than individuals when further interventions are applied. Mumford et al. found that groups receiving training to create common mental models for ideation generate more logical, workable solutions than individuals who
receive the same training (Mumford et al. 2001). This finding seems to indicate that groups are capable of generating higher quality ideas than individuals when a common mental model helped facilitate the use of all of the team’s cognitive resources effectively.

Whenever individuals work together, their cognitive differences become a relevant variable in that collaboration. Cognitive psychologists and other researchers use the term **cognitive gap** to describe these differences in cognitive level and/or cognitive style that can appear as any one of the following variations (Jablokow and Booth 2006; Kirton 2011).

a. A difference between the respective styles and/or levels of two individuals;
b. A difference between the style and/or level of an individual and the style mean or aggregate level of a group, respectively;
c. A difference between the respective style means or aggregate levels of two groups;
d. A difference between an individual or group and the requirements of a particular problem (i.e., between the respective styles and/or levels of each).

In general, these variations can be separated into two broad categories, namely: person–person gaps (a–c), and person–problem gaps (d) (Jablokow and Booth 2006).

In terms of cognitive style within teams, it has been shown that the just-noticeable-difference between individuals is 10 points on the KAI scale (Kirton 2011). This means that individuals are unlikely to notice cognitive style differences when working with someone with a KAI score that is within 10 points of their own score (in either direction), while larger gaps are more likely to be problematic. As noted by Jablokow and Booth (Jablokow and Booth 2006): “Gaps of 20 points or more between individuals have been shown to lead to significant problems, including poor communication, ‘finger-pointing’, misinterpretation of style differences as level deficiencies, and even loss of employment (Lindsay 1985; McCarthy 1988; Kubeš and Spillerova 1992). In such cases, a healthy dose of mutual respect and significant coping skills are necessary to bridge the gap effectively (Kubeš and Spillerova 1992; Rickards and Moger 1994), or failure can follow (Lindsay 1985; Hammerschmidt 1996). Even with such understanding and skills in place, collaboration between two such individuals will require more effort and will be more likely
to cause stress than collaboration between individuals with closer styles; the larger the gap and
the longer the individuals interact, the greater the effort (and any stress) will be (McCarthy 1993;
Hammerschmidt 1996; Kirton 2011).” For the most part, these effects have been studied in
professional settings, with little attention to students in general and to engineers in particular.

These studies might lead us to believe that working in teams is often not beneficial.
However, since most of these studies only consider quantity of ideas, the overall ideation
performance of groups compared to individuals is still largely not well understood.

2.4 Ideation assessment

The goal of ideation is to generate ideas from which a solution can be selected. When
ideation is effective, it is more likely that a suitable solution will be found for the problem. In
order to assess the effectiveness of ideation, we must determine what to measure and how to
measure it. There are many ways to assess ideation; this section will detail current measures and
practices.

There are two approaches to assessing ideation effectiveness: process-based methods, and
outcome-based methods. Process-based methods attempt to follow the cognitive process that a
person takes while generating ideas. Outcome-based methods examine the results of the ideation
without regard to the steps an individual takes to get there. An example of outcome assessment
would be counting idea quantity. Outcome-based methods translate the results of ideation, the
ideas themselves, into numerical representations of performance. All of the measures discussed
and used in this paper are outcome-based so that the ideation performance could be analyzed
numerically.

Researchers from a variety of fields have presented metrics for assessing ideation
effectiveness. Though the actual metrics used vary dramatically, the majority of authors seem to
indicate that ideation effectiveness has multiple dimensions. From a performance standpoint, each idea is complex and can have several good and bad characteristics. Shah et al. and Dean et al. have provided very comprehensive frameworks for assessing ideation effectiveness, however it appears that no other research has used this approach to study team ideation (Dean et al. 2006; Shah, Vargas-Hernandez, and Smith 2003). Instead, researchers have used one or two metrics, ignoring the many other important aspects of ideation effectiveness, (see Table 1). Effective ideation is more than just generating many ideas, or generating ideas that are completely novel. To more completely understand effective ideation, it is important to look at a combination of meaningful measurements. This work serves to fill this gap by implementing a more comprehensive assessment to studying quantity, quality, variety, and novelty of individual and team ideation.

Shah et al. proposed an outcome-based, four-aspect approach to assessing ideation effectiveness: quality, quantity, novelty, and variety (Shah, Vargas-Hernandez, and Smith 2003). Quality and novelty are aspects of a single idea, while quantity and variety are only meaningful for idea sets. This approach offers a holistic view of ideation, where quantity is balanced by quality and variety by novelty. The challenge is to define the four aspects in a reliable and meaningful way. The sections below give definition and approaches to measuring these four aspects of ideation from previous studies. Figure 2 gives the general definitions and organization of the metrics used in this thesis.
<table>
<thead>
<tr>
<th>Article</th>
<th>Relevance</th>
<th>Workability</th>
<th>Specificity</th>
<th>Novelty</th>
<th>Variety</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cady &amp; Valentine 1999</td>
<td>Applicability</td>
<td>Adoptability</td>
<td>How well described</td>
<td>Novelty, Excitement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Durand &amp; VanHuss 1992</td>
<td>Appropriateness</td>
<td>How well described</td>
<td>Detail, depth, clarity</td>
<td>Originality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kramer, Kuo, &amp; Dailey 1997</td>
<td>Effectiveness</td>
<td>Feasibility</td>
<td>Creativity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valacich, Dennis, &amp; Nunamaker 1992</td>
<td></td>
<td>Importance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easton, Easton, &amp; Belch 2003</td>
<td>Usefulness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plucker, Beghetto, &amp; Dow 2004</td>
<td>Usefulness</td>
<td></td>
<td></td>
<td>Novelty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MacCrimmon &amp; Wagner 1994</td>
<td>Relevance</td>
<td>Workability</td>
<td>Thoroughness</td>
<td>Non-obviousness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wagner 1996</td>
<td></td>
<td>Implementation</td>
<td>Purpose</td>
<td>Originality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mcleod, Lobel, &amp; Cox 1996</td>
<td>Effectiveness</td>
<td>Feasibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Briggs et al. 1997</td>
<td>Quality</td>
<td></td>
<td></td>
<td>Unique ideas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Besemer &amp; O’Quin 1987</td>
<td>Resolution</td>
<td></td>
<td>Elaboration</td>
<td>Novelty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diehl &amp; Stroebe 1987</td>
<td></td>
<td>Feasibility</td>
<td>Originality</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mumford et al. 2001</td>
<td></td>
<td></td>
<td>Alternative solutions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connolly, et al. 1993</td>
<td></td>
<td></td>
<td>Rarity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potter &amp; Balthazard 2004</td>
<td>Relevance</td>
<td>Feasibility</td>
<td>Creativity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nagasundaram &amp; Bostrom 1994</td>
<td></td>
<td></td>
<td>Paradigm-Relatedness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gryskiewicz 1980</td>
<td></td>
<td></td>
<td>Paradigm-Relatedness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nelson et al. 2009</td>
<td></td>
<td></td>
<td>Variety</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shah et al. 2003</td>
<td></td>
<td>Quality</td>
<td>Rarity</td>
<td>Variety</td>
<td>Idea count</td>
<td></td>
</tr>
<tr>
<td>Dean et al. 2006</td>
<td>Effectiveness, Applicability</td>
<td>Implementability, Acceptability</td>
<td>Implicational Explicitness, Completeness</td>
<td>Rarity, Paradigm-Relatedness, Originality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>This work, 2015</td>
<td>Effectiveness, Applicability</td>
<td>Implementability, Acceptability</td>
<td>Clarity, Implicational Explicitness</td>
<td>Rarity</td>
<td>Variety</td>
<td>Idea count</td>
</tr>
</tbody>
</table>

Table 1 List of ideation metrics used in previous literature
Dimensions of creative ideas (Definitions from Dean et al. 2006)

Quality

Relevance
- Effectiveness = the degree to which the idea will solve the problem
- Applicability = the degree to which the idea clearly applies to the stated problem

Workability
- Implementability = the degree to which an idea can be easily implemented
- Acceptability = the degree to which an idea is socially or legally acceptable

Specificity
- Clarity = the degree to which the idea is clearly communicated with regard to grammar and word usage
- Implicational explicitness = the degree to which there is a clear relationship between the recommended action and the expected outcome
- Completeness = the number of independent subcomponents into which the idea can be decomposed, and the breadth of coverage with respect to who, what, where, when, why, and how

Novelty
- Rarity = the measure of how infrequently similar ideas appear within an idea set
- Originality = the degree to which the idea is not only rare but also ingenious, imaginative, or surprising
- Paradigm-relatedness = the extent to which the idea preserves or modifies the generally expected problem context paradigm

Dimensions of creative idea sets (Definitions from Shah et al. 2003)

- Quantity = the count of ideas generated during an ideation session
- Variety = the extent to which the solution space was explored

Figure 2 Ideation metric descriptions
2.4.1 Quality

Perhaps the most obvious assessment to begin with is quality. Does the idea make sense? Is it feasible? Does it solve the stated problem? In more general terms, is the idea useful? Cady and Valentine define idea quality as the degree to which an idea that fills a need or solves a problem can be successfully adopted by an organization (Cady and Valentine 1999). This definition allows for ideas that solve a problem well but are unable to be adopted by an organization indicating that quality has multiple important dimensions. The following sections will explore the different dimensions of quality found in the literature following the theoretical framework for idea quality put forth by Dean, (Dean et al. 2006).

Dean defines quality ideas as having three characteristics: workability, relevance, and specificity (Dean et al. 2006). Each of these characteristics is meant to relate directly to the usefulness of an idea without regard to its novelty.

2.4.1.1 Relevance

An idea must apply to the given problem context to be considered useful. In other studies this has been called appropriateness (Durand and VanHuss 1992), effectiveness (Kramer, Kuo, and Dailey 1997; Valacich, Dennis, and Nunamaker 1992), importance (Valacich, Dennis, and Nunamaker 1992), and usefulness (Easton, Easton, and Belch 2003). Dean et al. elegantly organized descriptions from previous literature into the two sub-dimensions of effectiveness and applicability. The authors defined effectiveness as the degree to which the idea will solve the problem, and applicability as the degree to which the idea clearly applies to the stated problem (Dean et al. 2006). These definitions are designed to allow the relevance dimension of quality, the sum of effectiveness and applicability, to remain independent from the workability of an idea.
2.4.1.2 Workability

Whether or not an idea is workable has both physical and social dependencies. Evaluating ideas based on physical feasibility has been used by many different authors (Plucker, Beghetto, and Dow 2004; MacCrimmon and Wagner 1994; Wagner 1996; McLeod, Lobel, and Cox 1996). Briggs et al. used a measure of ease of implementability to correspond to the feasibility of an idea (Briggs et al. 1997). This approach is effective because it easily allows for financial considerations, not just technical feasibility.

Though an idea may be physically feasible to carry out, an idea must also be socially acceptable. Unacceptable ideas are unlikely to be adopted by organization as solutions; therefore, according to Cady’s definition, they cannot be high quality. Also, Plucker emphasizes the importance of assessing the usefulness within a social context (Plucker, Beghetto, and Dow 2004).

2.4.1.3 Specificity

The third and final dimension of quality has more to do with the quality of the work than the quality of the concept. Though an idea might be workable and relevant, the U.S. patent office requires new patent ideas to be clear, detailed, and complete (Jones 1971). These terms seem to refer to quality of communication, but it stands to reason that if an idea cannot be communicated in an understandable way, it is not a useful idea. Besemer and O’Quin expand this dimension of quality into the area of product analysis by measuring elaboration and synthesis. Products with good elaboration and synthesis are described as being organic, elegant, complex, understandable, and well crafted (Besemer and O’Quin 1987). Though these measures were used in final product analysis, to some extent, they are still applicable to the ideation phase of design. Dean et al.
compile these into a dimension of quality called specificity with three sub-dimensions: clarity, completeness, and implicational explicitness. However, clarity is not considered in the author’s analysis due to low inter-rater reliability (Dean et al. 2006).

2.4.2 Novelty

Novelty or originality has long been considered an vital part of the definition of creativity among many authors (Diehl and Stroebe 1987; Besemer and Treffinger 1981; MacCrimmon and Wagner 1994; Cady and Valentine 1999). It has been described as unusual but potentially plausible solutions (Mumford et al. 2001), newness (Besemer and Treffinger 1981), and rare, unusual or uncommon ideas (Connolly, Routhieaux, and Schneider 1993). Dean identified three sub-dimensions that other researchers had used to measure novelty in the literature: rarity, originality, and paradigm-relatedness.

2.4.2.1 Rarity

Novelty has been described as ideas that had not been previously expressed (MacCrimmon and Wagner 1994). In other instances, it is described as uncommon or infrequent, in other words, rare. One way to determine this is to count the number of times the same ideas appear within a data set (Connolly, Routhieaux, and Schneider 1993). With this method, the lower the rarity score, the more rare the idea is relative to the other ideas within the set.

How infrequently an idea appears, or, in other words, how rare it is, captures one important aspect of how novel an idea is, but in many ways, this measure is insufficient. Dean et al. claimed that original ideas were rare, imaginative, and ingenious. The infrequency of an idea says nothing about how ingenious or imaginative it is.
2.4.2.2 Originality

Besemer calls originality the most often cited criterion of creativity (Besemer and Treffinger 1981). This is true but it takes on many different definitions depending on the author. Some of the traditional definitions for originality are too general for the present context. For example, calling ideas that are “statistically infrequent” (Guilford 1950) original, overlaps with the previously defined rarity metric. Other researchers have measured originality by rated ideas for “creativity” (Potter and Balthazard 2004), making it subjective to the varied definitions of creativity. Originality as proposed by Dean et al. is a metric for measuring ideas on a scale from mundane to imaginative.

2.4.2.3 Paradigm-relatedness

Some authors have argued that originality is not a sufficient measure of how novel an ideas is (Nagasundaram and Bostrom 1994; Gryskiewicz 1980). Therefore, they propose measuring the paradigm-relatedness of an idea in addition to originality. Adaption-innovation theory indicates that this dimension of ideation novelty should be related to cognitive style (Kirton 1976).

Paradigm-relatedness can be defined as the extent to which an idea either works within or challenges the currently prevailing paradigms, frames, or habitual routines used to constrain and think about a particular problem. Paradigm-preserving ideas operate within the existing ways of thinking about the problem context, while paradigm-modifying ideas operate within redefined boundaries that create a different way of thinking about the problem context. Paradigm-preserving ideas are incremental by nature and paradigm-modifying ideas are more radical.
Depending on the situation, both paradigm-preserving and paradigm-modifying ideas are valuable for solving problems (Wright et al. 2015; Dean et al. 2006).

### 2.4.3 Quantity

The quantity of ideas, sometimes called idea fluency, has long been an important measure of ideation effectiveness. Idea quantity is seemingly a trivial measurement to make; however, it can be measured in different ways depending on the structure of the study. In some studies, researchers have found it necessary to develop protocols for idea counting to distinguish between unique ideas, because some of the ideas an individual generated were very similar or were elaborations of a previous idea. This is particularly important in protocol studies where the ideas must be evaluated from verbal dialogue of participants.

Alternately, the study can be structured such that the participant indicates what they consider to be separate ideas in their work. This method relies on the assumption that all of the ideas that an individual generates during one idea session are unique in some way.

### 2.4.4 Variety

The final measure of effectiveness considered here is variety of ideation. Variety is defined as the extent to which the design space is explored by the ideas generated. Correlations have been found between design space exploration and quality of final solution (Dylla 1991). In the majority of ideation studies variety is not measured directly; rather, the number of unique ideas or quantity has been used. While quantity seems to be related to the amount of the design space that is explored, more information is needed when comparing idea sets of the same number of ideas.
Shah et al. proposed a hierarchical tree method for evaluating ideation variety (Shah, Vargas-Hernandez, and Smith 2003). In this method, each idea falls into a categorization tree that has four levels: physical principle, working principle, embodiment, and detail. Once several ideas have been categorized into the tree’s structure, the ideas can be compared by looking at the level at which the ideas differ. Ideas that differ at the physical principle level are considered to be the most different and are given more weight than differences at the detail level. Nelson et al. proposed calculating the variety score of an idea set by assigning specific weights to differentiations at each level of the hierarchical tree and then summing the total of the weighted differentiations (Nelson et al. 2009).

2.5 Self Assessment

Ideation research has shown that an individual’s perceptions of ideation overestimate their actual performance (Paulus, Larey, and Ortega 1995; Paulus and Yang 2000). Other research on idea generation has also suggested that designers are not always good judges of the effect of different interventions on their actual performance and may fail to recognize interventions that are hindering their performance (Linsey et al. 2010). Nevertheless, perceptions are relatively easy to collect and can provide some insight into the impact of different interventions when used appropriately. For example, if individuals generate ideas under the same condition but have different perceptions of difficulty, other factors, such as cognitive style, may be considered for further insight (Jablokow et al. 2015). Further, establishing reliable trends with respect to change in perceptions as a result of an intervention can provide a foundation for exploring relationships between those perceptions and more objective measures such as the outcome-based performance metrics described in the previous section.
Chapter 3

Research Methods

This chapter details the research approaches used to answer the following research questions.

3.1 Research Questions

Many studies investigate the effectiveness of team ideation. None of them have given a holistic view of ideation effectiveness, however, often only including idea quantity and/or a limited view of quality and novelty. Also, existing research does not considered an individual team member’s cognitive style when analyzing team ideation. The research questions listed below are motivated by the gaps in understanding left by previous research by using a holistic, multi-dimensional view of ideation effectiveness, while considering individual cognitive style factors.

1. **How is working in a team related to an individual’s perceptions of their ideation?**
2. **How is working in a team related to ideation performance?**
3. **How is an individual’s cognitive style related to their perceptions of ideation?**
4. **How is an individual’s cognitive style related to their performance?**
5. **How are ideation performance and perception related?**
3.2 Participants

The 86 participants in this study were undergraduate university students. From Iowa State University, there were 60 sophomore mechanical engineering students, and the other 26 students were freshmen at Penn State University pursuing a variety of engineering majors, including mechanical, chemical, biomechanical, civil and industrial engineering. The average age of the participants was 19.8 (sd=1.85) with a range from 17-30. Only 12 (~14%) of the participants were female. Nationwide, only about 24% of STEM jobs are held by women (Beede et al. 2011), indicating that the gender disparity might be slightly exaggerated in this small sample of students. The race of participants in the sample was as follows: 75 (~87%) Caucasian, 7 (~8%) Asian, 3 (~3%) Hispanic, and 1 (~1%) African American.

Of these participants, only 64 had reliable KAI scores. This sub-set of participants was used for all analyses involving KAI. The KAI distribution of this group is shown in Figure 3, the line indicates the expected normal distribution (m=95, sd=17) (Kirton 2011). The average total KAI score among the 86 participants was 91.2 (sd=14.6) with a range from 57 to 125. Over larger populations the average is approximately 95 (sd=17) ranging from 43 to 149 (Kirton 2011). The comparison indicates that the sample of students in this study were slightly more adaptive than the general population with very little representation of the highly innovative cognitive styles. This sample bias may have made it difficult to see trends related to cognitive style.
3.3 Data Collection

The data were collected from the participants in three parts. First, all of the students in the study completed a KAI® cognitive style inventory; this results in a total KAI score and the three sub-factor scores, SO, E, and R/G. A certified practitioner then reviews them for reliability. Next, they participated in two separate ideation sessions, each comprised of 20 minutes of ideation followed by a reflection survey. Session 1 was completed individually, and during session 2, the participants worked in two-person (in several cases, three-person) teams but still recorded their ideas and reflections individually. All participants completed session 1 before they completed session 2. This was done to make it easier to administer the study, however, this makes
it impossible to know if there was any order effect from the different sessions. Further research is necessary to understand whether or not this oversight in this study’s protocol had any significant effect.

Before the sessions began, the participants were given the following basic instructions for how to work during the ideation session:

- To generate a wide range of ideas
- To avoid evaluating ideas
- To record their ideas through words and sketches
- To continue working through entire ideation session

All of the instructions given to participants can be seen in Appendix G.

Also, for each idea generated during session 2, the participants were asked to indicate which person on the team initiated the idea, as well as how much they contributed to the idea overall using the following questions:

- Who initially brought up this idea?
- Identify to what extent this idea was generated and developed by you, by your teammate, or by some combination? (on a scale from 0-100 %)

In this study, participants were asked to record each idea on a separate sheet of paper, so the assumption was made that each idea sheet represented a unique idea in the mind of the participant. Therefore, the number of ideas sheets that each person filled out was used directly as the quantity of ideas (see Appendices A and B).

Four different problem contexts were used in this study, and the participants were always given a different problem context in session 2 from the one they received in session 1. The four problem contexts were selected from a group of ten problem contexts that were evaluated in a pilot study. The pilot study showed how these contexts were considered comparable in difficulty
level (Rosenberg 2014). A shortened version of the problem context is listed below; the full version can be seen in Appendix C.

- **Snow Transporter**: Design a way for individuals without lots of skill and experience skiing or snowboarding to transport themselves on snow.
- **Jar Opener**: Design a way for individuals who have limited or no use of one upper extremity to open a lidded food container with one hand.
- **Belonging Securer**: Design a way for someone to secure several of his or her belongings in a public area to prevent theft without disrupting the space.
- **Rainwater Catcher**: Design a way for remote villagers to catch, store, and access rainwater.

After each ideation session a reflection survey was administered consisting of both multiple choice (Likert scale) and short answer questions. The same ten questions were used in both sessions, with three additional questions specifically about teaming used only in *session 2*. The following questions were assessed using a 7-point Likert scale.

- How creative do you feel that your ideas were?
- How diverse, or different from each other, do you feel that your ideas were?
- How elaborate, detailed, or “fleshed-out,” do you feel that your ideas were?
- How easy or difficult was it for you to come up with design ideas?

All of the questions above appeared on both the individual and team ideation surveys, while the following question was only used for the team ideation reflections:

- How much did working on a team make it easy or difficult for you to come up with design ideas?

The rest of the reflection questions, shown below, were short answer questions. They will only be analyzed qualitatively. The full survey can be seen in Appendix D.

- What made it easy or difficult for you to come up with design ideas?
• How did working in a team impact your process for generating ideas and/or the ideas you generated? Please explain.

3.4 Idea Evaluation

All of the 570 ideas generated by the participants were assigned a random idea number and blinded by removing all of the identification information from the idea sheet. Further, the verbal descriptions were transcribed via services from Captricity Inc. (http://captricity.com). The transcriptions helped coders read the ideas more easily and reduced the number of interpretation disagreements. The ideas were evaluated for each metric in random order by trained coders.

3.4.1 Metric assessment

An iterative procedure was used to develop the metrics and train the coders. First, two coders would read the metric description and look at examples. Next, they would evaluate a sample of ideas (~50) from one of the problem contexts on that metric. Then they would compare codes by calculating the Cronbach alpha score for inter-rater reliability. If the alpha score was less than 0.7, they would discuss differences between their codes and generate protocols for coding to increase reliability. If the alpha score were greater than 0.7 it was recorded and the coders would divide the rest of the ideas and evaluate them separately. Once all of the ideas for a problem context were coded then they would move to a new problem context. The goal of the iterations was to ensure that the coding schemes could be effectively and reliably applied to all of the four problem contexts. Throughout this process the coders generated coding protocols for each metric and, where necessary, some problem context specific instructions to increase
reliability. All of the metric instructions can be found in the training documents in Appendices E and F.

3.4.1.1 Quantity of ideas

This was measured by simply counting the number of idea sheets that the participants filled out in a given ideation session. The participants were given instructions to use one sheet of paper for each idea and to number them according to the order they were generated. This allowed the participant to determine for themselves when an idea was different enough to constitute a new idea. Therefore, all idea sheets were considered unique and were evaluated as such, even if they appeared similar. In some cases, it appeared that participants tried to describe multiple ideas on one idea sheet, however, because the instructions were explicit, these ideas were evaluated as one single idea as well.

3.4.1.2 Quality metrics

The rubrics for the quality metrics came from Dean’s work, because it seemed to be the most comprehensive treatment of ideation quality, and the metrics were developed to be independent of problem context. Several of the quality metrics from Dean et al.’s work could not be reliably applied to the problem contexts used in this study. The completeness sub-dimension of quality never achieved reliable results through several coder attempts, receiving alpha scores < 0.7 in every trial. The clarity and implicational explicitness metrics achieved reliable results in the Snow Transporter context but had alpha scores slightly less than the 0.7 thresholds in the other contexts. The reliability results are seen in Table 2. The results from the clarity, and implicational explicitness metrics were still used in the analysis because the inter-rater reliability was near the
acceptable level; however, the completeness metric results are excluded from the analysis, because it could not be coded reliably.

<table>
<thead>
<tr>
<th>Metric</th>
<th>Reliability Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness</td>
<td>Reliable in all four contexts.</td>
</tr>
<tr>
<td>Applicability</td>
<td>Reliable in all four contexts.</td>
</tr>
<tr>
<td>Implementability</td>
<td>Reliable in all four contexts.</td>
</tr>
<tr>
<td>Acceptability</td>
<td>Reliable in all four contexts.</td>
</tr>
<tr>
<td>Clarity</td>
<td>Reliable in snow transporter context, coding for all contexts completed.</td>
</tr>
<tr>
<td>Implicational</td>
<td>Reliable in snow transporter context, coding for all contexts completed.</td>
</tr>
<tr>
<td>Explicitness</td>
<td></td>
</tr>
<tr>
<td>Completeness</td>
<td>Unreliable in all trails. Coding not completed.</td>
</tr>
</tbody>
</table>

The rubrics for evaluating quality were taken directly from Dean’s work, (see Appendix E), with two exceptions where the wording had to be changed slightly:

- In the rubric for effectiveness, the words “solves unrelated problem” were changed to “does not solve given problem”. This change helps to maintain continuity between the metric levels.
- In the rubric for implementability, the words “promotions and events” were changed to “costs and changes”. The problem contexts seldom had anything to do with business strategies.
3.4.1.3 Variety Trees

The theoretical framework for evaluating variety within an idea set came from Shah et al. (Shah, Vargas-Hernandez, and Smith 2003). The authors organize functions into four hierarchical levels: physical principle, working principle, embodiment, and detail levels. Ideas that differed at higher levels received more points than ideas that differed at lower levels. However, the authors did not give explicit instruction on how to evaluate variety. Therefore, it was necessary to develop a method for reliably evaluating ideas so that the variety of each idea set could be assessed.

Problem specific hierarchical trees were created for each problem context. Each problem context was broken down into the minimum number of functions that were necessary to solve the problem. Then the functions were organized into hierarchical trees with branches at the physical principle, working principle, and embodiment levels. Several development iterations for each tree were conducted, and experts that were familiar with the problem context descriptions reviewed and edited the trees. Figure 4 shows the variety tree used for the belonging securer problem context.
Figure 4 Example of hierarchical variety tree
 Coders were trained to categorize ideas into the embodiment level of the final trees. The embodiment was used as the lowest level in the trees rather than the detail level because it was assumed that every idea was unique at the detail level. In other words, rather than identifying every possible detail category in the tree, it was assumed that every idea differed to some degree at the detail level. All of the final variety trees and the variety coder training document can be seen in Appendix F.

Categorizing the ideas using the hierarchical trees was a method that yielded sufficient inter-rater reliability across all of the problem contexts (alpha>0.71). However, there seemed to be some biases built into the trees that could have been the cause of some repeated error. For example, in Figure 4 it can be seen that the “physically secure” branch of the tree has three branches in the working principle level while the “digitally secure” branch only has one branch at the working principle. This is a problem because differences between ideas at the working principle level are weighted more heavily than differences at the embodiment level. Therefore, idea sets with several ideas in the “physically secure” branch of the tree may be more likely to receive a higher variety score than idea sets with several ideas in the “digitally secure” branch.

Once the ideas were categorized, a variety score was calculated using Nelson et al.’s formula; see ( 1 ). This formula corrects the double counting errors that occurred with Shah’s previous formulation for variety scoring (Nelson et al. 2009).

\[
V = \sum_{j=1}^{m} f_j \left( S_j (b_j - 1) + \sum_{k=2}^{4} S_k \sum_{l=1}^{b_k} d_l \right)
\]  

(1)

Where \( V \) is the variety score for an idea set; \( f_j \) is a weighting factor for each function \( j \) with \( m \) being the total number of functions; \( S_k \) is the hierarchical weight for the levels \( k \); \( b_k \) is the number of branches at hierarchal level \( k \); and \( d_l \) is the number if differentiations at node \( l \). The hierarchical weights, \( S_k \), were 10 for the physical principle level, 5 for the working principle level,
2 for the embodiment level, and 1 for the detail level. Equal weight was given to all functions in a problem context, so if there were three functions then \( f = 1/3 \), with two functions \( f = 1/2 \) and for problem contexts with only one function \( f = 1 \).

The variety score, \( V \), is strongly correlated to quantity of ideas (\( r = 0.750; p < 0.001, N=86 \)). In the majority of the analyses it was useful to normalize the variety score to a 0-10 scale. This was done by simply dividing \( V \) by \( N-1 \) (the total number of ideas minus 1, i.e., the maximum number of differentiations possible). This was called the normalized variety score.

In instances where an idea did not fit into any of the categories in the final variety tree, they were assumed to differ from other ideas at the physical principle level. This occurred with less than 1% of the ideas. Figure 5 shows an example of an idea that did not fit into any of the categories of the tree shown in Figure 4. So this idea was scored as if it were a new physical principle branch of the tree, differing from other ideas in the set at the highest level in the tree.

Develop fast acting glue that is strong and keep the item in place, and can only be neutralized by a chemical in the true owner's possession.

Figure 5 Variety outlier example
3.4.1.4 Rarity Score

The rarity score was used to represent how novel an idea was. It is a measure of how infrequent an idea occurred within the dataset. This was done using the variety trees as well. A training set of over 500 ideas from the four problem contexts was categorized using the variety trees. All of the ideas were generated during individual ideation, without any intervention. Then the number of times each embodiment category appeared within the training set was counted, i.e., the frequency of each idea category. Finally, the infrequency, or rarity, of each idea category was calculated using Shah et al.’s formula for rarity (Shah, Vargas-Hernandez, and Smith 2003), see (2).

\[
S_{jk} = \frac{T_j - C_{jk}}{T_j} \times 10
\]

Where \(S_{jk}\) is the rarity score for an idea category \(k\) in problem context \(j\), \(T_j\) is the total number of ideas in problem context \(j\), and \(C_{jk}\) is the number of ideas in problem context \(j\) that fell within category \(k\). Table 3 shows the frequency and rarity scores for each idea category in the belonging securer variety tree. Outlier categories, like the one shown in Figure 5, that did not show up in the training set of ideas were considered unique receiving a rarity score of 10.
Table 3 Example rarity scores for belonging securer context

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Frequency</th>
<th>Rarity Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>-1</td>
<td>Outlier</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>0</td>
<td>Not applicable to function</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Covering</td>
<td>19</td>
<td>8.74</td>
</tr>
<tr>
<td>2</td>
<td>Compartment</td>
<td>43</td>
<td>7.15</td>
</tr>
<tr>
<td>3</td>
<td>External Lock</td>
<td>30</td>
<td>8.01</td>
</tr>
<tr>
<td>4</td>
<td>Force field</td>
<td>3</td>
<td>9.80</td>
</tr>
<tr>
<td>5</td>
<td>Suction</td>
<td>1</td>
<td>9.93</td>
</tr>
<tr>
<td>6</td>
<td>Magnet</td>
<td>2</td>
<td>9.87</td>
</tr>
<tr>
<td>7</td>
<td>Motion Sensor</td>
<td>20</td>
<td>8.68</td>
</tr>
<tr>
<td>8</td>
<td>Camera</td>
<td>9</td>
<td>9.40</td>
</tr>
<tr>
<td>9</td>
<td>Noisy Material</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>10</td>
<td>Alarm field</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>11</td>
<td>Light</td>
<td>0</td>
<td>NA</td>
</tr>
<tr>
<td>12</td>
<td>Invisibility</td>
<td>2</td>
<td>9.87</td>
</tr>
<tr>
<td>13</td>
<td>Buddy</td>
<td>8</td>
<td>9.47</td>
</tr>
<tr>
<td>14</td>
<td>Make undesirable</td>
<td>8</td>
<td>9.47</td>
</tr>
</tbody>
</table>

3.4.2 Focus on individuals

The purpose of this research is to investigate the perceptions, performance, and cognitive style of individuals while working alone and while working in small teams. All of the analyses focused on the individual as the unit of interest. Even while working in teams, all of the ideas and responses were recorded and reported independently by the individuals. Therefore, even though during session 2 participants worked in two and three person teams, their work was all evaluated and analyzed as individuals, because the study was designed such that they recorded their ideas independently. Looking at the idea sheets of teammates, it is obvious that one teammate did not always record the same ideas as the other teammate.
Similarly, all of the quality and novelty metrics were evaluated per idea while variety and quantity were evaluated a single score for an entire idea set. Therefore, all of the quality and novelty metrics were averaged over the idea set so that they could be compared per individual against all the other measurements.

### 3.5 Answering the Research Questions

1. **How is working in a team related to an individual’s perceptions of their ideation?**

To answer this question, it was necessary to determine whether there was any significant change in the creativity, diversity, elaboration, and ease of ideation perceptions for an individual as they were working alone to working in groups. For this, the perceptions of ideation from the *session 1* and *session 2* reflection surveys and the difference between the two sessions were all reported. The change perceptions recorded in the two sessions was evaluated using paired t-tests and the relationships between different perceptions were evaluated using a Pearson correlation analysis. The *difference* in perceptions, responses in *session 2* minus responses in *session 1*, was also analyzed for significant relationships via Pearson correlations.

2. **How is working in a team related to ideation performance?**

Is there a significant change in ideation performance when working as an individual to working in a team? Previous research leaves us unable to know what to expect. Similar to the first research question, this was addressed by comparing the change in quantity, quality, variety, and novelty of ideas generated individually and while working in teams. The
changes and their significance were determined using a paired t-test. The relationships between different performance scores in session 1, session 2, and the difference in performances were evaluated using a Pearson correlation analysis.

3. **How is an individual’s cognitive style related to their perceptions of ideation?**

The KAI inventory score and its sub factor scores were used to represent each participant’s cognitive style in relation to preferred amount of structure when solving problems. The relationships between cognitive style and perceptions of ideation were investigated by calculating Pearson correlation values of KAI with perceptions during session 1, session 2, and the difference between the sessions.

4. **How is an individual’s cognitive style related to their performance?**

To answer this question the Pearson correlations between cognitive style and the performance metrics during session 1, session 2, as well as the difference in performances were calculated.

5. **How are ideation performance and perception related?**

The reflection survey questions only have to do with creativity, diversity, elaboration, and ease of ideation, while the performance metrics are quantity, quality, variety, and novelty. Though they do not intend to measure the same things, Pearson correlations between the performance scores and the perceptions were calculated to better understand the relationships that exist.
Chapter 4

Results

The following analysis is organized by research question. For each research question, the results are reported for the individual work (session 1), for teamwork (session 2), and then the changes from individual work to teamwork (difference) are reported.

The reflection survey responses will be referred to as perceptions of ideation, and the key word from each question will be used to the represent specific question.

- Creativity = Responses to the question “How creative do you feel that your ideas were?”
- Diversity = Responses to the question “How diverse, or different from each other, do you feel that your ideas were?”
- Elaboration = Responses to the question “How elaborate, detailed, or “fleshed-out,” do you feel that your ideas were?”
- Ease = Responses to the question “How easy or difficult was it for you to come up with design ideas?”
- Impact of Team = Responses to the question “How much did working on a team make it easy or difficult for you to come up with design ideas?”
- Percent Initiator = Percentage of the participants’ recorded ideas in session 2 where the participant answered “Me” to the question “Who initially brought up this idea?”
- Average Contribution = Average of participants’ responses for ideas recorded in session 2 to the question “Identify to what extent this idea was generated and developed by you, by your team members, or by some combination? (on a scale from 0-100 %)”
- \( \Delta = \) the change in a measure, (measure in session 2 – measure in session 1). When \( \Delta \) of a measure is positive, that measure was higher in session 2 than session 1.
Throughout the analysis, Pearson correlation r-values will be reported. The strength of these correlations will be categorized using the standard conventions in psychological and social science research as shown in Table 4 (Jacob Cohen 1988; J. Cohen 1992).

### Table 4 Classification of correlation strengths

<table>
<thead>
<tr>
<th>r-value</th>
<th>Strength of correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 0.1</td>
<td>Weak</td>
</tr>
<tr>
<td>&gt; 0.3</td>
<td>Moderate</td>
</tr>
<tr>
<td>&gt; 0.5</td>
<td>Strong</td>
</tr>
</tbody>
</table>

#### 4.1 How is working in a team related to an individual’s perceptions of their ideation? (Research question #1)

This section examines the reflection survey responses that participants completed after each ideation session. The data represent the students’ perceptions about the ideation experience both individually (session 1), and as a team (session 2).

#### 4.1.1 Individual perceptions of ideation (session 1)

First, the data from session 1 were analyzed separately to determine any patterns in student perceptions before they worked in teams. It was assumed that their responses represent their natural perceptions of their own ideation and that outside influences were negligible. The influence of the different problem contexts was investigated by performing an analysis of variance between students who received the different problem contexts for each perception response. The results are reported in Table 5. Many of the perception responses were not normally distributions (Anderson-Darling normality test; p<0.05), therefore, the Kruskal-Wallis rank sum analysis of variance was used. There were no statistically significant difference participants’ perceptions of ideation between the different problem contexts.
Table 5 Analysis of variance in perceptions of participants who received different problem contexts (Kruskal-Wallis analysis of variance; N=86)

<table>
<thead>
<tr>
<th>Perception</th>
<th>Chi-squared</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creativity</td>
<td>2.05</td>
</tr>
<tr>
<td>Diversity</td>
<td>3.90</td>
</tr>
<tr>
<td>Elaboration</td>
<td>5.73</td>
</tr>
<tr>
<td>Ease</td>
<td>5.41</td>
</tr>
</tbody>
</table>

*p<0.05

The distributions of perception responses for session 1 are given in Figure 6. The responses fall along a seven-point scale with 4 being neutral. The means and standard deviations of responses are given below each plot. All of the means are slightly above neutral but the distributions show a wide range of responses for each question.

Figure 6 Session 1 reflection survey responses (N=86)
The relationships between these four perceptions were explored by calculating a Pearson correlation between each of the survey questions in session 1 (see Table 6). Moderate positive correlations were found between participants’ perception of creativity and diversity of ideation, as well as between creativity and ease of ideation during this session.

<table>
<thead>
<tr>
<th></th>
<th>Creativity</th>
<th>Diversity</th>
<th>Elaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diversity</td>
<td>0.347†</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elaboration</td>
<td>0.092</td>
<td>-0.018</td>
<td></td>
</tr>
<tr>
<td>Ease</td>
<td>0.307**</td>
<td>0.042</td>
<td>0.180</td>
</tr>
</tbody>
</table>

**p<0.01; †p<0.001

4.1.2 Perceptions of ideation while working in teams (session 2)

Next, the perceptions from session 2 were analyzed separately from session 1. Perceptions of ideation responses for each reflection question are shown in Figure 7. The means and standard deviations are reported below each plot. Again, all of the mean values are greater than 4.0 (neutral).
The survey at the end of session 2 had another question about the impact of working in a team that did not appear in the session 1 survey; the distribution of these responses is shown in Figure 8. The participants’ responses range from very difficult (1), to neutral (4), to very easy (7). The distribution of responses was significantly skewed towards very easy.
Also in session 2, participants indicated whether they initiated each idea and rated their perceived contribution to the development of each idea. These responses were averaged across the total number of ideas generated by each participant. Table 7 shows the correlations between all of the ideation perceptions survey questions, as well as the perceived contribution questions from session 2. Several weak to moderate correlations were found. Participants’ perceptions of creativity correlated positively with their perceptions of diversity, elaboration, ease, and impact of team. Perception of elaboration was also positively correlated with perception of perceptions of ease and impact of teaming. Perception of ease was positively correlated with the impact of team perception. The perception of impact of team was negatively correlated with both of the perceived
contribution responses. There was a strong correlation between the percent of ideas generated by an individual and their perceived average contribution per idea.

Table 7 R-values between perception responses in session 2 (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Creativity</th>
<th>Diversity</th>
<th>Elaboration</th>
<th>Ease</th>
<th>Impact of Team</th>
<th>Percent Initiator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diversity</td>
<td>0.382†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elaboration</td>
<td>0.466†</td>
<td>0.168</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ease</td>
<td>0.318**</td>
<td>0.047</td>
<td>0.349†</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact of Team</td>
<td>0.295**</td>
<td>0.043</td>
<td>0.249*</td>
<td>0.305**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent Initiator</td>
<td>0.095</td>
<td>0.070</td>
<td>0.144</td>
<td>0.249</td>
<td>-0.319*</td>
<td></td>
</tr>
<tr>
<td>Avg. Contribution</td>
<td>0.049</td>
<td>0.089</td>
<td>0.031</td>
<td>0.045</td>
<td>-0.312**</td>
<td>0.568†</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

4.1.3 Changes of perception from individual to teaming ideation (difference)

The comparison of perceptions in session 1 and session 2 are given in this section. The difference is always calculated as the session 2 responses minus the session 1 response. Therefore positive values indicate that the participants’ response was higher value during session 2 than the response to the same question in session 1. Figure 9 reports the change in perception responses for the four reflection questions that appeared in both surveys. The means at the bottom of each plot indicate a positive shift in means for all four survey questions, however, the magnitude is small in the case of diversity and ease of ideation.
Figure 9 *Difference* between sessions reflection survey responses (N=86)

Table 8 shows the correlations between the changes in perception responses. Weak positive correlations were found between the change in creativity and change in diversity and elaboration. Change in elaboration was correlated with change in ease.

Table 8 R-values between the changes in perception responses (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>∆ Creativity</th>
<th>∆ Diversity</th>
<th>∆ Elaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆ Diversity</td>
<td>0.272*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>∆ Elaboration</td>
<td>0.280**</td>
<td>0.027</td>
<td></td>
</tr>
<tr>
<td>∆ Ease</td>
<td>-0.043</td>
<td>-0.043</td>
<td>0.277*</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01
There was a statistically significant increase of 0.66 in average perception of creativity from working alone to working in teams (paired t-test, p<0.001; see Table 9). The increases in perceived diversity, elaboration, and ease of ideation were small in magnitude and not significant.

Table 9 Difference in Means from Session 1 to Session 2 (paired t-tests; N=86)

<table>
<thead>
<tr>
<th>Change in mean</th>
<th>Creativity</th>
<th>Diversity</th>
<th>Elaboration</th>
<th>Ease</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.66†</td>
<td>0.09</td>
<td>0.32</td>
<td>0.14</td>
</tr>
</tbody>
</table>

†p<0.001

4.2 How is working in a team related to ideation performance? (Research question #2)

The results of student ideation performance are reported in this section. The performance data consist of four main metrics: quantity, quality, variety, and novelty. The trends in session 1 and session 2 are investigated separately and then compared.

4.2.1 Individual ideation performance

The following results come from the session 1 data, where participants worked alone and recorded their work individually. General statistics about each metric are reported, and then they are compared to the other metrics via correlation analysis.

4.2.1.1 Quantity

Figure 10 is a histogram showing the count of participants in session 1 who generated the given number of ideas. The majority of students generated two or three ideas, and the average number of ideas was 3.53. Two of the students generated as many as eight ideas during the twenty-minute session.
The relationship between quantity, the quality metrics, and rarity are shown in Table 10 as r-values from a Pearson correlation analysis. Quantity of ideas showed a weak negative correlation with effectiveness, implementability, acceptability, clarity, and implicational explicitness of idea sets. There was a moderate negative correlation between quantity and applicability.

Table 10 R-values between quantity of ideas and other performance metrics in session 1 (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Effectiveness</th>
<th>Applicability</th>
<th>Implementability</th>
<th>Acceptability</th>
<th>Clarity</th>
<th>Implicational Explicitness</th>
<th>Rarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>-0.221*</td>
<td>-0.359†</td>
<td>-0.217*</td>
<td>-0.225*</td>
<td>-0.277**</td>
<td>-0.265*</td>
<td>-0.097</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001
4.2.1.2 Quality

The relationships (r-values) between the six quality metrics in session 1 are reported in Table 11. A moderate positive correlation was found between effectiveness and applicability. Also, weak positive correlations resulted for implementability with applicability and clarity with acceptability. Clarity scores and implicational explicitness score showed a strong positive correlation.
Table 11 R-values between all of the quality metrics in session 1 (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Effectiveness</th>
<th>Applicability</th>
<th>Implementability</th>
<th>Acceptability</th>
<th>Clarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicability</td>
<td>0.490†</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementability</td>
<td>-0.075</td>
<td>0.221*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceptability</td>
<td>0.152</td>
<td>0.199</td>
<td>0.243</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clarity</td>
<td>-0.140</td>
<td>0.067</td>
<td>0.200</td>
<td>0.224*</td>
<td></td>
</tr>
<tr>
<td>Implicational Explicitness</td>
<td>0.128</td>
<td>0.080</td>
<td>0.136</td>
<td>0.136</td>
<td>0.571†</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

Overall, the effectiveness metric had the lowest mean and largest standard deviation, of the quality metrics that used a four-point scale. Implicational explicitness (evaluated on a three-point scale) showed a smaller mean and larger standard deviation when compared to clarity (also on three point scale) see Table 12.

Table 12 Mean and standard deviations of quality metrics in session 1

<table>
<thead>
<tr>
<th></th>
<th>Effectiveness (1-4)</th>
<th>Applicability (1-4)</th>
<th>Implementability (1-4)</th>
<th>Acceptability (1-4)</th>
<th>Clarity (1-3)</th>
<th>Implicational Explicitness (1-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.92</td>
<td>3.73</td>
<td>3.43</td>
<td>3.67</td>
<td>2.40</td>
<td>2.04</td>
</tr>
<tr>
<td>SD</td>
<td>0.60</td>
<td>0.40</td>
<td>0.42</td>
<td>0.43</td>
<td>0.45</td>
<td>0.52</td>
</tr>
</tbody>
</table>

4.2.1.3 Variety

By an analysis of the variance, it was discovered that there was a problem context effect on the variety performance (ANOVA; F=2.27; p<0.1). The variety scores for the snow transporter context were significantly higher than the jar opener context (Welch two-sample t-test; t=2.7; p<0.05) and the rainwater catcher context (Welch two-sample t-test; t=3.2; p<0.01). This was
adjusted by reducing all of the variety scores of the snow transporter problem by 30% bringing the average score down near to the averages of the other three contexts.

Table 13 shows general statistics about the distribution of the variety scores. The minimum is not shown because it is always zero, and the low score is achieved when there is only one idea in an idea set and thus there is no variety of ideas.

Table 13 Maximum, median, mean, and standard deviations of variety scores in session 1

<table>
<thead>
<tr>
<th></th>
<th>Variety score</th>
<th>Normalized Variety score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>33.00</td>
<td>10.00</td>
</tr>
<tr>
<td>Median</td>
<td>8.57</td>
<td>3.56</td>
</tr>
<tr>
<td>Mean</td>
<td>9.62</td>
<td>3.75</td>
</tr>
<tr>
<td>SD</td>
<td>6.91</td>
<td>2.07</td>
</tr>
</tbody>
</table>

The variety score and the normalized variety score’s correlations to all of the other performance metrics are reported in Table 14. The normalized score is simply the variety score for an idea set divided by one less than the total number of ideas in the set. It can be seen how this decouples variety from quantity, thereby showing which of the quality metrics are truly related to variety and which are related only to quantity of ideas. Variety has a moderate negative correlation with effectiveness and applicability, the two relevance metrics. There also seems to be a moderate positive correlation between rarity and variety that can only be observed in the normalized variety score.

Table 14 R-values between variety score and other performance metrics in session 1 (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Quantity</th>
<th>Effectiveness</th>
<th>Applicability</th>
<th>Implementability</th>
<th>Acceptability</th>
<th>Clarity</th>
<th>Implicational Explicitness</th>
<th>Rarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>0.750†</td>
<td>-0.388†</td>
<td>-0.509†</td>
<td>-0.239*</td>
<td>-0.131</td>
<td>-0.218*</td>
<td>-0.296**</td>
<td>0.173</td>
</tr>
<tr>
<td>Normal Variety</td>
<td>0.040</td>
<td>-0.374†</td>
<td>-0.342**</td>
<td>-0.032</td>
<td>-0.002</td>
<td>-0.036</td>
<td>-0.132</td>
<td>0.351**</td>
</tr>
</tbody>
</table>
4.2.1.3 Novelty

An analysis of variance brought to light that there were statistically significant differences between rarity scores in the four problem contexts (ANOVA; $F=3.87; p<0.05$). Further investigation showed that the rarity scores for the jar opener problem context were higher than the snow transporter scores (Welch two-sample t-test; $t=3.39; p<0.01$). To eliminate this effect all of the rarity scores for the jar opener context were reduced by 5%. With this change the analysis of variance did not show any significant differences in the rarity scores of the four problem contexts.

Table 15 shows the distribution of rarity score in the idea sets in session 1. It should be noted that, due to the method of calculation, there is only about a three-point range of rarity scores. The theoretical range is 0-10, however, 0 is only achieved when all the idea in the training set are identical and 10 can only be achieved when all of the ideas in the training set are completely unique.

<table>
<thead>
<tr>
<th>Rarity score</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rarity score</td>
<td>9.22</td>
<td>6.14</td>
<td>8.14</td>
<td>0.65</td>
</tr>
</tbody>
</table>

The rarity scores of idea sets in session 1 were related to the quality metrics, however, no statistically significant results were discovered, see Table 16.

<table>
<thead>
<tr>
<th>Rarity</th>
<th>Effectiveness</th>
<th>Applicability</th>
<th>Implementability</th>
<th>Acceptability</th>
<th>Clarity</th>
<th>Implicational Explicitness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rarity</td>
<td>-0.188</td>
<td>-0.148</td>
<td>-0.065</td>
<td>0.035</td>
<td>0.063</td>
<td>-0.008</td>
</tr>
</tbody>
</table>

*p<0.05
4.2.2 Teaming ideation performance

Next, the students’ performances while working in teams (session 2) were analyzed separate from the individual ideation data.

4.2.2.1 Quantity

Figure 11 shows the distribution of quantity of ideas during session 2. The most common number of ideas generated is three and the mean number of ideas is 3.02. One of the most noticeable differences from session 1 to session 2 (see Figure 10) is that the number of participants who generated only one idea increased dramatically from 2 to 16.

Figure 11 Quantity of ideas generated in session 2 (N=86)
Table 17 reports the r-values of correlations between quantity, the quality metrics, and the rarity score for idea sets generated during session 2. Quantity showed a weak negative correlation with effectiveness.

Table 17 R-values between quantity of ideas and other performance metrics in session 2 (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Effectiveness</th>
<th>Applicability</th>
<th>Implementability</th>
<th>Acceptability</th>
<th>Clarity</th>
<th>Implicational Explicitness</th>
<th>Rarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>-0.265*</td>
<td>-0.056</td>
<td>-0.121</td>
<td>-0.083</td>
<td>-0.043</td>
<td>-0.055</td>
<td>0.045</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

4.2.2.2 Quality

Table 18 reports the means and standard deviations of the quality metrics in session 2. Again effectiveness had the lowest mean and largest standard deviation among the four-point scale metrics, as did implicational explicitness among the three-point scale metrics.

Table 18 Mean and standard deviations of quality metrics in session 2 (N=86)

<table>
<thead>
<tr>
<th></th>
<th>Effectiveness (1-4)</th>
<th>Applicability (1-4)</th>
<th>Implementability (1-4)</th>
<th>Acceptability (1-4)</th>
<th>Clarity (1-3)</th>
<th>Implicational Explicitness (1-3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.07</td>
<td>3.76</td>
<td>3.37</td>
<td>3.59</td>
<td>2.28</td>
<td>1.83</td>
</tr>
<tr>
<td>SD</td>
<td>0.54</td>
<td>0.37</td>
<td>0.52</td>
<td>0.46</td>
<td>0.55</td>
<td>0.54</td>
</tr>
</tbody>
</table>

The correlations the six quality metrics in session 2 are reported in Table 19. Similar to the session 1 correlations seen in Table 11, there was a strong positive correlation between clarity and implicational explicitness. Also, a weak positive correlation was found between implementability and acceptability that was not present in the session 1 data.
Table 19 R-values between performance metrics in *session 2* (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Effectiveness</th>
<th>Applicability</th>
<th>Implement-ability</th>
<th>Acceptability</th>
<th>Clarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Applicability</td>
<td>0.199</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implement-ability</td>
<td>-0.167</td>
<td>0.067</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceptability</td>
<td>-0.041</td>
<td>0.137</td>
<td>0.251*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clarity</td>
<td>0.004</td>
<td>-0.114</td>
<td>-0.090</td>
<td>-0.196</td>
<td></td>
</tr>
<tr>
<td>Implicational Explicitness</td>
<td>0.046</td>
<td>-0.193</td>
<td>-0.098</td>
<td>-0.172</td>
<td>0.554†</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

4.2.2.3 Variety

The variety scores from the idea sets in *session 2* received the same 30% reduction adjustment to the snow transporter context, as described in section 4.2.1.3. In *session 2*, the variety score correlated with the rarity score similar to *session 1* (see Table 20). Also, a positive correlation between the normalized variety score and quantity of ideas was observed.

Table 20 R-values between variety score and other performance metrics in *session 2* (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Quantity</th>
<th>Effectiveness</th>
<th>Applicability</th>
<th>Implement-ability</th>
<th>Acceptability</th>
<th>Clarity</th>
<th>Implicational Explicitness</th>
<th>Rarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>0.780†</td>
<td>-0.198</td>
<td>-0.031</td>
<td>-0.255*</td>
<td>-0.082</td>
<td>0.017</td>
<td>0.044</td>
<td>0.326**</td>
</tr>
<tr>
<td>Normal Variety</td>
<td>0.271*</td>
<td>-0.027</td>
<td>0.108</td>
<td>-0.336**</td>
<td>-0.026</td>
<td>0.111</td>
<td>0.105</td>
<td>0.348**</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001
Table 21 provides the general distribution results of the variety score of idea sets generated in session 2. The minimum score for variety scores is zero and it is given to idea sets that are comprised of only one idea.

<table>
<thead>
<tr>
<th>Variety score</th>
<th>Normalized variety score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>28.00</td>
</tr>
<tr>
<td>Median</td>
<td>9.05</td>
</tr>
<tr>
<td>Mean</td>
<td>8.58</td>
</tr>
<tr>
<td>SD</td>
<td>6.85</td>
</tr>
</tbody>
</table>

**4.2.2.4 Novelty**

The rarity scores did not show any statistically significant correlations to any of the quality metrics, see Table 22. Table 23 shows the general statistics about the distribution of rarity scores in session 2.

<table>
<thead>
<tr>
<th>Rarity</th>
<th>Effectiveness</th>
<th>Applicability</th>
<th>Implement-ability</th>
<th>Acceptability</th>
<th>Clarity</th>
<th>Implicational Explicitness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.024</td>
<td>0.012</td>
<td>-0.158</td>
<td>-0.108</td>
<td>-0.057</td>
<td>0.056</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

<table>
<thead>
<tr>
<th>Rarity</th>
<th>Max</th>
<th>Min</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>9.42</td>
<td>5.67</td>
<td>8.18</td>
<td>0.74</td>
</tr>
</tbody>
</table>
4.2.3 Changes in performance from individual to teaming ideation

Finally, in this section, the changes in performance for each participant is analyzed. The participants’ performance during session 1 is used as a control to determine the effect of working in teams. The change, \( \Delta \), in each metric is calculated by subtracting the performance during session 1 from the performance during session 2. Therefore, positive values indicate that the performance increased when the participant worked in a team and negative values show a decrease in the performance.

4.2.3.1 Quantity

Figure 12 shows the change in quantity of ideas between session 1 and session 2. There was a decrease of 0.51 in the average number of ideas generated while working on teams (two-sample paired t-test, \( p<0.01 \)). However, it was most common (22 instances of 86 or 26%) for participants to generate the same number of ideas while working on a team as when working alone.
Figure 12 Difference in number of ideas generated from session 1 to session 2

There was a weak negative correlation between the change in number of ideas and the change in implementability, see Table 24.

<table>
<thead>
<tr>
<th>Δ # of Ideas generated</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>-5</td>
<td>0</td>
</tr>
<tr>
<td>-4</td>
<td>5</td>
</tr>
<tr>
<td>-3</td>
<td>10</td>
</tr>
<tr>
<td>-2</td>
<td>15</td>
</tr>
<tr>
<td>-1</td>
<td>20</td>
</tr>
<tr>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

Table 24 R-values between the change in quantity to the change in other performance metrics (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th>Δ Quantity</th>
<th>Δ Effectiveness</th>
<th>Δ Applicability</th>
<th>Δ Implementability</th>
<th>Δ Acceptability</th>
<th>Δ Clarity</th>
<th>Δ Implicational Explicitness</th>
<th>Δ Rarity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-0.140</td>
<td>-0.107</td>
<td>-0.228*</td>
<td>-0.069</td>
<td>-0.109</td>
<td>-0.053</td>
<td>0.049</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001
4.2.3.2 Quality

The Pearson correlations between the changes in each of the quality metrics are shown in Table 25. Change in effectiveness and change in applicability showed a moderate positive correlation, as did change in clarity and change implicational explicitness. The change in implementability showed a moderate negative correlation with change in effectiveness. Also, correlations between clarity and implicational explicitness were also found in the session 1 and session 2 data when they were analyzed separately.

<table>
<thead>
<tr>
<th>Δ Applicability</th>
<th>Δ Effectiveness</th>
<th>Δ Applicability</th>
<th>Δ Implementability</th>
<th>Δ Acceptability</th>
<th>Δ Clarity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.299**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ Implementability</td>
<td>-0.319**</td>
<td>0.088</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ Acceptability</td>
<td>-0.117</td>
<td>-0.077</td>
<td>0.157</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Δ Clarity</td>
<td>-0.034</td>
<td>0.096</td>
<td>0.168</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>Δ Implicational Explicitness</td>
<td>0.049</td>
<td>-0.083</td>
<td>-0.098</td>
<td>-0.140</td>
<td>0.354†</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

Table 26 shows the results of two-sample paired t-tests for each of the quality metrics. Clarity and implicational explicitness show statistically significant decreases in the mean values when the students worked in teams. The change in implicational explicitness was nearly double the magnitude of the change in clarity.

<table>
<thead>
<tr>
<th>Change</th>
<th>Change in mean</th>
<th>Effectiveness</th>
<th>Applicability</th>
<th>Implementability</th>
<th>Acceptability</th>
<th>Clarity</th>
<th>Implicational Explicitness</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0.15</td>
<td>0.02</td>
<td>-0.06</td>
<td>-0.03</td>
<td>-0.12*</td>
<td>-0.21**</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01
4.2.3.3 Variety

The results of a Pearson correlation analysis between the change in variety score and change in quantity, quality metrics, and rarity score in shown in Table 27. The change in implementability shows a weak negative correlation with change in variety. Change in rarity and change in variety have a moderate positive correlation.

Table 27 R-values between the change in variety scores and the change in the other performance metrics (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>∆ Effectiveness</th>
<th>∆ Applicability</th>
<th>∆ Implementability</th>
<th>∆ Acceptability</th>
<th>∆ Clarity</th>
<th>∆ Implicational Explicitness</th>
<th>∆ Effectiveness</th>
<th>∆ Rarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆ Variety</td>
<td>0.666†</td>
<td>-0.172</td>
<td>-0.194</td>
<td>-0.234*</td>
<td>-0.004</td>
<td>-0.013</td>
<td>-0.013</td>
<td>0.340**</td>
</tr>
<tr>
<td>∆ Normal Variety</td>
<td>-0.009</td>
<td>-0.009</td>
<td>-0.110</td>
<td>-0.281*</td>
<td>0.140</td>
<td>-0.002</td>
<td>-0.025</td>
<td>0.435†</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

Table 28 reports the general distribution of the change in variety from session 1 to session 2. A two-sample paired t-test did not show a statistically significant change in variety or normalized variety.

Table 28 Maximum, minimum, mean, and standard deviation of the change in variety scores (N=86)

<table>
<thead>
<tr>
<th></th>
<th>∆ Variety Score</th>
<th>∆ Normalized variety score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>18.00</td>
<td>1.67</td>
</tr>
<tr>
<td>Min</td>
<td>-21.00</td>
<td>-2.00</td>
</tr>
<tr>
<td>Mean</td>
<td>-1.48</td>
<td>-0.06</td>
</tr>
<tr>
<td>SD</td>
<td>8.63</td>
<td>0.75</td>
</tr>
</tbody>
</table>

4.2.3.4 Novelty

Pearson correlation analyses between rarity and the quality metrics did not yield any statistically significant relationships (see Table 29). No statistically significant change in mean
rarity was found between individual and team ideation. The general distribution statistics of the change in rarity scores is shown in Table 30.

<table>
<thead>
<tr>
<th></th>
<th>∆ Effectiveness</th>
<th>∆ Applicability</th>
<th>∆ Implementability</th>
<th>∆ Acceptability</th>
<th>∆ Clarity</th>
<th>∆ Implicational Explicitness</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆ Rarity</td>
<td>-0.181</td>
<td>-0.108</td>
<td>-0.063</td>
<td>-0.025</td>
<td>-0.081</td>
<td>-0.071</td>
</tr>
</tbody>
</table>

*p<0.05

Table 30 Maximum, minimum, mean, and standard deviation of the change in rarity scores (N=86)

<table>
<thead>
<tr>
<th></th>
<th>∆ Rarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>2.36</td>
</tr>
<tr>
<td>Min</td>
<td>-2.65</td>
</tr>
<tr>
<td>Mean</td>
<td>0.03</td>
</tr>
<tr>
<td>SD</td>
<td>0.95</td>
</tr>
</tbody>
</table>

4.3 How is an individual’s cognitive style related to their perceptions of ideation? (Research question #3)

This sections presents the results of Pearson correlation analyses between the participants’ KAI scores, used to represent cognitive style, and the participants’ perceptions of their ideation. Individual ideation perceptions, team ideation perceptions, and the change in perceptions are considered separately. The KAI scores were only measured once, and they do not change for an individual.
4.3.1 Cognitive style in perceptions of individual ideation

Table 31 shows correlations between KAI and its sub-factors with the four ideation perception survey questions from session 1. There was a weak positive correlation between total KAI score and one’s perception of ideation creativity. There were also moderate positive correlations between the participants’ perception of the diversity of their ideation and total KAI, as well as the sufficiency of originality sub-factor of KAI.

Table 31 R-values between perceptions and KAI in session 1 (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAI total</th>
<th>KAI SO</th>
<th>KAI E</th>
<th>KAI RG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creativity</td>
<td>0.266*</td>
<td>0.182</td>
<td>0.236</td>
<td>0.232</td>
</tr>
<tr>
<td>Diversity</td>
<td>0.318*</td>
<td>0.323**</td>
<td>0.158</td>
<td>0.231</td>
</tr>
<tr>
<td>Elaboration</td>
<td>-0.076</td>
<td>-0.013</td>
<td>-0.153</td>
<td>-0.060</td>
</tr>
<tr>
<td>Ease</td>
<td>0.298*</td>
<td>0.235</td>
<td>0.189</td>
<td>0.265*</td>
</tr>
</tbody>
</table>

* p < 0.05

4.3.2 Cognitive style in perceptions of team ideation

The relationships between perceptions of ideation and KAI during team ideation are reported as Pearson correlations in Table 32. There was a weak positive correlation between perceptions of elaboration and the efficiency sub-factor of KAI. The positive correlations between total KAI, sufficiency of original and efficiency sub-factors with ease were moderate.
Table 32 R-values between perceptions and KAI in session 2 (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creativity</td>
<td>0.035</td>
<td>-0.009</td>
<td>0.009</td>
<td>0.081</td>
</tr>
<tr>
<td>Diversity</td>
<td>0.029</td>
<td>0.109</td>
<td>0.075</td>
<td>-0.104</td>
</tr>
<tr>
<td>Elaboration</td>
<td>0.025</td>
<td>-0.047</td>
<td>0.249*</td>
<td>-0.039</td>
</tr>
<tr>
<td>Ease</td>
<td>0.330**</td>
<td>0.305*</td>
<td>0.286*</td>
<td>0.204</td>
</tr>
<tr>
<td>Impact of Team</td>
<td>-0.143</td>
<td>-0.098</td>
<td>-0.172</td>
<td>-0.099</td>
</tr>
</tbody>
</table>

*p < 0.05; **p < 0.01

4.3.3 Cognitive style and the change of perceptions from individual to team ideation

Finally, the changes in perceptions were analyzed with KAI, and the results are reported in Table 33. The only statistically significant correlation was between change in perception of elaboration and the efficiency sub-factor of KAI.

Table 33 R-values between change in perceptions and KAI (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Creativity</td>
<td>-0.223</td>
<td>-0.185</td>
<td>-0.220</td>
<td>-0.146</td>
</tr>
<tr>
<td>Δ Diversity</td>
<td>-0.196</td>
<td>-0.142</td>
<td>-0.054</td>
<td>-0.233</td>
</tr>
<tr>
<td>Δ Elaboration</td>
<td>0.081</td>
<td>-0.029</td>
<td>0.331**</td>
<td>0.014</td>
</tr>
<tr>
<td>Δ Ease</td>
<td>-0.050</td>
<td>-0.033</td>
<td>0.042</td>
<td>-0.094</td>
</tr>
</tbody>
</table>

**p < 0.01
4.4 How is an individual’s cognitive style related to their performance? (Research question #4)

This section investigates relationships between participants’ ideation performance with their KAI scores (cognitive style).

4.4.1 Cognitive style in individual ideation performance

Table 34 and Table 35 show the r-values for Pearson correlations between KAI and quantity, and variety. No statistically significant relationships were discovered.

Table 34 R-values between quantity and KAI scores in session 1 (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAI&lt;sub&gt;Total&lt;/sub&gt;</th>
<th>KAI&lt;sub&gt;ISO&lt;/sub&gt;</th>
<th>KAI&lt;sub&gt;E&lt;/sub&gt;</th>
<th>KAI&lt;sub&gt;RG&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>0.101</td>
<td>0.076</td>
<td>-0.094</td>
<td>0.188</td>
</tr>
</tbody>
</table>

*p<0.05

Table 35 R-values between variety scores and KAI scores in session 1 (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAI&lt;sub&gt;Total&lt;/sub&gt;</th>
<th>KAI&lt;sub&gt;ISO&lt;/sub&gt;</th>
<th>KAI&lt;sub&gt;E&lt;/sub&gt;</th>
<th>KAI&lt;sub&gt;RG&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>0.035</td>
<td>0.018</td>
<td>-0.044</td>
<td>0.081</td>
</tr>
<tr>
<td>Normalized Variety</td>
<td>0.101</td>
<td>0.054</td>
<td>0.044</td>
<td>0.132</td>
</tr>
</tbody>
</table>

*p<0.05

The average quality metrics for idea sets generated in session 1 were analyzed with KAI. There were moderate negative correlations of total KAI with clarity, and of the Rule/Group conformity sub-factor of KAI with clarity (see Table 36). There were no other significant relationships discovered between the quality performance metrics and KAI during session 1.
Likewise, there were no statistically significant correlations between KAI and rarity scores in session 1 (see Table 37).

### Table 36 R-values between quality metrics and KAI scores in session 1 (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness</td>
<td>-0.031</td>
<td>-0.051</td>
<td>0.002</td>
<td>-0.012</td>
</tr>
<tr>
<td>Applicability</td>
<td>-0.109</td>
<td>-0.071</td>
<td>-0.119</td>
<td>-0.087</td>
</tr>
<tr>
<td>Implementability</td>
<td>-0.196</td>
<td>-0.163</td>
<td>-0.078</td>
<td>-0.195</td>
</tr>
<tr>
<td>Acceptability</td>
<td>-0.173</td>
<td>-0.210</td>
<td>-0.101</td>
<td>-0.079</td>
</tr>
<tr>
<td>Clarity</td>
<td>-0.333**</td>
<td>-0.239</td>
<td>-0.158</td>
<td>-0.361**</td>
</tr>
<tr>
<td>Implicational</td>
<td>-0.229</td>
<td>-0.186</td>
<td>-0.162</td>
<td>-0.191</td>
</tr>
<tr>
<td>Explicitness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01

### Table 37 R-values between rarity score and KAI scores in session 1 (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rarity</td>
<td>-0.060</td>
<td>0.031</td>
<td>-0.048</td>
<td>-0.141</td>
</tr>
</tbody>
</table>

*p<0.05

### 4.4.2 Cognitive style in team ideation performance

Table 38, Table 39, Table 40, and Table 41 report the correlations between cognitive style and the ideation performance metrics in session 2. The only statistically significant finding was a weak positive correlation of the efficiency sub-factor of KAI and applicability.
Table 38 R-values between quantity and KAI scores in *session 2* (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>-0.074</td>
<td>-0.061</td>
<td>-0.134</td>
<td>-0.012</td>
</tr>
</tbody>
</table>

*p<0.05

Table 39 R-values between variety scores and KAI scores in *session 2* (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variety</td>
<td>-0.195</td>
<td>-0.156</td>
<td>-0.215</td>
<td>-0.121</td>
</tr>
<tr>
<td>Normalized Variety</td>
<td>-0.229</td>
<td>-0.234</td>
<td>-0.021</td>
<td>-0.220</td>
</tr>
</tbody>
</table>

*p<0.05

Table 40 R-values between quality metrics and KAI scores in *session 2* (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effectiveness</td>
<td>0.039</td>
<td>0.098</td>
<td>0.166</td>
<td>-0.124</td>
</tr>
<tr>
<td>Applicability</td>
<td>-0.056</td>
<td>-0.145</td>
<td>0.286*</td>
<td>-0.126</td>
</tr>
<tr>
<td>Implementability</td>
<td>0.043</td>
<td>-0.018</td>
<td>0.022</td>
<td>0.100</td>
</tr>
<tr>
<td>Acceptability</td>
<td>-0.120</td>
<td>-0.160</td>
<td>0.095</td>
<td>-0.290</td>
</tr>
<tr>
<td>Clarity</td>
<td>-0.085</td>
<td>0.002</td>
<td>-0.171</td>
<td>0.013</td>
</tr>
<tr>
<td>Implicational Explicitness</td>
<td>-0.078</td>
<td>-0.019</td>
<td>-0.073</td>
<td>-0.104</td>
</tr>
</tbody>
</table>

*p<0.05
Table 41 R-values between rarity score and KAI scores in session 2 (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Novelty</td>
<td>-0.087</td>
<td>0.036</td>
<td>-0.074</td>
<td>-0.176</td>
</tr>
</tbody>
</table>

*p<0.05

4.4.3 Cognitive style in the changes in performance from individual to teaming ideation

These results investigate relationships in how people of different cognitive styles respond differently to teamwork in terms of performance. The analysis will be Pearson correlations between the change in performance scores vs. KAI scores using the performance during session 1 as the benchmark for each individual to see how teaming affects them. Similar to the previous section, the only statistically significant relationship between KAI and the change in performance was a weak positive correlation of the efficiency sub-factor of KAI and change in applicability.

Table 42 R-values between change in quantity and KAI scores (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Quantity</td>
<td>-0.181</td>
<td>-0.142</td>
<td>-0.040</td>
<td>-0.208</td>
</tr>
</tbody>
</table>

*p<0.05

Table 43 R-values between change in variety scores and KAI scores (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th></th>
<th>KAITotal</th>
<th>KAISO</th>
<th>KAIE</th>
<th>KAIRG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Variety</td>
<td>-0.162</td>
<td>-0.121</td>
<td>-0.113</td>
<td>-0.148</td>
</tr>
<tr>
<td>Δ Normalized Variety</td>
<td>-0.224</td>
<td>-0.202</td>
<td>-0.039</td>
<td>-0.234</td>
</tr>
</tbody>
</table>

*p<0.05
Table 44 R-values between change in quality metrics and KAI scores (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th>Δ Effectiveness</th>
<th>KAI Total</th>
<th>KAI SO</th>
<th>KAI E</th>
<th>KAI RG</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.053</td>
<td>0.111</td>
<td>0.117</td>
<td>-0.079</td>
<td></td>
</tr>
<tr>
<td>Δ Applicability</td>
<td>0.044</td>
<td>-0.044</td>
<td>0.278*</td>
<td>-0.020</td>
</tr>
<tr>
<td>Δ Implementability</td>
<td>0.178</td>
<td>0.101</td>
<td>0.075</td>
<td>0.229</td>
</tr>
<tr>
<td>Δ Acceptability</td>
<td>0.039</td>
<td>0.033</td>
<td>0.169</td>
<td>-0.053</td>
</tr>
<tr>
<td>Δ Clarity</td>
<td>0.192</td>
<td>0.125</td>
<td>0.061</td>
<td>0.240</td>
</tr>
<tr>
<td>Δ Implicational Explicitness</td>
<td>0.116</td>
<td>0.127</td>
<td>0.069</td>
<td>0.068</td>
</tr>
</tbody>
</table>

*p<0.05

Table 45 R-values between change in rarity scores and KAI scores (Pearson correlations; N=61)

<table>
<thead>
<tr>
<th>Novelty</th>
<th>KAI Total</th>
<th>KAI SO</th>
<th>KAI E</th>
<th>KAI RG</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.018</td>
<td>0.056</td>
<td>0.019</td>
<td>-0.032</td>
<td></td>
</tr>
</tbody>
</table>

*p<0.05

4.5 How are ideation performance and perception related? (Research question #5)

This final research question explores relationships between evaluated ideation performance and ideation perception ratings. These relationships were analyzed using Pearson correlations and will be reported for session 1, session 2, and then the differences between the sessions.
4.5.1 Individual ideation

The r-values reported in Table 46 are the correlations between perceptions and performances during session 1. Interestingly, participants’ perceptions of ideation creativity and ease do not show any statistically significant correlations to performance while working individually. Participants’ perception of elaboration resulted in a weak negative correlation with quantity of ideas. Perception of diversity was weak to moderately related to a number of the performance measurements. It showed weak negative correlations with effectiveness, applicability, and clarity while having a moderate positive relationship with variety.

Table 46 R-value between performance metrics and perceptions of ideation in session 1 (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Creativity</th>
<th>Diversity</th>
<th>Elaboration</th>
<th>Ease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>0.147</td>
<td>0.139</td>
<td>-0.243*</td>
<td>0.032</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>-0.057</td>
<td>-0.245*</td>
<td>0.001</td>
<td>0.153</td>
</tr>
<tr>
<td>Applicability</td>
<td>-0.151</td>
<td>-0.233*</td>
<td>0.095</td>
<td>0.204</td>
</tr>
<tr>
<td>Implementability</td>
<td>0.040</td>
<td>-0.078</td>
<td>0.141</td>
<td>-0.043</td>
</tr>
<tr>
<td>Acceptability</td>
<td>-0.189</td>
<td>-0.167</td>
<td>0.088</td>
<td>0.225</td>
</tr>
<tr>
<td>Clarity</td>
<td>-0.013</td>
<td>-0.238*</td>
<td>0.132</td>
<td>0.036</td>
</tr>
<tr>
<td>Imp. Exp.</td>
<td>0.017</td>
<td>-0.117</td>
<td>0.141</td>
<td>-0.056</td>
</tr>
<tr>
<td>Rarity</td>
<td>-0.008</td>
<td>0.005</td>
<td>-0.122</td>
<td>-0.025</td>
</tr>
<tr>
<td>Variety</td>
<td>0.074</td>
<td>0.297**</td>
<td>-0.277**</td>
<td>0.034</td>
</tr>
<tr>
<td>Normal Variety</td>
<td>0.070</td>
<td>0.340**</td>
<td>-0.014</td>
<td>0.034</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

4.5.2 Team ideation

An investigation of perceptions and performances in session 2, while working in teams, brought different results than were seen in the previous section. Creativity still did not have any statistically significant relationships with any of the performance metrics, but perception of elaboration did not either. Perceptions of diversity had a weak negative correlation with implementability and a moderate positive correlation with rarity. There was not a correlation
between diversity and variety as was seen in session 1. Ease of ideation correlated weakly with both applicability and rarity (Table 47).

Table 47 R-value between performance metrics and perceptions of ideation in session 2 (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Creativity</th>
<th>Diversity</th>
<th>Elaboration</th>
<th>Ease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>0.144</td>
<td>0.130</td>
<td>-0.164</td>
<td>0.078</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>0.069</td>
<td>0.116</td>
<td>0.007</td>
<td>0.197</td>
</tr>
<tr>
<td>Applicability</td>
<td>0.061</td>
<td>-0.048</td>
<td>0.156</td>
<td>0.264*</td>
</tr>
<tr>
<td>Implementability</td>
<td>-0.128</td>
<td>-0.253*</td>
<td>-0.092</td>
<td>0.032</td>
</tr>
<tr>
<td>Acceptability</td>
<td>-0.170</td>
<td>0.014</td>
<td>-0.023</td>
<td>-0.008</td>
</tr>
<tr>
<td>Clarity</td>
<td>-0.086</td>
<td>-0.042</td>
<td>0.014</td>
<td>0.002</td>
</tr>
<tr>
<td>Imp. Exp.</td>
<td>0.192</td>
<td>0.000</td>
<td>0.122</td>
<td>0.129</td>
</tr>
<tr>
<td>Rarity</td>
<td>0.199</td>
<td>0.311**</td>
<td>0.036</td>
<td>0.174</td>
</tr>
<tr>
<td>Variety</td>
<td>0.162</td>
<td>0.159</td>
<td>-0.108</td>
<td>0.079</td>
</tr>
<tr>
<td>Normal Variety</td>
<td>-0.013</td>
<td>0.070</td>
<td>-0.034</td>
<td>0.019</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

The perceptions about team impact and contribution to team work were also analyzed with the performance measurements. Other than a weak positive correlation between acceptability and impact of team, there were no statistically significant findings in this analysis (Table 48).

Table 48 R-value between performance metrics and perceptions of team experience in session 2 (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>Impact of Team</th>
<th>Percent Initiator</th>
<th>Average Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>0.006</td>
<td>-0.007</td>
<td>-0.136</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>0.093</td>
<td>0.171</td>
<td>0.062</td>
</tr>
<tr>
<td>Applicability</td>
<td>0.076</td>
<td>-0.078</td>
<td>-0.141</td>
</tr>
<tr>
<td>Implementability</td>
<td>0.023</td>
<td>-0.192</td>
<td>-0.090</td>
</tr>
<tr>
<td>Acceptability</td>
<td>0.258*</td>
<td>-0.065</td>
<td>-0.200</td>
</tr>
<tr>
<td>Clarity</td>
<td>-0.002</td>
<td>-0.141</td>
<td>-0.147</td>
</tr>
<tr>
<td>Imp. Exp.</td>
<td>0.145</td>
<td>-0.052</td>
<td>0.014</td>
</tr>
<tr>
<td>Rarity</td>
<td>0.029</td>
<td>-0.166</td>
<td>-0.015</td>
</tr>
<tr>
<td>Variety</td>
<td>0.067</td>
<td>-0.001</td>
<td>-0.153</td>
</tr>
<tr>
<td>Normal Variety</td>
<td>-0.008</td>
<td>0.100</td>
<td>-0.052</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001
4.5.3 Change from individual to team ideation

The r-values reported in Table 49 show the relationships between changes in performance and changes in perception. The change in clarity score showed two weak relationships that were not seen in session 1 or session 2. It was negatively correlated with change in creativity and positively correlated with change in ease. The variety score reflected the combination of those two weak relationships and a positive moderate correlation was found between change in variety score and change in diversity.

Table 49 R-value between change in performance metrics and change in perceptions if ideation (Pearson correlations; N=86)

<table>
<thead>
<tr>
<th></th>
<th>∆ Creativity</th>
<th>∆ Diversity</th>
<th>∆ Elaboration</th>
<th>∆ Ease</th>
</tr>
</thead>
<tbody>
<tr>
<td>∆ Quantity</td>
<td>0.175</td>
<td>0.211</td>
<td>-0.203</td>
<td>0.188</td>
</tr>
<tr>
<td>∆ Effectiveness</td>
<td>-0.111</td>
<td>-0.074</td>
<td>0.000</td>
<td>0.058</td>
</tr>
<tr>
<td>∆ Applicability</td>
<td>-0.055</td>
<td>-0.182</td>
<td>0.074</td>
<td>0.027</td>
</tr>
<tr>
<td>∆ Implementability</td>
<td>-0.027</td>
<td>-0.113</td>
<td>0.035</td>
<td>0.067</td>
</tr>
<tr>
<td>∆ Acceptability</td>
<td>-0.171</td>
<td>0.019</td>
<td>-0.198</td>
<td>-0.048</td>
</tr>
<tr>
<td>∆ Clarity</td>
<td>-0.236*</td>
<td>-0.190</td>
<td>0.100</td>
<td>0.225*</td>
</tr>
<tr>
<td>∆ Imp. Exp.</td>
<td>-0.011</td>
<td>-0.150</td>
<td>0.161</td>
<td>0.197</td>
</tr>
<tr>
<td>∆ Rarity</td>
<td>0.149</td>
<td>0.106</td>
<td>0.040</td>
<td>0.125</td>
</tr>
<tr>
<td>∆ Variety</td>
<td>0.057</td>
<td>0.303**</td>
<td>-0.131</td>
<td>0.185</td>
</tr>
<tr>
<td>∆ Normal Variety</td>
<td>-0.49</td>
<td>0.196</td>
<td>-0.002</td>
<td>0.137</td>
</tr>
</tbody>
</table>

*p<0.05; **p<0.01; †p<0.001

4.6 Summary

Figure 13, Figure 14, and Figure 15 show visual summaries of the statistically significant correlations found within the data. Each line represents a correlation where the p-value was less than 0.05. Positive correlations are shown as black lines and negative correlations are shown as grey lines. Figure 13 summarizes the correlations found in session 1, Figure 14 those in session 2, and Figure 15 shows the correlations found in the difference between the sessions. The strengths of correlations are not represented in the figures.
Session 1 Summary of Correlation Findings

Positive Correlation:  
Negative Correlation:  

Figure 13 Summary of findings from session 1
Session 2 Summary of Correlation Findings

Positive Correlation: ———
Negative Correlation: ———

Figure 14 Summary of findings from session 2
Figure 15 Summary of findings from the change between sessions
Chapter 5

Discussion

Throughout all of the analyses there were interesting findings pertaining to all of the research questions. This section will synthesize those findings into meaningful discussion.

5.1 A new question

Quantity of ideas has been shown to be less for groups working together than for groups of individuals working separately (Paulus et al. 1993; Linsey et al. 2010; Steiner 1972; Diehl and Stroebe 1987). This effect, called the group process loss, was observed in a slightly different way in the present study. It was shown that individuals generally recorded fewer ideas when working in two- or three-person teams than when they worked alone (two-sample paired t-test; t=3.28; p<0.01). Table 52 shows several select cases of ways that participants explained this process loss in their own words; however, the majority of people seemed unaware that they were recording fewer ideas. They even indicated that working in a group helped them generate more ideas, though this was not generally the case. This begs the question, why students are so sure that working in teams is making ideation easier, when the truth is that they are generally recording fewer ideas? The following are two possible explanations for the overall decrease in ideas generated while in teams that might help answer this question: conglomeration and evaluation. These two behaviors are explained here so that they can be referred to throughout the rest of the discussion of the results.
5.1.1 Conglomeration

When the participants worked as teams, it became much more common for them to only record one idea while working in a team, increasing from 2 to 16 instances out of 86 participants.

It seemed like some of the 16 participants who choose to only record one idea during session 2 were generating ideas verbally with their teammates and combining elements of several ideas into one design. This behavior can be called “conglomeration”, because the mixing several ideas, or elements of several idea, into one. Table 50 shows some of the participants’ comments that seemed to allude to this type of behavior.

<table>
<thead>
<tr>
<th>ID</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>220</td>
<td>[We] came up with multiple ideas and brought them into one idea</td>
</tr>
<tr>
<td>236</td>
<td>Yes, because ideas get mixed and a better solution comes out</td>
</tr>
<tr>
<td>488</td>
<td>We built on an initial idea very quickly</td>
</tr>
<tr>
<td>512</td>
<td>[We] built on other’s ideas for better product</td>
</tr>
<tr>
<td>425</td>
<td>It helped to combine our ideas in order to make them better and to come up with more solutions.</td>
</tr>
<tr>
<td>434</td>
<td>It made it easier because we sort of combined ideas to make our designs better.</td>
</tr>
</tbody>
</table>

5.1.2 Evaluation

Participants were explicitly instructed to avoid evaluating their ideas during the idea session (see Appendix G). It was explained that evaluating ideas during the ideation phase can be counterproductive and that there is something to be learned even from ideas that will not work. Students will often use evaluation to eliminate ideas that their feel are ineffective before they are recorded, thus reducing the total number of ideas recorded during ideation. Table 51 shows several participants’ comments that indicate that some pre-evaluation did occur to some extent.
Table 51 Participant comments about evaluation during teamwork

<table>
<thead>
<tr>
<th>ID</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>216</td>
<td>We mainly thought of ideas individually and then tweaked each other’s ideas.</td>
</tr>
<tr>
<td>235</td>
<td>It makes it better to share ideas and come up with the best one.</td>
</tr>
<tr>
<td>483</td>
<td>Somewhat easy with more flowing of ideas, but not too easy because everyone commented on the practicality of the ideas, narrowing our brainstorm</td>
</tr>
<tr>
<td>436</td>
<td>Working in a team allows you to expand on an idea and get feedback on whether an idea will be practical</td>
</tr>
<tr>
<td>504</td>
<td>Tough because [teammates] shoot down ideas</td>
</tr>
</tbody>
</table>

5.2 How is working in a team related to an individual’s perceptions of their ideation?

The results from reflection surveys showed that overall, the participants in the study felt that working in teams made a significant difference in how they felt about ideation. This is not surprising, but it is important to recognize that working alone or working in teams does have an effect on the experience of the participants. Generally, participants felt that working in a team made ideation easier and that the work was more creative (Figure 8 and Table 9). It is difficult to identify exactly why this feeling pervades participants’ perceptions of ideation but possible explanations include a psychological phenomenon or a social bias.

Although the majority of the participants (85%) felt teaming made ideation easier, there were still several cases where participants felt the opposite. Table 52 shows the written explanations of several students who felt that working in teams either had no effect on ease of ideation or even made it harder. Several of the cases used language that indicated team process loss effects (like those presented by Diehl and Stroebe), such as production blocking, evaluation apprehension, and free riding (Diehl and Stroebe 1987).
Table 52 Comments from participants who did not feel that teams made ideation easier

<table>
<thead>
<tr>
<th>ID</th>
<th>Impact of Team</th>
<th>Description</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>229</td>
<td>3</td>
<td>I felt as if I said idea it was stupid or dumb so kept some to myself</td>
<td>Evaluation apprehension</td>
</tr>
<tr>
<td>219</td>
<td>1</td>
<td>I have hard time generating new ideas, When my team mates has ideas</td>
<td>Production blocking</td>
</tr>
<tr>
<td>511</td>
<td>2</td>
<td>[I] felt I needed to explain my ideas, couldn’t just toss ideas out</td>
<td>Production blocking</td>
</tr>
<tr>
<td>513</td>
<td>4</td>
<td>We were able to come with more total ideas by combining them, but it’s hard to say if the ideas would have occurred w/o me.</td>
<td>Free riding (teammate)</td>
</tr>
<tr>
<td>432</td>
<td>2</td>
<td>I was less open and quicker to dispose of ‘stupid ideas</td>
<td>Evaluation apprehension</td>
</tr>
<tr>
<td>437</td>
<td>4</td>
<td>They did not contribute at all</td>
<td>Free riding (teammate)</td>
</tr>
</tbody>
</table>

The first question in the reflection surveys both in session 1 and 2 was “How creative do you feel that your ideas were?” Because creativity can have several meanings, the reader was left to define creativity according to their own experience and opinion. With this in mind several of the findings point to how engineering students seem to view creativity in ideation. While working alone, participants who felt their ideation was creative also seemed to feel it was diverse and that is was easy to generate ideas. The same relationship remained the same while working in teams; however, participants also seemed to feel that more creative ideas were also more elaborate in teams. This indicates that, when they work in teams, the way engineering students view creativity may often broaden to include elaboration along with diversity.

A relationship between perception of ease and elaboration appeared in session 2 that was not seen in session 1. That is to say that while working in teams, the participants who felt that it was easier to ideate tended to feel that their ideas were more elaborate. This relationship was also seen in the analysis of the change in perceptions. As participants perceived an increase in ease of
ideation from session 1 to session 2 they tended to also experience an increase in perceived elaboration of their ideas. This points to the notion that working in teams may change the way that engineering students view elaboration in ideation, placing more importance on it.

Both in teams and alone, participants’ perception of creativity and ease of ideation were moderately correlated. While students felt that they were being “creative,” the also seemed to feel that ideation was easier. To this effect, often the word “flow” was used to describe creative ideation, creating a connection between the ease of coming up with ideas to how creative they were.

While working in teams, it was observed that perception of team impact had a weak to moderate positive correlation with perception of creativity, elaboration, and ease. In other words, as the participants rated the impact of teams higher, they tended to rate the creativity and elaboration of their ideas higher, and they tended to feel that it was easier to generate ideas. Interestingly, the impact of team responses also showed a moderate negative correlation with both of the responses about perceived contribution. This shows that as participants rated working on a team as making ideation easier, they seemed to rate their own contribution lower, both in percent of the ideas they initiated and in overall contribution. It is also true that students who felt that working in a team made ideation more difficult tended to rate their own contribution higher. This relationship seems natural. It could be that those who felt like their teammate did not help them ideate were more likely to take more credit for the ideas that were generated.

A strong positive relationship was observed between the percent of ideas that a participant claimed to have initiated and the overall perceived contribution to the ideation session. It seems obvious that people tend to give lots of credit to the person who came up with an idea first, such as the inventor of a new technology, and the people who help develop an idea further might receive less of the glory in the public eye. That is one possible explanation of why there is a strong relationship between idea initiator and contribution to idea within the dataset.
5.3 How is working in a team related to ideation performance?

When quantity of ideas was analyzed with quality of ideas, there were several interesting results. When participants worked alone, there were weak to moderate negative correlations between quantity and all of the quality metrics. There was a trend that as a participant generated more ideas, those ideas tended to have lower average effectiveness, applicability, implementability, acceptability, clarity, and implicational explicitness. While not necessarily surprising, this finding is significant, because it indicates an overall decrease in idea quality as more ideas are generated, i.e., quantity does not lead to quality. When working in teams, these relationships almost completely disappear, with the exception of effectiveness. So, while working in teams, as quantity of ideas increased the average effectiveness within those ideas sets tended to decrease, however, there did not seem to be a statistically significant negative correlation with applicability, implementability, acceptability, clarity, and implicational explicitness. It appears that working in teams can change or rather disrupt some of the relationships between quantity and quality of ideas that occur when working alone.

When the change in quantity was analyzed with the change in quality, a weak negative correlation was discovered with implementability. As the change in quantity of ideas from session 1 to session 2 increased the change in average implementability of idea sets tended to decrease.

It was observed that as participants went from ideating alone to ideating with a team, a general decrease in clarity (two-sample paired t-test; t=-2.04; p<0.05) and implicational explicitness (two-sample paired t-test; t=-3.11; p<0.01) occurred. For some reason, participants were generally less clear and explicit in the idea descriptions that they recorded while working on teams. It is possible that the participants were less capable of clearly describing ideas that their teammates had initiated. Also, it could be that the participants spent less effort on describing the ideas, because they had already spent time explaining them to their teammates.
There was a general increase in effectiveness when students worked in teams, however, the finding was just shy of attaining a statistically significant level (two-sample paired t-test; t=1.87; p<0.065). This relationship, though not statistically significant in this dataset, needs to be investigated further in other datasets to determine whether the relationship is random, or if teaming does lead to an increase in ideation effectiveness.

Analysis of the quality metric results from session 1 showed several statistically significant inter-metric correlations. Effectiveness had a moderate positive relationship with applicability, meaning that as the average effectiveness of an idea set increased, so did the applicability. The same relationship was seen in the analysis of the changes in quality, showing that individuals whose idea sets increased in effectiveness also tended to increase in applicability. This is consistent with correlations between these two metrics in other literature (Dean et al. 2006). However, this relationship was not present in the data collected during session 2. It is unclear why the relationship

When the data from session 1 and session 2 were analyzed separately there were no apparent correlations between effectiveness and implementability, yet there was a moderate negative correlation when the changes in quality were analyzed. Individuals whose idea sets increased in effectiveness from individual to team ideation seemed to often decrease in implementability.

In session 1, applicability showed a weak positive correlation with implementability and acceptability with clarity, but these relationships were not present in session 2 or in the analysis of change in quality. In the session 2 data, implementability showed a weak positive correlation with acceptability but it was not seen in the other analyses. Clarity had a strong positive correlation with implicational explicitness across all three analyses.

The variety analyses were reported in two different ways: the variety score, and the normalized variety score (see Table 14, Table 20, and Table 27). The normalized variety score
was used to help separate relationships that were primarily with quantity from the relationships that were primarily with variety, because the variety score and quantity were highly correlated to one another. Interestingly, even with the normalized variety score being de-coupled from quantity, there was a weak positive correlation between quantity and variety when participants were working in teams. This showed that, while working in teams, individuals that generated more ideas were likely to have more varied ideas. This relationship was not observed when participants worked alone.

It was seen in both session 1 and session 2 that participants with more varied idea sets also had higher average rarity scores. This relationship seems intuitive: as more of the idea space is explored (high variety score), rarer ideas are more likely to be discovered (high rarity score).

The normalized variety scores of idea sets generated in session 1 showed moderate negative correlation to effectiveness and applicability (the sum of which is the relevance dimension of quality). So, as participants generated idea sets with more variety, the average relevance of those idea sets tended to be lower. This trend between variety and relevance was not observed when participants generated ideas as teams. Pre-evaluation could be a possible explanation by making it possible for individuals to generate a wider variety of ideas while avoiding ideas that did not solve or pertain to the problem statement.

5.4 How is an individual’s cognitive style related to their perceptions of ideation?

Cognitive style seemed to be a factor that related to how individuals perceived ideation. People with a more innovative KAI tended to feel that their ideas were more creative. While these correlations were relatively weak, the relationship between cognitive style and perceived ease of ideation was more significant. It was seen that more innovative individuals found ideation easier while working alone and in teams. Also, in total KAI and SO, the more innovative felt their
individual ideation was more diverse. These findings seem fairly consistent with A-I theory. The high innovators are people who might describe themselves as “idea people.” They are likely to feel that they have lots of ideas and that it is often easy for them to generate these ideas when presented with a problem.

5.5 How is an individual’s cognitive style related to their performance?

Very few relationships existed between cognitive style and ideation performance. Yet during session 1, there were moderate negative correlations between total KAI and the rule/group conformity sub-factor and average clarity of idea sets. This shows that, while working individually, people who had more innovative cognitive styles tended to use less clear description of their ideas, and that had more adaptive cognitive styles tended to use more clear language. This observation is consistent with A-I theory. The rule/group sub-factor has to do with an individual’s preferences in how they will conform, or not, to perceived rules while solving a problem. The more adaptive individuals in this sub-factor tend to solve the problem through the rules and the more innovative are likely to solve the problem in spite of the rule. The more innovative are more liable to either rearrange or disregard a rule in order to solve a problem (Kirton 2011). Therefore, it appears that the more innovative individuals in this study were more likely to use unclear, incomplete or ambiguous language in the description of their ideas.

5.6 How are ideation performance and perception related?

It appears that student’s perception of the creativity of their ideation is not reflected in measures of quantity, quality, variety or novelty. If we assume that the measures used were a correct representation of ideation effectiveness, then it appears that students either did not
associate creativity with the dimensions of effective ideation or that they were unaware of the effectiveness of their own ideas. The latter notion is partially refuted by the fact that students’ perception of diversity showed a moderate correlation with the measured variety of their individual ideation, indicating that the students were often aware of when their ideation displayed high or low variety. This relationship was not seen when participants were working in teams.
Chapter 6

Conclusions and future work

Teamwork changes an individual’s performance and perceptions of ideation. However, it often changes things in different ways for different people. Cognitive style is just one of the factors that can shape the team experience for individuals. The following are several of the significant findings of this work and suggestions of how they can be understood and investigated in the future.

People tend to record fewer of their ideas when working in teams than when working alone. This finding is not new. It has been observed many times, and researchers have often pointed to this as a reason that teamwork was not beneficial in ideation activities, however, it is possible that this phenomenon has been misunderstood in the past. It was discovered that when people were working alone, as they produced more ideas, the quality of the ideas tended to be lower. This seems to indicate that generating more ideas is not always preferable. Further, the negative relationship between quantity and quality was not observed when the participants worked as teams. The quality of the idea set was more independent from quantity during teamwork than when working alone. These findings may indicate that the decrease in quantity of ideas from teamwork might not be as detrimental to ideation effectiveness as it has previously been portrayed.

How the team decided to work together had a large impact on the individual team member’s experience and the ideation outcomes. Many of the participants’ comments indicated that the team members selected methods in which they would work together to generate ideas. Evaluation was a method where team members seemed to verbally discuss each idea’s potential and then select those ideas they felt were best. This seemed to lead to fewer ideas overall being
recorded. Some team members using this method indicated that they felt like working in a team made it harder to generate ideas. Different from this were the teams that chose to “conglomerate” ideas. This method was similar to evaluation but instead of rejecting ideas that seemed less effective, team members shared ideas and tried to incorporate elements of their team member’s idea into their own ideas. While this method also seemed to lead to fewer total ideas recorded, many of the participants who used it felt that working in teams made ideation easier. This shows how important it is to select the appropriate work method while ideating as a team. The methods used in team ideation should be selected according to the desired outcome and the group’s preferences.

Cognitive style, assessed via the KAI inventory, seemed to be closely related to the individual’s perceptions of ideation. It did not however seem to be related to an individual’s performance in ideation. Future work should seek to identify cognitive factors that do relate to ideation performance. Cognitive level measures could be important for continuing this type of cognitive factors research.

Participants in this study seemed to respond to working in teams in a variety of ways. Because no specific ideation goals were presented to them, it seems like it was up to each group, or even individual, to decide what types of solutions they would pursue. Future investigation into teamwork could provide teams with specific ideation goals and then use the same rigorous idea evaluation metrics presented in this work. Future studies could also use reflection questions that help to understand team dynamics and team member roles. The findings in this thesis could serve as a benchmark for teams who worked without specific ideation goals.

It was seen that there were likely biases built into the variety evaluation methods. The use of hierarchical trees proved to be very reliable but too rigid to be adapted for ideas that did not fit in the problem paradigm. Future research could aim to create a new method for assessing variety that does not have these biases. This could be attempted using a similar theoretical framework for
variety as was presented in this work, but without the hierarchical trees. The variety training
document (Appendix F) could be used to inform future researchers of the strengths and
weaknesses of the methods used in this thesis.

6.1 Recommendations

The following are recommendations for engineering educators and managers, that may help to increase ideation effectiveness of engineering teams.

First, it is important for engineers to understand and value their own preferred style of ideation. Relationships between perceptions and KAI showed a general trend that more innovative styles tended to perceived their ideas as more creative, more diverse, and easier to generate. However, the more innovative participants did not necessarily perform better. Helping individuals to better understand the value and strengths of their own style may improve their perceptions of their own ideation.

In the reflection responses, several participants mentioned some sort of ideation method they used in their team. Some chose to record as many ideas as possible while others chose to try to record only what they thought was the best idea. It is important that team members choose an ideation method that will help them reach the goals of ideation session and that each member of the team understands the ideation method. For example, when a wide variety of solutions are desired, teams should choose to avoid evaluating ideas in any way. All team members should record all of their ideas and the team can evaluate later.

Finally, working in a team seems to make people feel more creative, but that doesn’t mean that people are actually more creative in teams. Teams should consider ideating
individually when there is a need for many diverse ideas. Then the team can bring all of the individual’s ideas together and evaluate them.
Works Cited


## Appendix A

### Session 1 idea sheet

<table>
<thead>
<tr>
<th>Idea Generation</th>
<th>Idea Sheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Your Name: _______________</td>
<td>Problem #: _______</td>
</tr>
</tbody>
</table>

**Idea Drawing:** Sketch your solution idea in the box below.

**Idea Description:** Describe the solution idea. How does it work? What are the features, mechanisms, and details?

<table>
<thead>
<tr>
<th>Idea Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sketch your solution idea in the box below.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Idea Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Describe the solution idea. How does it work? What are the features, mechanisms, and details?</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Idea Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

Appendix B

Session 2 idea sheet

Idea Generation

Your Name: ____________________  Problem #: _______  Idea #: ______

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

Teamwork: Who initially brought up this idea? (Circle one.)  Me  Another Team Member

Identify to what extent you feel this idea was generated and developed by you, by your team members, or by some combination. (Circle the best response.)

This idea was entirely my team members  My team members and I worked on this idea equally  This idea was entirely mine
Appendix C

Problem context descriptions

<table>
<thead>
<tr>
<th>Idea Generation</th>
<th>Problem Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-Skill Snow Transporter</td>
<td></td>
</tr>
</tbody>
</table>

**Problem #1A**

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.

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

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.

---

<table>
<thead>
<tr>
<th>Idea Generation</th>
<th>Problem Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-Hand Opener for Lidded Food Containers</td>
<td></td>
</tr>
</tbody>
</table>

**Problem #2A**

The local rehabilitation center helps to treat thousands of stroke patients each year. Many individuals who have had a stroke are unable to perform bilateral tasks, meaning they have limited or no use of one upper extremity (arm/shoulder). A common issue the hospital has observed with their stroke patients is in their ability to open jars and other lidded food containers. The ability to open lidded food containers is particularly important for patients who are living on their own, in which case they often don’t have help around for even basic tasks. A solution to helping them open lidded food containers with one hand would go along way in helping the patients to maintain their independence.

Design a way for individuals who have limited or no use of one upper extremity to open a lidded food container with one hand.

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.
<table>
<thead>
<tr>
<th>Idea Generation</th>
<th>Problem Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Remote Village Rainwater Catcher</strong></td>
<td><strong>Problem #4A</strong></td>
</tr>
</tbody>
</table>

In remote villages throughout many rural, underdeveloped areas of the world, easy access to fresh clean drinking water is very limited. Villagers must often walk long distances to a fresh water source, collect the water in large, awkward bins, and then carry the water back uphill to their home. Retrieving the fresh drinking water in this manner takes tremendous amounts of time and effort. In many cases, however, rainwater is a fresh and abundant source of water, but there are no solutions for effectively capturing, storing, and distributing the water.

Design a way for remote villagers to catch, store, and access rainwater.

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.

<table>
<thead>
<tr>
<th>Idea Generation</th>
<th>Problem Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Public Place Belongings Securer</strong></td>
<td><strong>Problem #3A</strong></td>
</tr>
</tbody>
</table>

Working in coffee shops and public places has become a common occurrence. Sometimes, however, it becomes necessary to step away for short periods of time to take a phone call or use the restroom. Once a workspace has been set up, it can be very inconvenient to pack it all away for these short absences. However, there is a danger of theft when leaving items in public places.

Design a way for someone to secure several of his or her belongings in a public area to prevent theft quickly without disrupting the space.

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.
Appendix D

Reflection surveys

Idea Generation

Reflection Survey

Your Name: __________________________  Problem #: ______

For the following questions, think only about the solution ideas that you came up with for this design problem. Do not think about any prior idea generation activity that you may have participated in using a different design problem. Also, do not look back at the problem statement or the solution ideas you generated. Just complete them as best you can from your memory of the activity. Finally, complete the questions in order.

Section 1

1. On a scale from 1 to 7, how creative do you feel that your ideas were? Circle one number.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not creative</td>
<td>Neutral</td>
<td>Very creative</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. On a scale from 1 to 7, how diverse, or different from each other, do you feel that your ideas were? Circle one number.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not diverse</td>
<td>Neutral</td>
<td>Very diverse</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. On a scale from 1 to 7, how elaborate, detailed, or “fleshed-out,” do you feel that your ideas were? Circle one number.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not elaborate</td>
<td>Neutral</td>
<td>Very elaborate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. What **existing solutions** for this particular design problem were you aware of or familiar with prior to this activity that may have influenced the solutions you came up with? Please explain.
Section 2

5. Imagine that you asked a co-worker to generate additional solution ideas for this same design problem. In a few sentences, explain to your co-worker what to focus on when coming up with their own solution ideas.

Section 3

6. On a scale from 1 to 7, how easy or difficult was it for you to come up with design ideas? Circle one number.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Very difficult</td>
<td>Neutral</td>
<td>Very easy</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Please explain your choice for the previous question. What made it easy or difficult for you to come up with design ideas?
Section 4

8. On a scale from 1 to 7, how much did the written description of the design task encourage you to come up with design ideas that were familiar versus ideas that were new? Circle one number.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>The written description encouraged very new ideas.</td>
<td>The written description didn’t encourage one sort of idea or another.</td>
<td>The written description encouraged very familiar ideas.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9. Think about the written description of the design task. What kinds of ideas (if any) do you feel the description encouraged or discouraged you to come up with? Please explain.

10. On a scale from 1 to 7, how much did the amount of information given in the written description of the design task make it easy or difficult for you to come up with design ideas? Circle one number.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>The amount of information made it very difficult for me.</td>
<td>The amount of information didn’t affect me.</td>
<td>The amount of information made it very easy for me.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When you have completed this reflection survey, please make sure your idea sheets are stacked in order (Idea #1 on top), with the design task description on top, and then place this reflection survey on the bottom of that stack. Please put the entire stack back in the folder provided.

Page 3 – You’re done! Thank you.
Section 5

11. On a scale from 1 to 7, how much did working in a team make it easy or difficult for you to come up with design ideas? Circle one number.

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working in a team made it very difficult for me</td>
<td>Working in a team didn’t affect me</td>
<td>Working in a team very easy for me</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working in a team made it very easy for me</td>
<td>Working in a team didn’t affect me</td>
<td>Working in a team very easy for me</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working in a team didn’t affect me</td>
<td>Working in a team very easy for me</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12. How did working in a team impact your process for generating ideas and/or the ideas you generated? Please explain.

13. Rank the ideas that you generated from the one you think is most likely to be successful (1) to the one you think is least likely to be successful. Also, circle your favorite idea.

a. Ranking 

<table>
<thead>
<tr>
<th>Idea #</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
<tr>
<td>5</td>
</tr>
<tr>
<td>6</td>
</tr>
<tr>
<td>7</td>
</tr>
<tr>
<td>8</td>
</tr>
<tr>
<td>9</td>
</tr>
<tr>
<td>10</td>
</tr>
</tbody>
</table>

b. For the idea that you ranked as most likely to be successful (1), explain why.

c. For the idea that you ranked as least likely to be successful, explain why.
Demographic survey

Section A

A. What is your gender?

☐ Male  ☐ Female  ☐ Other __________

B. What is your age? ______

C. Please select all races that apply to you:

☐ American Indian or Alaska Native  ☐ Asian  ☐ Black or African American

☐ Native Hawaiian or Pacific Islander  ☐ White  ☐ Other __________

D. Are you Hispanic or Latino/a?

☐ Yes  ☐ No

E. What is the highest year in school that you have successfully completed? __________

F. What is your intended major in college? __________________________

Section B

G. Would you like a photocopy of the design solutions you created in this session returned to you?

☐ No thanks. I don’t need a copy.  ☐ Yes, please make a photocopy for me.

H. We would like to use the ideas you generated to help us improve engineering education. Do you want your designs to be included in a research study on how engineering students generate design ideas (your real name will be removed from the sheets and never be used)?

☐ Yes, I am happy to help with research to improve engineering education.  ☐ No, I do not want my work to be included as part of research.

When you have completed this reflection survey, please make sure your idea sheets are stacked in order (Idea #1 on top), with the design task description on top, and then place this reflection survey on the bottom of that stack. Please put the entire stack back in the folder provided.

Page 5 – You’re done! Thank you.
Appendix E

Quality coding training document

Quality Metrics Training Document
Ideation Flexibility

Nicholas Giltrow
Kevin Helm
Cavin Israel
Peiquan Lin
Ajia Liu
Valery Pascoe
Rafael Suero
Wesley Teerlink
Introduction
Generating high quality ideas is vital to any design process. When assessing the quality of ideas, lots of questions come to mind. Does the idea make sense? Is it feasible? Does it solve the stated problem? In more general terms, is the idea useful? Cady and Valentine define the idea quality as the degree to which an idea that fills a need or solves a problem can be successfully adopted by an organization (Cady and Valentine 1999).

Dean defines quality ideas as having three characteristics: workable, relevant, and specific (Dean et al. 2006). Each of these dimensions of quality has at least two sub-dimensions. The sub-dimensions are graded on either a three or four-point scale and are meant to relate directly to the usefulness of an idea without regard to its novelty.

The contents of this document were developed while applying the metrics to over 1000 ideas. The document should be used to train individuals to evaluate the dimensions of quality reliably as well as serve as a reference for difficult cases. For all training, a two-coder system should be used to ensure reliability. Once the two coders have reached an acceptable inter-rater reliability, greater than 0.7 Cronbach alpha score on a sample of 50+ ideas, a single coder may be used for the remainder of the coding. Alternatively, a single coder can use data previously assessed by a trained coder to establish reliability.

Training
The coder needs to orient themself to the sub-dimension of idea quality they are attempting to evaluate so as to ensure reliable, repeatable results. There will always be a level of personal opinion involved in idea evaluation but the goal of training coders is to limit the effect of differing personal opinions between different coders. This document will help a coder learn to apply each metric in a similar way it has been applied to previously evaluated ideas.

Below are the training steps that a coder must take before being allowed to evaluate a new data set:

1. Become familiar with the problem context
2. Study the metric definition, rubric, and examples
3. Evaluate a previously coded set of ideas (50+)
4. Determine the inter-rater reliability score, Cronbach alpha
   a. If alpha ≥ 0.7, then training is complete
   b. If alpha < 0.7, then continue to step 5
5. Find and correct and patterns of coding discrepancies and repeat steps 1-4

Problem Contexts
It is vital to understand the problem contexts thoroughly before attempting to evaluate ideas. Upon the first read through, the problem contexts will appear really straightforward. However, when evaluating the ideas you will quickly find that some of the participants in the study understood the problem context in different ways. The four different problem contexts are described in the following sections.
**Low-Skill Snow Transporter Context**

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.

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

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.

**Task:** Design a way for individuals to transport themselves on snow.

**Constraints:** Little skill and experience, uphill/downhill, steering/braking

**Environment:** Rugged outdoor environments

**Stakeholders:** Users

---

**One-Hand Opener for Lidded Food Containers Context**

The local rehabilitation center helps to treat thousands of stroke patients each year. Many individuals who have had a stroke are unable to perform bilateral tasks, meaning they have limited or no use of one upper extremity (arm/shoulder). A common issue the hospital has observed with their stroke patients is in their ability to open jars and other lidded food containers. The ability to open lidded food containers is particularly important for patients who are living on their own, in which case they often don’t have help around for even basic tasks. A solution to helping them open lidded food containers with one hand would go along way in helping the patients to maintain their independence.

Design a way for individuals who have limited or no use of one upper extremity to open a lidded food container with one hand.

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.

**Task:** Design a way for individuals to open a lidded container.

**Constraints:** Require only one hand
Public Place Belonging Securer Context

Working in coffee shops and public places has become a common occurrence. Sometimes, however, it becomes necessary to step away for short periods of time to take a phone call or use the restroom. Once a workspace has been set up, it can be very inconvenient to pack it all away for these short absences. However, there is a danger of theft when leaving items in public places.

Design a way for someone to secure several of his or her belongings in a public area to prevent theft quickly without disrupting the space.

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.

Task: Design a way for someone to secure belongings to prevent theft
Constraints: Quickly, without disrupting the space
Environment: Public area
Stakeholders: Customers, storeowners, store employees

Remote Village Rainwater Catcher Context

In remote villages throughout many rural, underdeveloped areas of the world, easy access to fresh clean drinking water is very limited. Villagers must often walk long distances to a fresh water source, collect the water in large, awkward bins, and then carry the water back uphill to their home. Retrieving the fresh drinking water in this manner takes tremendous amounts of time and effort. In many cases, however, rainwater is a fresh and abundant source of water, but there are no solutions for effectively capturing, storing, and distributing the water.

Design a way for remote villagers to catch, store, and access rainwater.

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.

Task: Design a way villagers to catch, store and access rainwater
Constraints: Easier/faster than walking long distance to carry back in bins
Environment: Remote/rural areas

Quality
Relevance
An idea must apply to the given problem context to be considered useful. In other studies this has been called appropriateness (Durand and VanHuss 1992), effectiveness (Kramer, Kuo, and Dailey 1997; Valacich, Dennis, and Nunamaker 1992), importance (Valacich, Dennis, and Nunamaker 1992), and usefulness (Easton, Easton, and Belch 2003). Dean et al. elegantly separated these into the two sub-dimensions of effectiveness and applicability. The authors defined effectiveness as the degree to which the idea will solve the problem and applicability as the degree to which the idea clearly applies to the stated problem (Dean et al. 2006). These definitions are designed to allow the relevance dimension of quality, the sum of effectiveness and applicability, to remain independent from the workability of an idea.

Effectiveness
Effectiveness is defined as the degree to which the idea will solve the problem.

Many problem statements can be broken down into sub-problems. Effectiveness is how well the idea solves all aspects of the problem statement. In coding an idea solution, the coder first has to assume that the idea will work (no matter how extreme the idea). After assuming the idea will work, the coder also has to take into consideration the reasonability of the given solution. Reasonability was based on whether the idea was logical to solve the given problem. An idea that did not modify or did not modify in an effective way was given the lowest score. For instance, a snowboard with added foot grips did not effectively modify the snowboard so that no prior snowboarding skill was required.

<table>
<thead>
<tr>
<th>Effectiveness</th>
<th>Level Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Score</td>
<td>Level Description</td>
</tr>
<tr>
<td>4</td>
<td>Reasonable and will solve the stated problem without regard for workability (if you could do it, it would solve the main problem)</td>
</tr>
<tr>
<td>3</td>
<td>Reasonable and will contribute to the solution of the problem (It helps, but is only a partial solution)</td>
</tr>
<tr>
<td>2</td>
<td>Unreasonable or unlikely to solve the problem (it probably will not work)</td>
</tr>
<tr>
<td>1</td>
<td>Solves an unrelated problem (it would not work, even if you could do it)</td>
</tr>
</tbody>
</table>
**Snow Transporter Coding Protocol**

If the idea does not offer/involve a means or way of transportation\(^1\) alternative to basic snowboarding and skiing\(^2\)

Grade 1, Stop

Else,

Decide if the idea is similar enough to snowboarding/skiing that the user still requires skills associated with snowboarding/skiing.

If so,

Grade 2, Stop

Else,

Decide if the idea is otherwise unreasonable/unlikely to provide/allow/enable transportation

If so,

Grade 2, Stop

Else,

Decide if secondary criteria are met:

- Works both uphill/downhill\(^3\)
- Has control\(^4\)

If 1 or more criteria are unsatisfied

Grade 3, Stop

If all criteria are satisfied

Grade 4, Stop
Snow Transporter Examples

Treads imply uphill/downhill transportation
Control: steering directly drawn and braking implied through description
Skill differs from snowboarding/skiing
Provides transportation in snowy conditions
Reasonably addresses problem statement

Drawing:

Description:
Current snowmobile, uses tread for traction/push via motor, skis in front steer w/ easy to learn motorcycle like controls, windshield protects rider from wind, comfy seat, storage in the rear below.
3
Works uphill/downhill
Skill differs from skiing/ snowboarding
Reasonably addresses problem
But does not address anything about controlling

**Description:** SLED + GRAPPLING HOOK w/WINCH

**Idea Description:** Describe the solution idea. How does it work? What are the features, mechanisms, and details?
Effectiveness

Skill differs from skiing/ snowboarding
But unreasonable to solve the problem because there's no difference to walk on the snow

Bubble travel system: You travel in a bubble. The
Skill same as skiing
Does not meet requirement from the statement.

Description:
"THEY ARE BASICALLY A BOOT WITH ATTACHED MINI SKIS. SINCE THEY ARE SMALLER AND DIRECTLY ON YOUR BODY, THEY SHOULDN'T ALLOW YOU TO TRAVEL AS FAST, BUT WILL GIVE YOU MORE CONTROL ENHANCING SAFETY AND MAKING THEM MORE USER FRIENDLY. THERE IS ALSO A HEAL SPIKE FOR A BREAK."
*Jar Opener Coding Protocol*

Does not improve that of a standard can opener or lid opening mechanism

Grade 1, Stop

Else,

Decide if idea is otherwise unreasonable/ unlikely to provide/ allow/ enable opening of can/jar. (Does opening apply to specific type of lidded container)

If so,

Grade 2, Stop

Else,

Decide if criteria are met:

- Open a lid/can with 1 or fewer extremities
- Open a lid with little exertion (mechanical advantage)

If 1 of above criteria are met:

Grade 3, Stop

If all criteria satisfied

Grade 4, Stop
**Jar Opener Examples**

4

Improve of standard can opener (defined in the rubrics)

Only use one hand

Open lid with little exertion- because its mechanism

**Description:**

"A JAR OPENER THAT OPERATES ELECTRICALLY. THE UNOPEN JAR OR CONTAINER IS PLACED UNDER THE HOOD. THE MACHINE THEN CINCHES DOWN MUCH LIKE A CHUCK ON AN ELECTRIC DRILL. ONCE OPENED, THE JAR THEN DROPS ONTO THE MAT. WHEN THE USER WANTS THE TOP PUT BACK ON THE JAR IS AGAIN PLACED UNDERNEATH AND THE TOP IS PUT BACK AS IT WAS."
3
Improve of standard can opener
Only use one hand
But needs normal exertion--- because it only hold the top of jar

Code ID: 0006
Problem Context: Jar Opener

Description:
Place top of container into holster at top. Holster holds lid while container can be twisted. Adjustable size of holster and a release for the lid.
Unreasonable to solve the problem.
It needs two hands although it improves from the standard can/jar opener.
It breaks the jar or can

**Idea Drawing:** Sketch your solution idea in the box below.

Description:

sledge hammer
**Belonging Securer Coding Protocol**

Does not offer alternative to storing items in public

Grade 1, Stop

Else,

Decide if idea is otherwise unreasonable/ unlikely to provide/ allow/ enable storing of items.

If so,

Grade 2, Stop

Else,

Decide if criteria are met:

- Mechanism is secure
- Idea can store multiple items
- Mechanism quickly secures belongings
- Mechanism does not disrupt work space

If 1 of above criteria are met:

Grade 3, Stop

If all criteria satisfied

Grade 4, Stop

1Secure: free from risk of theft
Belonging Securer Examples

4

It is secure
Idea can store multiple items
Secures in short time-easy to be use
Does not disrupt work space---do not move anything while you leave

Description:

Table dome: A small dome will incase your table with your belongs till you return.
3
It is secure and can store multiple items
And it secures in short time
But needs move stuffs to the drawer-disrupt work space

Description:

It is a drawer under a table with electronic locks. The user just has to place all of his/her belongings in the drawer and set a 4-digit pin code. Mechanism - slider for the drawer and an electronic lock.
2
Unreasonable to solve the problem—the alarm only to warning the thief, do not have anything to protect the personal stuffs

Description:

A motion sensored alarm system so that if anyone came in a few inches of the stand it would go off. This device could be turned on/off.
Description:

Have employees carry a handy bag that carries their personal items in case they need to step away from their shift to make a phonecall.
Rainwater Catcher Coding Protocol

Does not offer alternative to standard rain collection\(^1\)

Grade 1, Stop

Else,

Decide if idea is otherwise unreasonable/ unlikely to provide/ allow/ enable the collection of water

If so,

Grade 2, Stop

Else,

Decide if criteria are met:

- Captures rainwater
- Store rainwater
- Distribute/access rainwater easily

If 1 of above criteria are met:

Grade 3, Stop

If all criteria satisfied

Grade 4, Stop

\(^1\)Standard- long distance walk, bins, carry uphill
Rainwater Catcher Examples

4
Captures rainwater
Store rainwater
Distribute/ access rainwater easily—send water into the house.

Description:

"Rain lands on root, runs of slant into gutter, which then flows water down into funnel. Funnel sends water down into storage tank. The water is accessed by a well that leads directly into the home. The well has multiple buckets to fetch water."
3
It can capture rainwater and store rainwater
But it does not have any function to distribute/ access water (people could not access water in a easy way)

**Idea Drawing:** Sketch your solution idea in the box below.

Description:

Simple rain barrel with a thin screen to prevent things falling in it.
2
Unreasonable to solve the problem
Sponge cannot capture water well and take a lot of labor force to get water

Description:

*GIANT SPONGE!!! *Sits on platform *Squeeze to dispense water *Casters for mobility
No way to store water and capture water

**Description:**

Dig a big whole in the ground
## Applicability

The degree to which the idea clearly applies to the stated problem

<table>
<thead>
<tr>
<th>Score</th>
<th>Level Description</th>
<th>Snow Transporter</th>
<th>Jar Opener</th>
<th>Belonging Securer</th>
<th>Rainwater Catcher</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Solves an identified problem that is directly related to the stated problem (do X to get Y, and Y is part of the stated problem)</td>
<td>• Provide power to allow uphill skiing  • Provide steering or breaking to a sled</td>
<td>• Fix jar to stationary surface  • Automate the process</td>
<td>• Provide locking mechanisms</td>
<td>• Allow capture of rainwater  • Allow distribution of rainwater</td>
</tr>
<tr>
<td>3</td>
<td>Solves an implied problem that is related to the stated problem (do X to get an implied Y, which applies to the stated problem)</td>
<td>• Make skiing less difficult for beginners  • Alter snow conditions to allow transportation</td>
<td>• Make it easier to grip jar  • Increase leverage or work advantage</td>
<td>• Devices that deter (not secure)</td>
<td>• Store water in long-term containers</td>
</tr>
<tr>
<td>2</td>
<td>May have some benefit within a special situation and somehow relates to the stated problem (do X, which somehow relates to the stated problem)</td>
<td>• Enable either skiing or sledding using the same device  • Make carrying a ski or snowboard easier</td>
<td>• Call service to open jar  • Opens only certain type of jar</td>
<td>• Provide surveillance</td>
<td>• Purify water</td>
</tr>
<tr>
<td>1</td>
<td>Intervention is not stated or does not produce a useful outcome (no X) or (do X for useless Y)</td>
<td>• May involve snow but not transportation  • Does not provide an alternative to snowboarding/skiing</td>
<td>• Does not involve opening food containers or jars</td>
<td>• Does not refer to securing or protecting belongings</td>
<td>• Does not refer to rainwater</td>
</tr>
</tbody>
</table>
Snow Transporter Examples

4

This idea receives a 4 for applicability because it solves the stated problem.

Description:

"A specially designed bicycle with 4.5 tires, dish brakes, and super low gearing for off road mobility I work in a bike shop and know this is possible"
This idea receives a 3 for applicability because it solves the implied problem that skiing/snowboarding is difficult without training, rather than the stated problem.

Description:

This design is intended to be held by the person who is a first time skier/snowboard & is used to add stability. The poles extend all the way to the snow as an extra pair of skis. They can also be used as stability when climbing back up the snow.
2
This idea receives a 2 for applicability because it enables switching between skiing and a toboggan, where the toboggan is a partial solution to the problem, and therefore only partially relates to the problem.

**Description:**

SKIS WITH RUNNERS THAT FIT TOGETHER TO MAKE TOBOGGAN
This idea receives a 1 for applicability because it does not provide a useful outcome. All it does is enable switching between skiing and snowboarding, which is not useful in the context of the problem.

Description:

Skis that can transform into a snow board the boot hole slide in place and the two skis come apart to become skis or become a snow board
Description:

"Jar goes into place, lid gets sealed and twist to open jar"
Description:

"Individual dish size - when microwaved, top expands/increases size, pops off easy (HEATED) - when put in fridge/freezer/cooler topshrinks to container making seal"
Problem Context: Jar Opener

Description:

Rubber pads for vice grips
Description:

gripping gloves
Belonging Secure Examples

4

This idea receives a 4 for applicability because it solves the stated problem.

Description:

If person leaves they can quickly shove all there things into a box that is secured to the floor. The box would lock and have a key. It would be located at the end of every table.
This idea receives a 3 for applicability because it solves the implied issue of deterring theft, not preventing it.

Description:

Use a screen to hide the products quickly.
This idea receives a 2 for applicability because it only solves the problem for a laptop, which is a particular scenario.

Description:

A holographic tiger reacts to movements around it. No one will mess with a tiger.
This idea receives a 1 for applicability because it does not solve the problem.

Description:

"A GPS detector. People can put the GPS detector to items, so no matter where the items go, you still can find it"
**Rain Catcher Examples**

4

This idea receives a 4 for applicability because it solves the stated problem.

**Description:**

WE COULD EVEN PUT A SMALL TURBINE INTO THE SYSTEM DURING RAINY TIMES. THIS COULD PRODUCE POWER FOR THE HOME AND THEY COULD EVEN SELL THE ENERGY.
This idea receives a 3 for applicability because it solves the implied problem of getting water to an individual by catching rainwater, but does not solve the stated problem.

**Description:**

Water hat that catches water and has straw for person to drink from
2
This idea receives a 2 for applicability because it solves an implied problem of getting water to the village, but only when there is a water source near enough to construct the suggested device, which is a particular scenario.

**Description:**

"Bucket conveyor. a string of buckets is connected from the water to the village, and motor or several people hoist the buckets from the water to the village."
No example
There were no ideas that received a 1 for applicability within our samples. However, a 1 would look like something that solves a problem that is unrelated to the stated problem.
Workability

Whether or not an idea is workable has both physical and social dependencies. Evaluating ideas based on physical feasibility has been used by many different authors (Plucker, Beghetto, and Dow 2004; MacCrimmon and Wagner 1994; Wagner 1996; McLeod, Lobel, and Cox 1996). Briggs et al. used a measure of ease of implementability to correspond to the feasibility of an idea (Briggs et al. 1997). This approach is effective because it easily allows for financial considerations not just technical feasibility.

Though an idea may be physically feasible to carry out, an idea must also be socially acceptable. Unacceptable ideas are unlikely to be adopted by organization as solutions therefore according to Cady’s definition they cannot be high quality. Also, Plucker emphasizes the importance of assessing the usefulness within a social context (Plucker, Beghetto, and Dow 2004).

<table>
<thead>
<tr>
<th>Implementability</th>
<th>Score</th>
<th>Level Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Low cost. No change to accommodate product</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Reasonable cost. Some change necessary for product</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Very expensive. Significant change necessary for product</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Financially unviable. Unachievable changes need to be made.</td>
<td></td>
</tr>
</tbody>
</table>
"Everyone wears a shoe, and they don't fall wearing one. Basically, they are used to the idea of wearing shoes. My design here is a shoeboard, as for beginners, this gives a feel like they are wearing a shoe, and it doesn't weigh them down. Light and easy to maneuver"
Description:

Fan boat or sled with attached manual braking system
Description:

Jet powered snowboard - has gas & break on handle bars also used to steady the driver
Description:

Hover-board Propel yourself/brake with ice picks
Description:

"use electricity to help up the cap, the cap expands and the person can easily open the jar. (might need gloves) (cap would need to be conductive)"
Description:

one solution to the lid idea could be to create a lid with a button that pops the lid not the jar open. The lid could then be pushed down easily and clicky/lock shut. This could all be done very easily with one hand.
Description:

a magnet yanks metal lid off of can
**Problem Context:** Jar Opener

**Description:**

"ROBOT MAID. DOES ALL THE WORK FOR YOU. TOWNSIDE, IS A ROBOT, POSSIBLY UP YOU. ... (THROW)"

**Idea Drawing:** Sketch your solution idea in the box below.
**Belonging Securer Examples**

4

Description:

Drop box the short absences. Employees Know code for box. Keeps belongings out of public space.
Description:

Barcodes on items triggers scanners for stolen goods and belongings. Simply requires barcodes on belongings
"The solution uses goo to lock the items in place. The goo is simply dropped onto the items to hold them in place. It is made of such a material that it doesn't damage the items, but is dissolved into a harmless gas when the user comes back and pours the opening agent on it."
Description:

Electromagnetic Force field that the user can turn on and off using some sort of remote
Rain Catcher Examples

Description:

Rain water runoff from the roof can be channel and collected in a tank.
Description:

"A funnel set above the ground with a wide diameter catches incoming rain. The rain goes down the funnel into an underground tank. A well is used to bring the water up from the tank for use. The well functions with two pulleys at the top and bottom, with multiple buckets placed on the line."
"Rain falls in the tree then while it is raining a tree vibrator machine comes and shakes off rain from leaves, then falls into a large storage tank. May have a filter attached to the funnel to separate leaves & chemicals"
Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

Water falls down dome and collects in moat.
## Acceptability

<table>
<thead>
<tr>
<th>Score</th>
<th>Level Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Common strategies that do not violate norms or sensibilities</td>
</tr>
<tr>
<td>3</td>
<td>Somewhat uncommon or unusual strategies that do not offend sensibilities</td>
</tr>
<tr>
<td>2</td>
<td>Offends sensibilities or totally unaccepted by society</td>
</tr>
<tr>
<td>1</td>
<td>Radically violates laws or sensibilities. Totally unacceptable business practice or totally unethical.</td>
</tr>
</tbody>
</table>
Description:

something you could toggle to brake the ski's
Description:

like a car -has a belt that can be brought out to help uphill -peddle on inside to function -easy to pull rope attached -light -steering wheel and brake to steer and brake -push on snow slowly brake is lowered when pushed to slow down
"These books have some sort of chemical/mechanical device to produce heat, enough to melt the snow under your feet. In shallow enough snow, this could allow you to travel faster both up and down hill."
Fire lawnmower: You walk behind a machine that melts the snow in front of you using fire.
Idea Drawing: Sketch your solution idea in the box below.

Description:

Place top of container into holster at top. Holster holds lid while container can be twisted. Adjustable size of holster and a release for the lid.
Description:

"In the case of cans, lids sometimes need to be cut off. A can opener that attaches to the can after puncturing, then being able to twist it with one hand."
"use electricity to help up the cap, the cap expands and the person can easily open the jar. (might need gloves) (cap would need to be conductive)"
Description:

It's a Hammer! It breaks the jar and allows you to get the contents. Readily available
When you go into the cafe you get a key to whatever table you are at and thus able to lock your stuff in the locker on the table.
Description:

Allow restroom or breakroom to see into public with one way glass.
Description:

Have tables that require a code to be entered to lower if from ceiling. If you need to walk away raise the table. When you come back enter code again and table will lower.
Description:

"A cord would be on a reel in the wall in a booth. the end of the cord is a laptop lock, which most all current laptops have a receiver for. Midway on the cord is a small padlock, which could be used to hold two zippers together on a backpack or briefcase. This device would be small & there could be one per side of a booth."
Description:

Rain water runoff from the roof can be channel and collected in a tank.
Description:

SINGLE HOME CATCHING SYSTEM. COLLECTS RUNOFF FROM ROOF AS WELL AS SOME RAINFALL. PASSES THROUGH A FILTERING SYSTEM & INTO STORAGE TANK. USES MESH COVERS TO KEEP OUT LARGE DEBRIS.
"Rain falls in the tree then while it is raining a tree vibrator machine comes and shakes off rain from leaves, then falls into a large storage tank. May have a filter attached to the funnel to separate leaves & chemicals"
Description:

A trough to collect rainwater would feed into easy distribute containers. A villager would attend the structure and change out containers when necessary.
Specificity
The final dimension of quality has more to do with the quality of the work than the quality of the concept. Though an idea might be workable, and relevant, the U.S. patent office requires new patent ideas to be clear, detailed, and complete (Jones 1971). These terms seem to refer to quality of communication but it stands to reason that if an idea cannot be communicated in an understandable way it is not a useful idea. Besemer and O’Quin expand this dimension of quality into the area of product analysis by measuring elaboration and synthesis. Products with good elaboration and synthesis are described as being organic, elegant, complex, understandable, and well crafted (Besemer and O’Quin 1987). Though these measures were used in the final product analysis, to some extent they are still applicable to the ideation phase of design. Dean et al. compile these into a dimension of quality called specificity with three sub-dimensions: clarity, completeness, and implication-explicitness. However, clarity is not considered in the author’s analysis due to low inter-rater reliability (Dean et al. 2006).

Clarity
The degree to which the idea is clearly communicated with regard to grammar and word usage (Dean et al. 2006).

It is important to remember when coding, clarity evaluates how well the design is conveyed to the coder with respect to grammar and word usage. The coder is not concerned with the feasibility of the idea. The coder is concerned with the purpose and idea behind the design but is not necessarily concerned with how the idea works. Clarity only defines how clear an idea is in terms of grammar and sentence structure. While coding, refrain from looking at the picture drawn by the designer. Seeing the picture might cause the coder to believe they understand the idea clearly even if the description is vague and incomplete.

To receive a score of 3 of clarity, the entire description must contain complete sentences. The description must be well written and understood completely so as to paint a vivid picture for the coder.

To receive a score of 2 of clarity, the description may contain sentence fragments. The idea might not be as clear as possible because of average descriptions. The coder might have some small questions about the design.

To receive a score of 1 of clarity, a description must use ambiguous words. The description generally contains only a few vague words or has extremely poor sentence structure. From the description alone, the coder is not able to visualize the design. Listing idea attributes would be given a 1.

Coding clarity is not context specific. As a coder, you should be able to take the same evaluation style and apply it across all problem contexts.
<table>
<thead>
<tr>
<th>Score</th>
<th>Level Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Well-developed written description or visual representation. The components are clear and commonly understood</td>
</tr>
<tr>
<td>2</td>
<td>Understandable but some of the descriptions or drawings might not be commonly understood. Contains fragments or obviously missing components to make the concept clear</td>
</tr>
<tr>
<td>1</td>
<td>Written description and drawing are vague/ambiguous. Difficult to understand.</td>
</tr>
</tbody>
</table>
"A pedal operated vehicle repeatedly uses a sharp rear tool to dig into ice/snow and then push off, taking tool out of ice with momentum. Only flat areas."
Description:

Jet powered snowboard - has gas & break on handle bars
also used to steady the driver
Description:

Crank a gear to turn a wheel on bottom of board to go up hill
Description:

Place top of container into holster at top. Holster holds lid while container can be twisted. Adjustable size of holster and a release for the lid.
Description:

a magnet yanks metal lid off of can
Description:

This design is a set which can open jars or added square containers. A quick change out of 1 piece allow for this suction cup attaches to counter.
Belonging Securer Examples

Description:

When you go into the cafe you get a key to whatever table you are at and thus able to lock your stuff in the locker on the table.
Description:

Have inventory numbers on packaged (stealable goods)
Idea Drawing: Sketch your solution idea in the box below.

Description:

--blank--
Find nearby basin where rain water already collects & pools & build an aqueduct system similar to Roman structures. Have it flow into a large storage tank.
Description:

roof & gatters painted with a special material so that rain water does not get containimated. Water down gutter into a bin on a cart of easy transportation
Description:

funnel + 5 gallon bucket
Implicational Explicitness

The degree to which there is a clear relationship between the recommended action and the expected outcome (Dean et al. 2006).

Implicational explicitness refers to actions and outcomes. When coding, it is helpful to keep in mind, “Do ‘X’ so that ‘Y’,” or “‘X’ results in ‘Y’.” If you find that a description contains an ‘X’ and a ‘Y’, there is implicational explicitness. How clear the relationship between the two are what will determine the score. Throughout descriptions, you may find several instances where multiple implications result in multiple actions. In these cases, determine the strongest and clearest relationship and score based on that single relationship.

It is important to note that the design prompt asks people to design a device for snow transportation. If a description uses a variation of this phrase, know that no new information is delivered in the description. We already assume that the person will design a device for snow transportation. In these cases, the score for implicational explicitness is 1 because of redundancy.

The general formula for finding an X and Y relationship is as follows:

- X: Design a device… (action)
- Y: For snow transportation… (recommended outcome)

However, implicational explicitness has no limiting factor on how specific the action and outcome are. It does not need to be a broad action and outcome relationship that encompasses the objective of the design. The relationship can have any degree of specificity so long as it is clear to the coder.

It is also important to note that the design prompt already asks people to design a device for snow transportation. If a description uses a variation of this phrase, know that no new information is delivered in the description. We already assume the person will design a device for snow transportation and, as a coder, do not use this general relationship. In these cases, the score for implicational explicitness is 1 because of redundancy.

Sometimes, you will notice a ‘Z’ component in the actions and outcomes. ‘Z’ can be recognized by phrases like:

- Z: So that… (descriptor)

A ‘Z’ phrase is just an added bonus to the ‘X and Y’ relationship. It is there to help explain or give a reason as to why the device will be designed. Ignore this component. It should not affect the score of the description. Remember that implicational explicitness only concerns itself with a recommended action (X) and an expected outcome (Y).

To receive a score of 3 of implicational explicitness, there must be a clearly stated action (X) and a clearly stated outcome (Y) with a very clearly stated relationship between the two.

To receive a score of 2 of implicational explicitness, the action (X) and outcome (Y) or one ot the other are stately vaguely and do not have a clear relationship.

To receive a score of 1 of implicational explicitness, either the action (X) or outcome (Y) are not stated and there is no clear relationship. Also, a redundant problem (explained earlier) that uses a variation of “Design a device for snow transportation,” should receive a 1.
Coding implicational explicitness is not context specific. As a coder, you should be able to take the same evaluation style and apply it across all problem contexts.

<table>
<thead>
<tr>
<th>Score</th>
<th>Level Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Implication is clearly state and makes sense ((X \Rightarrow Y))</td>
</tr>
<tr>
<td>2</td>
<td>Implication is not generally accepted or vaguely stated. ((X \text{ might} \Rightarrow Y, X \Rightarrow Y(\text{vague}))</td>
</tr>
<tr>
<td>1</td>
<td>Implication is not stated, even though it might be relevant ((X \text{ w/o } Y))</td>
</tr>
</tbody>
</table>

Implicational Explicitness
Description:

"larger, wider snowboard with many holes on the bottom - holes and larger surface area slows rider down for down hill - can be broken in two parts like large shoes to walk across plains and uphill like snow shoes."
Description:

"This design is similar to that of a snowboard, but includes wheels and a motor. When going downhill, the motor would not be needed. It is only needed when going uphill. There is a steering wheel to make driving easier."
Description:

"It is one these boats with a big fan on its back that is used to get around in scramps, however it is modified for snow"
**Description:**

This will be a rubber clamp that keeps the food container still while a person twists the lid off.
In the case of cans, lids sometimes need to be cut off. A can opener that attaches to the can after puncturing, then being able to twist it with one hand.
"This will be a belt that can hold the food container, acting as a second hand"
"The solution uses goo to lock the items in place. The goo is simply dropped onto the items to hold them in place. It is made of such a material that it doesn't damage the items, but is dissolved into a harmless gas when the user comes back and pours the opening agent on it."
Description:

Allow restroom or breakroom to see into public with one way glass.
Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

Assuming you are working near a fixed object,

Description:

"Assuming you are working near a fixed object, you could use a wire that attaches to the fixed object (e.g. table, desk, etc.) and then attaches to whatever you need to secure."
Rain Catcher Examples

Description:

Well at the bottom of the hill collects water. A windmill generates the energy needed to pump the water through a system of pipes and up the hill to the house.
Description:

"large storage bin with an open top collector. There is a mesh cover to keep the larger debris out & some sort of filter system to further clean the water. Depending on size, one can either be mounted over couple of homes or at the center of the village."
204

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

large, open top concrete storage pool. Rainwater is collected on outskirts of town and purified before use.
Completeness

The number of independent subcomponents into which the idea can be decomposed, and the breadth of coverage with regard to who, what, when, where, why, and how (Dean et al. 2006).

With the current definition and structure of completeness, this metric does not lead to reliable results between coders. Our difficulty arose from defining each category of completeness (who, what, when, where, why, how).

For example, the component of ‘what’ could possibly be defined as: What do you do? What does the design do? What is the design? What are the parts of the design?

Additionally, we had problems deciding when to count parts of the description. For example, if a part of the description is defined as a ‘what’, can it also be counted as a ‘how’, etc.? Should we count the same part of the description in multiple categories? Can we have more than one part of the description in each category?

In our work, we made the assumption that coding completeness is not context specific and we should be able to take the same evaluation style and apply it across all problem contexts.
Works Cited


Appendix F

Variety coding training document

Variety Metric Training Document
Ideation Flexibility

Nadine Geagea
Cavin Israel
Justin Roarty
Wesley Teerlink
# Table of Contents

**INTRODUCTION** .................................................................................................................. 209

**TRAINING PROCESS** ........................................................................................................... 209

**SNOW TRANSPORTER VARIETY CODING** ........................................................................... 210

**LOW-SKILL SNOW TRANSPORTER PROBLEM CONTEXT** .................................................. 210

**Contain User Function** ......................................................................................................... 210

**Operate Control Function** .................................................................................................... 223

**Transport User Function** ...................................................................................................... 239

**JAR OPENER VARIETY CODING** .......................................................................................... 257

**ONE-HAND OPENER FOR LIDDED FOOD CONTAINERS PROBLEM CONTEXT** ............... 257

**BELONGING SECURER VARIETY CODING** ......................................................................... 258

**PUBLIC PLACE BELONGING SECURER PROBLEM CONTEXT** .......................................... 258

**Secure Belongings Function** .................................................................................................. 258

**RAINWATER CATCHER VARIETY CODING** ....................................................................... 274

**REMOTE VILLAGE RAINWATER CATCHER PROBLEM CONTEXT** .................................... 274

**Collect Rainwater Function** .................................................................................................. 274

**Distribute Water Function** ................................................................................................... 288

**WORKS CITED** ..................................................................................................................... 303
Introduction
Variety is defined as the extent to which the design space is explored by the ideas generated and correlations have been found between design space exploration and quality of final solution (Dylla 1991). In the majority of pervious ideation studies variety is not measured directly, rather they use the number of unique ideas or quantity. While quantity seems to be related to the amount of the design space that is explored, more information is needed when comparing idea sets of the same number of ideas.

Shah et al. purposed a hierarchal tree method for evaluating ideation variety (Shah, Vargas-Hernandez, and Smith 2003). In this method each idea falls into a categorization tree that has four levels: physical principle, working principle, embodiment, and detail. Once several ideas have been categorized into the tree’s structure the ideas can be compared by looking at the level at which the ideas differ. Ideas that differ at the physical principle level are considered to be the most different and are given more weight than differences at the detail level. Nelson et al. purposed calculating the variety score of an idea set by assigning specific weights to differentiations at each level of the hierarchal tree then summing the total of the weighted differentiations (Nelson et al. 2009).

To categorize an idea, a trained coder will look at an idea, read the idea description, and then they determine the category that best describes how the solution achieves the given function. In cases where the idea does not address the stated function a “0” code can be given.

Training Process
The variety tree coding method is essentially a categorization task. Therefore, as the coder becomes acquainted with the problem context and function description they must also learn how to differentiate between each branch of the given tree. There will always be a level of personal opinion involved in idea evaluation but the goal of training coders is to limit the effect of differing personal opinions between different coders. This document will help a coder learn to apply each metric in a similar way it has been applied to previously evaluated ideas.

Below are the training steps that a coder must take before being allowed to evaluate a new data set:

1. Become familiar with the problem context
2. Study the function definition, variety tree and examples
3. Evaluate a previously coded set of ideas (50+)
4. Determine the inter-rater reliability score, Cronbach alpha
   a. If alpha ≥ 0.7, then training is complete
   b. If alpha < 0.7, then continue to step 5
5. Find and correct and patterns of coding discrepancies and repeat steps 1-4
Snow Transporter Variety Coding

Low-Skill Snow Transporter Problem Context

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.

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

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.

Task: Design a way for individuals to transport themselves on snow.
Constraints: Little skill and experience, uphill/downhill, steering/braking
Environment: Rugged outdoor environments
Stakeholders: Users
Functions: Contain User, Operate Control, and Transport User

Contain User Function
The Contain User tree is meant to determine how the user fits into the device or how the device fits onto the user. Therefore, to deduce a code the coder should think of the most comfortable way/easiest position at which the user could operate the device.
The physical principle and working principle branchers:
• Carry or Ride – For any solution where the user is either carried by or rides in the proposed device.
  o The distinctions at the working principle branches have primarily to do with the way the body is positioned during transport. Seated, standing, or laying down.
• Attach to User – For solutions that physically attach to the user
  o There are no distinctions at the working principle level
1) Active Seat
DeID-IS-P0258-H-1A-I02 (Sample 9) 552

Physical Principle “Carry or Ride” and Working Principle “Place to Sit”

“Active Seats” are places to sit that involve some sort of work from the user. In the example below the user is positioned in a way that allows them to pedal the bike.

![Diagram of bike mobile with ski]

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

Description:

"Bike mobile, have a track for the back wheel and use a bike frame and replace front wheel with ski."
2) Floor Seat

Physical Principle “Carry or Ride” and Working Principle “Place to Sit
A “Floor Seat” means that the user is seated low with the legs in front of them. In the example below the user sits in a tube, the most natural position would be for the user to sit in the hole with their legs out in front of them making this a “Floor Seat.”

Description:

It's a snow tube with jetpack on each side. Jetpack will supply the power and control the direction.
3) Relaxed Seat

DeID-IS-P0436-N-1A-I03 (Sample 19) 572
Physical Principle “Carry or Ride” and Working Principle “Place to Sit”
A “Relaxed Seat” means that the user is seated at a seat with an average height, comfortably. In the example below, the user would sit in the seat comfortably at an upright position, making this a “Relaxed Seat”.

Description:

A car with snow tires or heavy gripped tires would be an easy way to travel in snow. It would be powered by an engine that was fueled by gasoline. The tires would grip the snow and the user would still have control over direction and braking.
4) Kneel
Physical Principle “Carry or Ride” and Working Principle “Place to Sit”
“Kneel” means for the optimal use of the device requires the user to be bent down on their knees. In the example below, the user must bend down on their knees to optimally use the device the way it was designed.

Description:

"The solution idea is a knee-board. While comparable to the ones used in water, these will maintain more surfaced content to function like a snowboard. However, the kneeboard does not have to be stropped on your feet. It has handler to keep you mounted. Dragging snowshoe behind the board will serve as brakes. The rabbitiz to easily dismount will ? to ? uphill travel"
5) **Conveyor Belt**
Physical Principle “Carry or Ride” and Working Principle “Place to Stand”
“Conveyor Belt” would require the user to stand on top of it to be carried up to the destination. This is similar to a magic carpet ride as a ski/snowboard lift.
6) Platform
DeID-IS-P0266-H-1A-I03 (Sample 9)  783
Physical Principle “Carry or Ride” and Working Principle “Place to Stand”
“Platform” requires the user to stand on a platform to operate the device. The example below needs the user to grip the handlebars, by means of standing on the platform; therefore this classifies as a “Platform”.

![Diagram of Tracked Segway]

**Idea Description:** Describe the solution idea. How does it work? What are the features, mechanisms, and details?

**Description:**

**Tracked segway**
7) (Place to Lie)
Physical Principle “Carry or Ride” and Working Principle “Place to Lie”
“Place to Lie” requires the user to be in a laying down position to operate the device as intended. In the example below, the user must lie down to ride the device down the hill, making this classify as a “Place to Lie”.

Description:

"user lays down in a safely protected area between the thread rollers, user can see via cameras in front + back out on the sides that project images on user's display to guide future movement."
8) Harness
DeID-IS-P0215-T-1A-I03 (Sample 8) 951
Physical Principle “Carry or Ride” and Working Principles “Harness”
A “Harness” requires the user to grab onto it to be able to be carried by the device. In the example below, the user must hold onto the harness to be pulled along by the device, making this classify as a “Harness”.

Description:
A motorized and tracked pull-along to help transport and train users to use snowboards and skis.
9) Hands
DeID-IS-P0247-N-1A-I02 (Sample 8) 503
Physical Principle “Attach to User” and Working Principle “Attach to User”
“Hands” needs the user to use their hands to usually get up/down a device. The example below is “Hands” because the user must pull themselves up by their hands.

Description:

This grappling hook-like device can be shot up the hill and then with the cinch mechanism you can pull yourself up the hill.
10) Feet
DeID-IS-P0247-N-1A-I03 (Sample 8) 283
Physical Principle “Attach to User” and Working Principle “Attach to User”
“Feet” calls for the user this device requires the use of the users feet to operate the device. The example below is “Feet” because the user must attached their feet to the device in order to use it.

**Description:**

Basically it a small motorized snowmobile-snowboard that can be split in two to make skis.
11) Other
DeID-IS-P0243-N-1A-I02 (Sample 8) 103
Physical Principle “Attach to User” and Working Principle “Attach to User”
“Other” classifies any device that needs to be attached to the user but not by their hands or
feet. The example below is “Other” because the device must be attached to the users back.

Idea Drawing: Sketch your solution idea in the box below.

Jetpack
Operate Control Function
The Operate Control tree is meant to analyze how the user has control over the device, if they even do. Therefore, the coder should try to think of the device in motion to think of how the user would operate/stop the device.
1) **Floor Pedals**

DeID-IS-P0258-H-1A-I02 (Sample 9)  552

Physical Principle “Electromechanical” and Working Principle “Push or Pull”

“Floor Pedals” requires the user to press floor pedals to operate the device.

**Description:**

"Bike mobile, have a track for the back wheel and use a bike frame and replace front wheel with ski."
2) Buttons
DeID-IS-P0299-N-1A-I03 (Sample 10) 354

Physical Principle “Electromechanical” and Working Principle “Push or Pull”
“Buttons” requires the use of buttons to operate the device. In the example below the user must operate the device with the control display, which includes buttons.

Description:

"user lays down in a safely protected area between the thread rollers, user can see via cameras in front + back out on the sides that project images on user's display to guide future movement."
3) Levers
DeID-IS-P0270-H-1A-I01 (Sample 9) 105
Physical Principle “Electromechanical” and Working Principle “Push or Pull”
“Levers” means the user must twist or push/pull the lever to operate the device. In the example below, the user would need to twist the bar to operate the device.

Description:
"Bar is on a pivot of 30, push it forward and twist forward for forward speed, opposite for reverse. --reason the bar tilts on a 30 degrees is so you can get enough torque. --Button on each side will slow tank tread down in order to steer."
4) Joystick

Physical Principle “Electromechanical” and Working Principle “Control”

“Joystick” requires the user to use a joystick to operate the device. In the example below, the user must use the joysticks to operate the device.

Description:

"Skiis with tracks going around the outside, powered by motors driving the roller wheels. Ski sticks help steer by applying carrying power to the motors."
5) Steering Wheel

DeID-IS-P0215-T- 1A-I01 (Sample 8) 676

Physical Principle “Electromechanical” and Working Principle
“Steering Wheel” would require the user to use a steering wheel to steer/operate the device.
The example below demonstrates that the user must use a steering wheel to operate the device.

Description:

"Basically, it's a snowcat the size of a quad bike. Either use this or a snowmobile to have fun."
6) Handle Bars
DeID-IS-P0217-N-1A-I01 (Sample 8) 723

Physical Principle “Electromechanical” and Working Principle “Control”
“Handlebars” requires the user to hold onto handlebars to control the device. The example below demonstrates this need of handlebars to operate the device.

Description:

"This design is a combination of like a snow mobile and a skateboard skater. Basically, the snow board will still serve as a platform for the user. However the user will operate it with his/her hands at the handlebars. The handle bars would have a brake and speed control on them The system would run off of a little electric rechargeable battery. This electrical charge would give power to a snow mobile like belt below the board."
7) **Leaning Sensors**

DeID-IS-P0215-T-1A-I02 (Sample 8)

Physical Principle “Electromechanical” and Working Principle “Control”

“Leaning Sensors” can detect when the user leans, which controls the device. In the example below, when the user leans forward, the leaning sensors will allow this to move the device forward.

_Idea Description_: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

"By mounting snow floatation tires filled with foam to a Segway, you can enjoy snow with a segway."
8) Legs

Physical Principle “Direct Control” and Working Principles “User”

“Legs” requires the user to use their legs to provide the driving force to move the device. In the example below, the user peddle with their feet to operate the device.

Description:

This is a bike with snow treads.
9) Shift Weight (Lean)
DeID-IS-P0250-H-1A-I05 (Sample 9)  583

Physical Principle “Direct Control” and Working Principle “User”
“Shift Weight” requires the user to shift their weight in order to make the device move. In the example below, the user must lean forward to move the device forward.

Description:

SKIS WITH RUNNERS THAT FIT TOGETHER TO MAKE TOBOGGAN
10) Hands
DeID-IS-P0217-N-1A-I02 (Sample 8)
Physical Principle “Direct Control” and Working Principle “User”
“Hands” requires the users to use their arms to control the device. In the example below, the user must ‘rustle’ the ski arms with their hands to operate the device.

**Description:**

"The ides is electric skis, run by an electric rechargeable battery and uppercted by the user with mouted arcloy ski arms. The arcloy arms are free to rotate so the user can rotate them to the direction he/she wants to go. Also, the arms have a push button device at the top for a speed pedal and a brake. Individual rollers below each ski, turned by the belly, allow the ski to move across the surface of"
11) Reins
DeID-IS-P0482-N-1A-I01 (Sample 14) 411
Physical Principle “Direct Control” and Working Principle “Animals”
“Reins” are used when the user must use reins to control an animal. The example below clearly demonstrates the user using reins to control the horse it is riding on.

**Description:**

You could ride a horse instead of walking yourself.
**12) Verbal**

Physical Principle “Direct Control” and Working Principle “Human Other”

“Verbal” requires the user to verbally communicate with a human other to move. The example below demonstrates this interdependence to operate the device.

Description:

A tandem like system that is installed by an expert. The rider is in back so completion of the moves without wheeling about control.
13) Predetermined Path

Physical Principle “No User Control” and Working Principle “Predetermined Path”

“Predetermined Path“ already has the path mapped out for the user. The example below is shows this because the user doesn’t have much input of where to go.

Description:

This grogpling hook-like device can be shot up the hill and then with the cinch mechanism you can pull yourself up the hill.
14) **Automated Path**

Physical Principle “No User Control” and Working Principle “Automated Path”

“Automated Path” classifies any device where the path is automated and the user is guided by that. The example below is “Automated Path” because the user is carried along the path of the tank.

![Diagram of a magic carpet with tank track rollers](image)

**Idea Description:** Describe the solution idea. How does it work? What are the features, mechanisms, and details?

This is a magic carpet with tank track rollers on it. It is user friendly because it knows where you want to go and it takes you there.
Transport User Function
The Transport User tree is meant to analyze how the device moves, or transports the user. Therefore, the coder should try to understand the means that allows the device to be relocated.
1) Skis
DeID-IS-P0233-N-1A-I01 (Sample 8)  488

Physical Principle “Sliding” and Working Principle “(Sliding)”
“Skis” requires the user to ride skis in order to be transported. The example below depicts
the use of skis.

Description:

Super-hydrophobic nano coating on the bottom to reduce friction magnetic bindings for easy removal
2) Snowboard
DeID-IS-P0243-N-1A-I01 (Sample 8)

Physical Principle “Sliding” and Working Principle “(Sliding)”
“Snowboard” requires the user to use a snowboard in order to be transported. In the example below, the user slides using a snowboard-type device.

Description:

"Stand on a board, turn handle to steer. Handle attached to main platform & side arms. Turning changes angle of side skis. ? pedal will use friction to stop or ? it to point with side skis inward. Foot powered like scooter/skateboard or use feet to stop."
3) Sled
DeID-IS-P0250-H-1A-I05 (Sample 9)  583
Physical Principle “Sliding” and Working Principle “(Sliding)”
“Sled” requires the user to use a sled to be transported. In the example below, the user
would need to use the device as a sled, i.e. by kneeling on it.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and
details?

SKIS WITH RUNNERS THAT FIT TOGETHER TO MAKE TOBOGGAN

Description:

SKIS WITH RUNNERS THAT FIT TOGETHER TO MAKE TOBOGGAN
4) Snow Shoes

Physical Principle “Gripping” and Working Principle “Walking”

“Snow Shoes” require the user to wear shoes that allow them to walk through the snow. The example below demonstrates this use of snowshoes.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

Snow board that snaps together in middle which when together is still as firm as a normal snow board but when separated act as snow shoes to help the person walk up the snow.
5) Other Feature
DeID-IS-P0247-N-1A-I01 (Sample 8) 307
Physical Principle “Gripping” and Working Principle “Walking”
“Other feature” is another gripping-walking feature that is not snowshoes. The example below demonstrates that the user can use the device in many different ways.

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

Description:
"basically, it's a small snowboard that breaks into 3 pieces with the foot pieces being at the end so you can use them as snow shoes or small skis and then the middle part can snap together with the end pieces to create a snowboard."
6) Hands
DeID-IS-P0258-H-1A-I01 (Sample 9) 699
Physical Principle “Gripping” and Working Principle “Pulling”
“Hands” requires the user to pull themselves along using their hands. The example below demonstrates the user needing to pull themselves up.

Description:

Tie rope between two trees and pull yourself up to the top while placed on a sled.
7) **Crank**

DeID-IS-P0280-H-1A-I03 (Sample 9)  423

Physical Principle “Gripping” and Working Principle “Pulling”

“Crank” requires the user to be guided along the path, while not directly pulling themselves up. In the example below, the user is pulls the user up (without the user directly pulling themselves up).

![Diagram of Crank](image)

**Description:**

Grappling hook shoots into object. Motor tries to recoil reel of cable. Recoil pulls snowboarder across snow.
8) Wheels
DeID-IS-P0279-N-1A-I05 (Sample 9) 663
Physical Principle “Rolling” and Working Principles “Moving Device”
“Wheels” is a device that moves by the means of wheels. In the example below, the device has wheels as a means of motion.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

bicycle with skis on it and the tires having sheets sticking out through front and back when pedaled the sheets dig into snow and pushes user along
9) Treads
DeID-IS-P0281-N-1A-I03 (Sample 9) 601
Physical Principle “Rolling” and Working Principles “Moving Device”
“Treads” means the device requires the use of treads to move. In the example below, the treads allow for the device to move.

Description:

Snow-cycle. The snow-cycle takes the simplicity and ease of a bike and translates that to snow. The snow cycle-cycle works just like a regular bike but has ties that can grip and navigate through snow. It works almost like a manual snowmobile
10) **Conveyor**

Physical Principle “Rolling” and Working Principle “Stationary Device”

“Conveyor” transports the user without them having to move. In the example below, the user must get themselves on these tracks, and then they will be moved by the means of the conveyor belt/ train track.

**Description:**

Build more trains
"This product is a steerable chair on skis. When going uphill, a kite can be used to pull the person"
12) Airplane
DeID-IS-P0514-N-1A-I05 (Sample 14) 111
Physical Principle “Air Pressure” and Working Principle “Gliding”
“Airplane” requires the user to be transported in an airplane-type device. The example demonstrates how the user must be in the airplane device to be moved through the air, to its’ final destination.

Description:

Why walk when you can fly.
13) Hovercraft

Physical Principle “Air Pressure” and Working Principle “Hovercraft”
“Hovercraft” would be a device that hovers above the surface. The example below shows that this device hovers above the surface, using air pressure.

Description:

"Discs provide shock absorption, motors push air out, like hover craft"
14) Helicopter

Physical Principle “Air Pressure” and Working Principle “Fan”

“Helicopter” requires the device to move by means of a fan that powers a rotorcraft.
15) Fan Boat

Physical Principle “Air Pressure” and Working Principle “Fan Boat”

“Fan Boat” means the device is mainly driven by a fan, as it is its’ only means of motion. The example below demonstrates how the device is powered by the air pressure that drives the fan, making this classify under “Fan Boat”.

Description:

Fan boat or sled with attached manual braking system
16) **Jet**

DeID-IS-P0244-N-1A-I02 (Sample 8) 654

Physical Principle “Air Pressure” and Working Principle “Propulsion”

“Jet” requires the use of propulsion to power the device. The example below classifies as a “Jet” because it employs the use of jet engines.

**Description:**

This snowboard has attached jet engines to propel the user whenever they want to go. There is also a brake system that is acclimated by pressing down on the rear binding. Jet engines are activated by pressing down on the front binding.

None
Jar Opener Variety Coding

One-Hand Opener for Lidded Food Containers Problem Context
The local rehabilitation center helps to treat thousands of stroke patients each year. Many individuals who have had a stroke are unable to perform bilateral tasks, meaning they have limited or no use of one upper extremity (arm/shoulder). A common issue the hospital has observed with their stroke patients is in their ability to open jars and other lidded food containers. The ability to open lidded food containers is particularly important for patients who are living on their own, in which case they often don’t have help around for even basic tasks. A solution to helping them open lidded food containers with one hand would go a long way in helping the patients to maintain their independence.

Design a way for individuals who have limited or no use of one upper extremity to open a lidded food container with one hand.

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.

**Task**: Design a way for individuals to open a lidded container.

**Constraints**: Require only one hand

**Environment**: Kitchen

**Stakeholders**: Disabled people, food manufacturers

**Functions**: Open Jar Function
Belonging Securer Variety Coding

Public Place Belonging Securer Problem Context

Working in coffee shops and public places has become a common occurrence. Sometimes, however, it becomes necessary to step away for short periods of time to take a phone call or use the restroom. Once a workspace has been set up, it can be very inconvenient to pack it all away for these short absences. However, there is a danger of theft when leaving items in public places.

Design a way for someone to secure several of his or her belongings in a public area to prevent theft quickly without disrupting the space.

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.

Task: Design a way for someone to secure belongings to prevent theft
Constraints: Quickly, without disrupting the space
Environment: Public area
Functions: Secure Belongings

Secure Belongings Function

The Belonging Securer tree is meant to analyze the way in which one’s belonging is being secured while the owner has momentarily walked away. Therefore, the coder should think of the specific way in which the object is being secured, if at all.

At the physical principle level the belongings securer tree is segmented into three branches. The “Physically Secure” branch is for ideas that make it physically difficult to remove the customer’s items from the area. The “Digitally Secure” branch is different in that these ideas use some sort of alarm to notify others that a theft has occurred. Therefore they are not necessarily physically secure but the electronic security system makes it secure. Finally, if the belonging is being held safe in a way that it is not literally secure, the “Not Secure” branch should be followed. These ideas usually involve either some sort of deception or they deter theft in some other way.

The working principle level of the tree comes next. After choosing an appropriate physical principle, a working principle must be chosen. This level of the tree is more specific and has more categories in which a certain idea can be placed in. For example, if an idea had a belonging being physically secure, you must now look at how the belonging is being physically secured i.e. locked.

The last level of the tree is the embodiment level. Examples of each embodiment code are given in the following section.
1.) Covering
DeID-IS-P0225-T-3A-I03 (Sample 8) 398
After looking at the Idea Drawing and reading the Idea Description, we can follow the tree down to Physically Secure. The description reads “latches & locks” so we can then move down the Locked branch. Finally, seeing the picture and reading “bubble,” we choose 1 Covering.

Description:

Retractable bubble the comes from the floor & covers entire workspace. Either latches & locks or makes it more noticable when someone is standing.
2.) **Compartment**
DeID-IS-P0223-N-3A-I01 (Sample 8) 373

After looking at the Idea Drawing and reading the Idea Description, we can follow the tree down to Physically Secure. The description reads “lock box” so we can then move down to the Locked branch. Finally, seeing the picture and reading “box,” we choose **2 Compartment**.

**Idea Drawing:** Sketch your solution idea in the box below.

![Idea Drawing Image]

**Idea Description:** Describe the solution idea. How does it work? What are the features, mechanisms, and details?

"Lock box mounted under table with key (like lockers @ water parks/pools) with laptop lock cable. You can throw your small valuables in the box and lock your computer, step away, and then come back later Pool lockers"
3.) **External Lock**
DeID-IS-P0228-N-3A-I01 (Sample 8) 806

After looking at the Idea Drawing and reading the Idea Description, we can follow the tree down to Physically Secure. The description reads “laptop lock” so we can then move down to the Locked branch. Finally, seeing the picture and reading “cord,” we choose 3 External Lock.

**Idea Drawing:** Sketch your solution idea in the box below.

![Idea Drawing](image)

**Description:**

"A cord would be on a reel in the wall in a booth. the end of the cord is a laptop lock, which most all current laptops have a receiver for. Midway on the cord is a small padlock, which could be used to hold two zippers together on a backpack or briefcase. This device would be small & there could be one per side of a booth."
4.) Forcefield
DeID-IS-P0244-T-3A-I01 (Sample 8) 854
After looking at the Idea Drawing and reading the Idea Description, we can follow the tree down to Physically Secure. The description reads “force field” so we can then move down to the Forcefield branch. We choose 4 Forcefield.

**Idea Drawing**: Sketch your solution idea in the box below.

**Description**:

Electromagnetic force field. When you try to steal an item and the force field will repel you away. The owner would be able to turn it off and on
5.) **Suction**  
DeID-IS-P0504-N-3A-I02 (Sample 14)  838  
After looking at the Idea Drawing and reading the Idea Description, we can follow the tree down to Physically Secure. The drawing shows a labeled suction cup and the description further supports the idea, so we can go down the Hold Down branch and choose 5 Suction.

*Description:*  
Suction cup that needs a code to release pressure. Use steel cables to secure what you want
6.) Magnet

After looking at the Idea Drawing and reading the Idea Description, we can follow the tree down to Physically Secure. The drawing shows a battery and the description mentions a battery which “magnetizes” the table, so we can go down the Hold Down branch and choose 6 Magnet.

Description:

Battery magnetizes the table so all metal items are stuck to the table.
7.) Motion Sensor
DeID-IS-P0247-T-3A-I03 (Sample 8)  720
After looking at the Idea Drawing and reading the Idea Description, we can follow the
tree down to Digitally Secure. The description says there is a “motion sensor alarm
system,” so we can go down the Alarm branch to 7 Motion Sensor.

Description:

Motion sensor alarm system that sets off an audible alarm if
something enter the predetermined area. If it senses this an
option net launching system will be triggered from the
ceiling to detain the captor.
8.) Camera System

After looking at the Idea Drawing and reading the Idea Description, we can follow the tree down to Digitally Secure. The description says there is a “small camera” that would be able to send video feed to a phone or other device, so we can go down the Alarm branch to 8 Camera.

Description:

"This solution works by putting out a small camera that watches your stuff. This camera can then be viewed by your phone or tablet, or maybe a wireless screen that comes with it. This way you can watch your stuff."
9.) Noisy Material
10.) Alarm ‘Field’
DeID-IS-P0247-T-3A-I01 (Sample 8) 356

**Description:**

Electromagnetic Force field that the user can turn on and off using some sort of remote
11.) Light
12.) Invisibility
DeID-IS-P0504-N-3A-I03 (Sample 14) 359
After looking at the Idea Drawing and reading the Idea Description, we can follow the
tree down to Not Secure since there isn’t really anything in place to keep the object from
being physically taken. The drawing shows some sort of invisibility cloak, so we can go
down the Hidden branch to 12 Invisibility.

Idea Drawing: sketch your solution idea in the box below.

Sheet uses cameras or pre loaded picture of blank
workspace. Throw the sheet over your stuff and it disappears
to thieves x distance away.
13.) Buddy
DeID-IS-P0223-N-3A-I03 (Sample 8) 800
After looking at the Idea Drawing and reading the Idea Description, we can follow the tree down to Not Secure since there isn’t really anything in place to keep the object from being physically taken. The description says there would be a “secretary who…watches your stuff,” so we can go down the Buddy branch. We choose 13 Buddy.

**Idea Drawing:** Sketch your solution idea in the box below.

![Idea Drawing Image]

**Idea Description:** Describe the solution idea. How does it work? What are the features, mechanisms, and details?

Secretary who tags along & watches your stuff (and obviously has a permit to carry.) Scott Reithmeier
14.) Make Undesirable
DeID-IS-P0314-N-3A-I04 (Sample 10) 20
After looking at the Idea Drawing and reading the Idea Description, we can follow the tree down to Not Secure since there isn’t really anything in place to keep the object from being physically taken. The description says there would be a “laptop disguise” that would make the laptop look like a common object that no one would want to steal, so we can go down the Make Undesirable branch. We choose 14 Make Undesirable.

Description:

LAPTOP DISGUISE. MAKES YOUR VALUEABLE ELECTRONICS LOOK LIKE A BOOK/ROCK/FLOWER POT/PLACEMAT/PART OF TABLE/ SMALL MAMMAL/TISSUE BOX/ETC.
Rainwater Catcher Variety Coding

Remote Village Rainwater Catcher Problem Context
In remote villages throughout many rural, underdeveloped areas of the world, easy access to fresh clean drinking water is very limited. Villagers must often walk long distances to a fresh water source, collect the water in large, awkward bins, and then carry the water back uphill to their home. Retrieving the fresh drinking water in this manner takes tremendous amounts of time and effort. In many cases, however, rainwater is a fresh and abundant source of water, but there are no solutions for effectively capturing, storing, and distributing the water.

Design a way for remote villagers to catch, store, and access rainwater.

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.

Task: Design a way villagers to catch, store and access rainwater
Constraints: Easier/fast than walking long distance to carry back in bins
Environment: Remote/rural areas
Stakeholders: Villagers
Functions: Collect Rainwater, Distribute Water

Collect Rainwater Function
The Collection tree is meant to analyze how a village will collect rainwater. At the embodiment level of the Collection tree, storage methods are defined. It is important to not be confused with distribution as this aspect has a separate tree.
The Physical Principle “Direct” can be defined as rainwater falling directly into a reservoir, container, or well. The Physical Principle “Indirect” can be defined as rainwater falling into a container through run-off or by first falling into a gutter system, tarp, or funnel. In “Indirect,” rainwater does not fall immediately into the collection system.
The Working Principle “Reservoir” can be defined as an open pool or basin. The Working Principle “Container” can be defined as a closed storage tank for the water. The Working Principle “Well” can be defined as an underground well. The Working Principle “Gutter System” can be defined as gutters or pipes along houses to guide the run-off water to a collection system. The Working Principle “Tarp” can be defined as a material that allows water to collect on it with or without a drainage system. The Working Principle “Funnel” can be defined as a large funnel-like device that collects water and channels it to a collection system. The Working Principle “Run-Off” can be defined as water that flows downhill into a collection system due to gravity.
1) Closed
Physical Principle “Direct” and Working Principle “Reservoir”
Rainwater falls directly into a reservoir of water that can be closed.

Description:

"Collection surface that drains into an interior storage vessel,"
2) Open

Physical Principle “Direct” and Working Principle “Reservoir”

Rainwater falls directly into a reservoir that is open to the environment.

Description:

"Dig a big hole in the ground, put a rubber liner inside (like a swimming pool) to trap water, villages can come and use the water"
3) **Container**

Physical Principle “Direct” and Working Principle “Container”

Rainwater falls directly into a container.

Description:

"This idea is a big silo, when the rain comes you open the lid. When it is done raining you close the lid to prevent debris. The nozzle allows for water to be poured."
4) (Well)
Physical Principle “Direct” and Working Principle “Well”
Rainwater falls directly into a well.

Description:

A windmill pumps water to the top of a hill where a house is.
5) Store
Physical Principle “Indirect” and Working Principle “Gutter System”
Rainwater falls into a gutter system that channels the water into storage.

Description:

roof & gatters painted with a special material so that rain water does not get contaiminated. Water down gutter into a bin on a cart of easy transportation
6) Home
Physical Principle “Indirect” and Working Principle “Gutter System”
Rainwater falls into a gutter system that channels the water into a villager’s home.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

when it is raining, the rainwater will be collected on top

Description:

"When it is raining, the rainwater will be collected on top of a rural house in a big container. In the roof there will be a removable cover, that when opened, will allow water to flow down into a pipe that leads all the way down inside the house."
7) (Tarp)
Physical Principle “Indirect” and Working Principle “Tarp”
Rainwater falls into a tarp.

"Fabric that absorbs moisture from the air, and drain it down to the tank below it."
8) Container
Physical Principle “Indirect” and Working Principle “Funnel”
Rainwater falls into a funnel that channels the water into a container.

**Idea Drawing:** Sketch your solution idea in the box below.

![Diagram of rainwater collection system](image)

**Idea Description:** Describe the solution idea. How does it work? What are the features, mechanisms, and details?

"Rain water in the ground is drained and funnel into an underground water tank, and then pump up to the ground above. "

9) Reservoir
Physical Principle “Indirect” and Working Principle “Funnel”
Rainwater falls into a funnel that channels water into a reservoir.

Description:

Set up a big field with a lot of funnels to gather water and a big closed underground reservoir. The funnels will collect the water and the closed reservoir will keep it clean and nicely stored.
10) Home
Physical Principle “Indirect” and Working Principle “Funnel”
Rainwater falls into a funnel that channels water into a villager’s home.

Description:

"We utilized the existing house structure to catch rain. The roof has a large surface area to catch rain. The water is funneled down to large elevated cisters. From there, we could instal a lower bucket to drop the water into."
11) Container
Physical Principle “Indirect” and Working Principle “Runoff”
Rainwater falls and runs-off into a container.

Description:

Rain water runoff from the roof can be channel and collected in a tank.
12) Reservoir
Physical Principle “Indirect” and Working Principle “Runoff”
Rainwater falls and runs-off into a reservoir.

Description:
"use the natural slope of the land to move, dig small channels along roads & paths that lead to a small pond or well. line storage with stone & mortar, or plastic to prevent seeping."
Distribute Water Function
The Distribution tree is meant to analyze how rainwater will be distributed to a village once it leaves the collection site. The distribution of rainwater can be categorized as automatic via pipes, pumps, and pulleys; manual on or off site distribution; and no distribution required via runoff.

The Physical Principle “Automatic” can be defined as created distribution systems that work without human intervention. The Physical Principle “Manual” can be defined as created distribution systems that require the physical operation of a person/villager. The Physical Principle “None Required” can be defined as no physical principle is required because there is no mechanism to distribute the water, it is only distributed by gravity in run-off.

The Working Principle “Pipes” can be defined as an enclosed piping system that lets water flow to the distribution site. The Working Principle “Pumps” can be defined as a device that can pump the water from underground to the distribution site. The Working Principle “Pulleys” can be defined as a pulley system that transports water, usually in a bucket or similar device, to the distribution site. The Working Principle “On-Site” can be defined as the village/home where the rainwater was collected. The Working Principle “Off-Site” can be defined as rainwater collection sites away from the village/home. The Working Principle “To User” can be defined as the villager manually transporting the rainwater to the village/home. The Working Principle “Run-Off” can be defined as rainwater that runs-off of devices to transport the water to a village/home via gravity.
1) In Home

Physical Principle “Automatic” and Working Principle “Pipes”
Rainwater is distributed by automatic pipes in a villager’s home.

"We utilized the existing house structure to catch rain. The roof has a large surface area to catch rain. The water is funneled down to large elevated cisters. From there, we could instal a lower bucket to drop the water into."
2) To Container
Physical Principle “Automatic” and Working Principle “Pipes”
Rainwater is distributed by automatic pipes to a container.

Idea Drawing: Sketch your solution idea in the box below.

Description:

"Fabric that absorbs moisture from the air, and drain it down to the tank below it."
3) On-Site
Physical Principle “Automatic” and Working Principle “Pumps”
Rainwater is distributed by automatic pumps on-site (village/home where the rain was collected).

**Description:**

Rain water filters through the ground to an underground metallic barrier. This barrier funnels the water to an underground storage area accessible by a pump above ground.
4) Off-Site
Physical Principle “Automatic” and Working Principle “Pumps”
Rainwater is distributed by automatic pumps at off-site locations away from village/home. 

Description:

"If the village was uphill, the collected rainwater usually would be somewhere below that level. We can use a ram pump to pump the water using the difference in pressure. The ram pump is to make a system of pipes in different levels. Distribution of water"
5) Bucket
Physical Principle “Automatic” and Working Principle “Pulleys”
Rainwater is distributed by automatic pulleys with buckets to carry water.

Idea Drawing: Sketch your solution idea in the box below.

Description:

"Bucket conveyor. a string of buckets is connected from the water to the village, and motor or several people hoist the buckets from the water to the village."
6) Pump
Rainwater is distributed manually by villagers through pumps on-site (village/home where rain was collected).

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

One large rainwater collector in the village would feed to each household, where water would be used via pumps or simply gravitational potential (water tower).
7) Faucet
Rainwater is distributed by turning a faucet to let water flow on-site (village/home where rain was collected).

![Diagram of rainwater catcher]

Description:

water tower like structure - collects Rain water through open top - Rain water travels down tube - valve at end of tube opens and closes in order to let water flow out - distributed in areas of remote villages for all villagers to USE
8) Pulley
Rainwater is distributed by manual operation of a pulley on-site (village/home where rain was collected).

**Description:**
- Build a large tank (Able to store large amount of water) - Net above the tank (Prevent unnecessary precipitates and bugs to enter the fresh water) - Filter (Ensure cleanliness of water) - Pulley (requires human power to function the sweeper in order to remove precipitates on the net.)
9) Walk to it
The user leaves the village/home and walks to the collection site away from the village/home.

Description:

a Hammock that collects water
10) **(To User)**


The user manually transports the rainwater to a village/home.

**Description:**

DOME/SEMI-CIRCLE SHAPED SHELTER IS BUILT WHERE IT IS MODE FORMS WATER PROOF MATERIALS. AS THE RAIN FALLS IT WILL HIT THE SHELTER AND FLOW DOWNWARDS TO THE HALF PIPE AND INTO THE TANK. THE STORAGE TANK WILL BE INSTALLED WITH A DISPENSER.
11) Roof
Physical Principle “None Required” and Working Principle “Runoff”
Rainwater runs off roofs for distribution.

Description:

Rain water runoff from the roof can be channel and collected in a tank.
12) Road
Physical Principle “None Required” and Working Principle “Runoff”
Rainwater runs off roads for distribution.

Description:

"Put a barrier for water flow on the edges of the hilltop, angling to distribute it to one location. Before it reaches, it flows through a large bed of moss to filter then sits in an enclosed basin near the town"
13) Other
Physical Principle “None Required” and Working Principle “Runoff”
Rainwater runs off unspecified objects for distribution, other than roofs or roads.

**Description:**

Screens of absorbant fabric rotate during a rare storm as the fabric becomes saturated water runs down to a collection point below. Rotation could be mind powered.
Works Cited


Appendix G

Study protocol and instructions

Idea Generation

Presentation Script

Ideation Flexibility – Presentation Script

Table of Contents

ME 415 Session- 3 Interventions ................................................................. 2
Foundation and Neutral Idea Generation ...................................................... 3
  Slide 1: Idea Generation Activity ............................................................... 3
  Slide 2: Idea Generation is KEY in the Design Process ................................ 3
  Slide 3: Idea Generation Best Practices ..................................................... 4
  Slide 4: Idea Generation Session 1 – Your turn ........................................ 5
  Slide 5: Idea Generation Session 1 – Reflection ....................................... 6
  Slide 6: Break ............................................................................................ 6

Feel free to get a drink of water or use the restrooms, and then please come right back here so we can do the next activity. And when you come back please sit in the same seat. .................................................................................. 6

Intervention – Ideation Teaming ................................................................. 7
  Slide 1: Idea Generation Activity – Teams .................................................. 7
  Slide 2: Idea Generation in Teams ............................................................... 7

So in every team, it is crucial that the team works together, but it is equally important that the individual has their own ability to be independent. Both are needed to be successful ........................................................................ 7

  Slide 3: Idea Generation Session 2 – Your turn ........................................ 8
  Slide 4: Idea Generation Session 2 – Reflection ....................................... 9
ME 415 Session- 3 Interventions

The sessions are 170 minutes in duration:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Duration</th>
<th>Start Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. KAI Testing</td>
<td>22 min</td>
<td>8:00</td>
</tr>
<tr>
<td>2. Welcome and Introduction</td>
<td>5 min</td>
<td>8:22</td>
</tr>
<tr>
<td>3. Idea Generation Session 1 – Neutral</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Intro</td>
<td>2 min</td>
<td>8:27</td>
</tr>
<tr>
<td>b. Activity</td>
<td>20 min</td>
<td>8:29</td>
</tr>
<tr>
<td>c. Reflection</td>
<td>10 min</td>
<td>8:49</td>
</tr>
<tr>
<td>4. Break</td>
<td>5 min</td>
<td>8:59</td>
</tr>
<tr>
<td>5. Idea Generation Session 2 – Framing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Intro</td>
<td>2 min</td>
<td>9:04</td>
</tr>
<tr>
<td>b. Activity</td>
<td>20 min</td>
<td>9:06</td>
</tr>
<tr>
<td>c. Reflection</td>
<td>10 min</td>
<td>9:26</td>
</tr>
<tr>
<td>6. Break</td>
<td>5 min</td>
<td>9:36</td>
</tr>
<tr>
<td>7. Idea Generation Session 4 – Teaming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Intro</td>
<td>2 min</td>
<td>10:18</td>
</tr>
<tr>
<td>b. Activity</td>
<td>20 min</td>
<td>10:20</td>
</tr>
<tr>
<td>c. Reflection</td>
<td>10 min</td>
<td>10:40</td>
</tr>
<tr>
<td>8. Break</td>
<td>5 min</td>
<td>10:13</td>
</tr>
<tr>
<td>a. Intro</td>
<td>2 min</td>
<td>9:41</td>
</tr>
<tr>
<td>b. Activity</td>
<td>20 min</td>
<td>9:43</td>
</tr>
<tr>
<td>c. Reflection</td>
<td>10 min</td>
<td>10:03</td>
</tr>
<tr>
<td>10. Thank You and Farewell</td>
<td></td>
<td>10:50</td>
</tr>
<tr>
<td>Total</td>
<td>90 min</td>
<td></td>
</tr>
</tbody>
</table>
Idea Generation

Foundation and Neutral Idea Generation

Slide 1: Idea Generation Activity

Hello everyone, I’m ___________. I’m working with a team from three universities—Penn State, Iowa State and University of Michigan—to teach you a very important, but often overlooked, part of the design process—idea generation. You all have some experience generating ideas for design problems but today you are going to be learning some different techniques. Hopefully you will be able to take what you have learned and apply it to future design problems that you encounter.

In this session I’ll tell you a little bit about idea generation and then you’ll have the opportunity to generate your own design ideas. You will have four different design problems to work on, which I will give to you one at a time, and after each one I’ll collect your ideas. Today you will learn about problem framing, heuristic tools, and teaming as techniques for improving idea generation. I’m going to teach you about a tool for idea generation, and then we’ll do an activity for you to practice using it.

My team is also interested in studying how engineering students come up with design solutions. As engineering educators, a lot of what we learn about good design comes from studying the ideas that you come up with in activities like these. So we are very glad to be here and to be helping you with this activity. If you don’t want us to include your work in our research about generating ideas, then at the very end of this session, there will be a place for you to let us know that. When we do this sort of research, we never use real names, so you don’t have to worry about that. Regardless, we are planning to have a good time generating solutions to some interesting engineering design challenges, and we hope you learn a lot from the experience.

So let’s get started.

Slide 2: Idea Generation is KEY in the Design Process

One of the challenges for both engineering students and practicing engineers is to develop good solutions to design problems.

Being successful in generating ideas is crucial in the overall process. The ideas that you generate at the beginning of the process determine what is possible in your final product, and if you stop generating ideas too early, then there can be a whole range of possible designs that you never even consider. Research suggests that the first idea you think of is very rarely the best idea. And that is important because once you choose an idea, then you start to commit a lot of time and
energy to developing it and you stop thinking about all the other ideas. So we’re going to talk about what are some good ways to generate solution ideas, so that when you do commit to one idea, you can feel confident that you have considered many of your options. [Say something about the funnel representation…]

**Slide 3: Idea Generation Best Practices**

Generating solution ideas is not always easy, and over time, we develop habits for idea generation. But we want to lay the groundwork and teach you some of the best practices that you should try to use whenever you’re generating ideas. These three things have been shown by research to be helpful for successful design, and we want you to practice these strategies today:

1. Generate different ideas
   a. Generating ideas that are very similar to one another doesn’t give you the opportunity to explore different ways of approaching the problem. When you generate a wide range of ideas, it gives you more chance to think of different aspects of the problem in different ways, and that may ultimately lead you to a better solution. So do your best to generate different ideas.

2. Avoid evaluating your ideas
   a. It is very easy to focus on all the problems or issues with an idea—why it won’t work and isn’t any good. But early on in a design process, when you are just trying to generate ideas, that can be counterproductive. No final design is going to end up exactly like it was proposed. And even if an idea is chosen, you are going to have to improve on it throughout the rest of the design process to actually make it work. But also, there is usually something to be learned even from those ideas that don’t work and don’t seem like the best options. So do your best to avoid evaluating your ideas during idea generation, and especially in the activities today.

3. Record your ideas using drawings and text
   a. It is important to sketch while generating solutions, because the drawings help you think through ideas for yourself, eventually communicate your ideas with others, and stimulate new ideas. It doesn’t matter whether you think of yourself at good at drawing or not. The drawings don’t need to be perfect, or even pretty. The most important thing is that you are trying to represent your idea. And you can use labels and text to add to your drawings, to say what the different parts are and then to explain how the idea works. So do your best to record each idea using drawings and text.
Slide 4: Idea Generation Session 1 – Your turn…

As part of today’s activities, there will be four idea generation sessions. Let’s start with the first one.

You are going to be working on your own. For a later activity, you’ll work with each other, but research has shown that it’s best to give yourself some individual time first to generate ideas.

Each of you has four folders in front of you. Pull out the first folder that says ‘Neutral’ on the front. (Hold up sample folder here). The first page is the description of your design problem. In a moment, you can start the activity by reading through that description. Not everyone has the same problem, so just focus on the one that you have.

When you finish reading through the problem description, you will notice that you also have a stack of idea sheets, the white ones. (Experimenter should hold up the Idea Sheet.) As you think of ideas, record them on these sheets. Use a new idea sheet for each solution idea that you come up with. Be sure to label every idea sheet with your name, the problem number that you are working on (which is listed on the problem description sheet just under the title), and an idea number (1, 2, 3, …) in the order that you generate the ideas. The idea sheet has two boxes. The top box is for you to draw and label your idea, and the bottom box is for you to describe how the idea works. If you run out of sheets, please just raise your hand and I’ll bring more to you.

When I say you can begin, then …

1. You will have 20 minutes to generate ideas
   a. And it’s important that you try your best for the whole time
2. Start by reading through the design problem description
3. Then generate your ideas and record them (one idea per page)
4. Remember
   a. Generate different ideas
   b. Avoid evaluating your ideas
   c. Record your ideas using drawings and text

Any questions?

Okay, you can begin now… [NOTE Start Time: _________ Finish Time (+20): _________]

At five minutes remaining: There are now five minutes remaining.

At one minute remaining: There is now just one minute remaining. Please finish up your current idea.

(Experimenter should start passing out the Reflection Surveys.)
Okay, please stop generating ideas. Put your idea sheets in a pile in order with the first idea you generated on top, then the second, and so on. Then put the problem description on the top, and place the whole pile back into the folder.

Now, I’d like you to spend ten minutes reflecting about your experience generating ideas in this activity. Research has shown that being what’s called a “reflective design practitioner” – that is, thinking about what you have designed and why – is one of the ways to become better at design. I am passing out the reflection sheet now. When you are done, put the completed reflection sheet into the folder with your design ideas.

Please start now. [NOTE Start Time: _________ Finish Time (+10): ________ ]

At five minutes remaining: There are now five minutes remaining.

At one minute remaining: There is now just one minute remaining. Please finish up and make sure you answer all of the questions.

At the end: Okay, please put the reflection survey in your folder and leave your folder at your seat. I will come around to get your folders as we are doing the next activity.

Slide 6: Break

Now we are going to take a five-minute break.

One rule, please do not talk with anyone about the design problems that you had or the ideas you generated. At the very end, you are welcome to talk as much as you want about it, but please don’t do it right now. Thank you.

Feel free to get a drink of water or use the restrooms, and then please come right back here so we can do the next activity. And when you come back please sit in the same seat.
Slide 1: Idea Generation Activity – Teams

All right, for this next activity, you will all get the opportunity to get up and move around a little bit.

Let’s recap. Now you have generated ideas for two problems in different contexts by yourself. You are probably starting to get a sense of your own style and approach to idea generation – what works for you and what doesn’t. But many design problems are solved in teams – not alone. So I’d like to give a little practice working in a two- (or three-) person team to generate ideas on this next problem.

Slide 2: Idea Generation in Teams

Teaming is an effective method for idea generation. By working in teams, you can use the unique experiences of everyone involved to develop a more diverse set of solutions.

One of the most important things to do when working in teams is to respect each other’s ideas. Especially at this early stage in a real design process, it is just not productive to shut each other down. Instead, use each other as a resource for thinking about new ideas that you wouldn’t have thought of on your own, or new ways at looking at the problem. You can also use each other as a resource for improving and elaborating on your own ideas, and as a resource for thinking of new ideas together that either one of you might have not been able to generate on your own.

Here are some options for ways to work together with someone else:

1. Actively participate – engage with each other, talk, discuss
2. Stay on topic – use this time to discuss this problem, not other things
3. Clarify ideas – sometimes the best thing you can do is just be curious, ask questions that help you both understand the good parts of an idea
4. Build on each other’s ideas – don’t shut each other down and focus on the negative, instead make suggestions, add to the idea, focus on the positive
5. Combine ideas – take some of your ideas and some of theirs and make a new idea

But, and this is very important, even though you should respect each other’s ideas, the other person shouldn’t be making any decisions for you. Ultimately, you should decide which ideas you think are worth pursuing, and which parts of those ideas, and in which ways.

So in every team, it is crucial that the team works together, but it is equally important that the individual has their own ability to be independent. Both are needed to be successful.
Slide 3: Idea Generation Session 2 – Your turn…

This activity is going to be similar to the first activity. You’re going to get a problem description and idea sheets. I have given each of you a new folder with the new problem description (in blue). **This time you will work together with the person next to you in a team.** You should have the same “Team Letter” on your folders. There may be one team of 3, but everyone else will work in a 2-person team. Not every team has the same problem, so just focus on the one that your team has. You should talk together to come up with ideas and to elaborate on them.

Just like last time, as you think of ideas, record them on the idea sheets, the white pages. **Even though you are working as a team to generate ideas, we’d like you each to record the ideas on your own sheets.** Discuss with your partner, but then record the ideas however you think is best (in your own words, with your own drawing, in your own way). Use a new idea sheet for each solution idea that you come up with. Be sure to label every idea sheet with your name, the problem number that you are working on (which you can get on the problem description sheet right near the top under the title), and the idea number (1, 2, 3, …) in the order that you generate the ideas.

And then the idea sheet has two boxes. The top box is for you to draw and label your idea, and the bottom box is for you to describe how the idea works. If you run out of sheets, please just raise your hand and I’ll bring more to you. But then at the bottom is a place for you to indicate whether you or your team member first thought of the idea, and then how much you contributed to generating and developing that idea (coming up with it and elaborating it).

When I say you can begin, then …

1. You will have 20 minutes to generate ideas
   a. And it’s important that you try your best for the whole time
2. Start by reading through the design problem description
3. Then generate your ideas with you team, but record them individually (one idea/page)
4. Remember
   a. Generate different ideas
   b. Avoid evaluating your ideas
   c. Record your ideas using drawings and text

Any questions?

Okay, you can begin now… [NOTE Start Time: _________ Finish Time (+20): ________]

**Consistent reminders to be said out loud to the whole group every 5 minutes:** (1) Keep working the whole time; (2) keep discussing with your team; and (3) keep recording your ideas.

**At five minutes remaining:** There are now five minutes remaining. Try to get another idea.

**At one minute remaining:** There is now just one minute remaining. Finish up your current idea.

*(Experimenter should start passing out the Reflection Surveys.)*
Slide 4: Idea Generation Session 2 – Reflection

Okay, please stop generating ideas. Like last time, please put your idea sheets in a pile in order with the first idea you generated on top, then the second, and so on. Then put the problem description on the top, and place the whole pile back into the folder.

Now, I’d like you to spend ten minutes reflecting about your experience generating ideas in this activity. I am passing out the reflection sheet now. This reflection is similar to the last one, but has a couple extra parts, so please go through the whole thing carefully. And make sure you answer all of the questions based on your experience with this activity. Don’t think about the first activity that we did before. **This is something you should do individually based on your own experience in the team.**

When you are done, put the completed reflection sheet into the folder with your design ideas, then and I will collect the folders.

Please start now. [NOTE Start Time: _________  Finish Time (+10): ________ ]

At five minutes remaining: There are now five minutes remaining.

At one minute remaining: There is now just one minute remaining. Please finish up and make sure you answer all of the questions.

At the end: Okay, please put the reflection survey in your folder. I will come around to get your folders as we are doing the next activity.

(Go directly to the Error! Reference source not found. section to finish out the session.)

Slide 5 (cont.): Thank You

Thanks so much for participating today. I hope that you learned a lot about idea generation. I also hope that you remember the cards and use them in your design tasks throughout your program here and throughout your engineering career.

(Session over.)