Design problem exploration

by

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The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

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DEDICATION

I would like to dedicate this thesis to my family for being my biggest supporters during the master's program. Ali, thank you for your guidance and wisdom when I needed it the most, especially the late-night pep talks. Mom, thank you for always believing in me and cheering me on with anything I set my mind to. Dad, thank you for your generosity, knowledge in developing the tool, and for graciously appeasing my last-minute requests. Grandma and Grandpa, thank you for your constant positivity and unconditional love.

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ABSTRACT

The problem generation space is a critical stage in the design process that reflects the outcome of a solution. However, limited research has been conducted on problem space within design education to aid in the creative process. Within the problem generation space, there are multiple alternative views to reframe a problem statement which ultimately impact the solution. More novel problem statements have reflected an increase in unique concepts. By providing a toolset for students to diversify their problems, new perspectives of the problem are taken into the idea generation space. Research has identified heuristics that frame a problem, which have found to be helpful.

Two studies are provided to understand the relationship between heuristics and reframed statements. Study 1 analyzed students' reframed statements without the aid of heuristics. Sixteen strategies were observed in this classroom study. In Study 2, a digital tool with twelve identified strategies were used to provide a randomized selection for implementation. Design and engineer students took part in a classroom study; each completed three strategies to compare the outcomes. The goal of Study 2 was to identify whether the students implemented the strategies and how they used each within their statements. A complementary aim was to understand how much diversity was created among the new problems after strategy use. The research reported in this paper uncovers certain strategies that performed superior in various conditions amongst other strategies within the problem generation space.

CHAPTER 1. INTRODUCTION

Spurring innovation and creativity is the ultimate objective of the design process. At first glance, many design problems can be simple to solve in their presented form; however, the first ideas are typically obvious solutions and do not lead the designers to explore innovative solutions. Instead, the problem must be reframed to provide new solution opportunities. What does spur innovation is the ability to looking beyond the original problem in order to uncover the true problem, a process known as problem exploration. This includes restructuring problems as it defines the set of possible solutions; as a result, it is crucial in order to search for innovative solutions of this constrained set. Empirical studies have shown that creative solutions derive from a 'co-evolution' of understanding the underlying problem during the development of the solution (Dorst & Cross, 2001).

Through design education, industrial design students are taught the fundamentals of the design process from beginning with a design brief to eventually resulting in a technical and thoughtful solution. Although the design process is taught in design studios, there are still unknowns as to how a designer makes decisions on which problem to solve. In order to continually generate creative solutions, it is imperative for students to be taught ways to engage in creative thinking through design processes.

Within the problem generation space, there are multiple alternative views to reframe a problem statement. Previous research has shown there are heuristics that have been used as ways to frame a problem, which have found to be helpful. However, there is minimal research on how the students make decisions based on the heuristics and which ones are most effective to implement in the problem space.

This thesis focuses on such strategies evidenced by prior research, developing a digital tool to facilitate using the strategies and the impact of this tool on students' exploration of the problem space. The goal of the study is to identify heuristics that are most influential in the problem definition space.

Research Motivation

When problem statements are rewritten in multiple ways, it prompts us to gather information in different ways. The ability to see a problem in new ways expands the potential to discover new possibilities of problems (Cropley, 2015). Imagine how many different perspectives the students did not have the opportunity to consider once the original problem was handed to them.

In previous studies (Studer, et. al, 2018; Studer, et. al, 2017), students were provided a problem, asked to generate solutions, and then prompted to re-write a problem statement from the solution. In this sense, they were not asked to change their way of thinking. Task-wise, they were not doing anything differently to generate concepts, however data shows the students were cognizant their problem transformed. Currently, we do not know at what point in the process where this transformation occurs and what is most effective during this stage. Our theory is that using these strategies might help generate a broader set of possible problems.

Experimental Approach

An interpretive perspective will be the approach that guides this study. Since the goal of the study is understanding the world in which designers go about generating problems, a social constructivist framework will be utilized. It is important to recognize their way of thinking in order to interpret ways to improve their experience. The emergent ideas through an interpretive and social constructivist lens are obtained through methods like observing and open coding (Creswell & Creswell, 2013).

Thesis Structure

The content of this paper is divided into six chapters, each discussing a vital component of the research. Two studies were conducted to further understand the impact of strategies used within the problem space. Chapter 2 contains an extensive literature review of research on problem exploration, including common definitions, importance, and existing strategies. Chapter 3 contains Study 1, which elaborates the strategies that were uncovered when students were asked to reframe their problem statements. Open coding was conducted to generate a list of prevalent characteristics. Chapter 4 discusses the design and usability of the tool used in Study 2. Chapter 5 encapsulates Study 2, which details the data collection, analysis, and results of the four research questions. Finally, Chapter 6 summarizes the conclusions drawn from the thesis, and details plans for future work. All references are provided at the end of each chapter. Appendix A contains the IRB approval, Appendix B contains the informed consent document provided to each participant for the study, and Appendix C is the protocol template packet explained in Chapter 5.

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Studer, J., McKilligan, S., Seifert, C., & Daly, S. (2017). Problem Exploration Strategies during Engineering Design. *Journal of Engineering Education*.

CHAPTER 2. LITERATURE REVIEW

Overview

There is abundant research in the design solution space, however there is little knowledge in the problem generation space surrounding creativity which is a guiding reason to conduct this study. It is important for designers to produce a thoughtful problem statement as it is the foundation for the rest of the design process. For both studies, a series of cognitive strategies, also known as heuristics, were identified to aid in the creation of creative problem statements. Cognitive heuristics are commonly used by design practitioners as they are shown to enhance the creative potential of designs. Heuristics applied in design education are transformational strategies that apply relevant and intentional variation to a concept in the hopes of constructing new ideas (Yilmaz, et.al, 2010). These heuristics are used as an initial starting point to transform a concept or statement, in this case. The more heuristics one uses, the greater the breadth of ideas there are to increase the chances of developing a novel design.

Importance of Problem Exploration

There is a need to improve a student's ability to think creatively since in the future they will be the ones responsible for improving the design of future products (Court, 1998). Problem exploration is beneficial in the beginning of the design process of a project so that all of the building blocks of design criteria are grounded around a deep understanding of the problem (Snider, Culley, & Dekoninck, 2013). However, in an academic setting, students are already provided with a 'perfect-case' scenario for a design problem where the student only needs to focus on the solution. This means that there is minimal attention on the problem space itself which is an important part of creative learning and perception of the complete picture (Cropley, 2003).

Not only is it considered a building block, it is suggested to be a contributor of innovative solutions. According to (Einstein & Infeld, 1938), "…the formulation of the problem is often more essential than its solution… To raise new questions, new possibilities, to regard old problems from a new angle requires creative imagination and marks real advances in science" (p. 92). One component of innovation is to look beyond the presented problem in order to fully explore the "real" problem at hand, a process called 'problem exploration'. When a problem is restructured, this process of exploration can lead to new discoveries and ultimately aid in novel solutions to the problem. In order to encourage this process of exploration, there needs to be a way to help design students receive different perspectives on design problems. This requires a deep understanding of the cognitive processes students use to redefine their statements (Getzels & Csikszentmihalyi, 1976).

Problem exploration involves asking questions of design problems to determine the principal components and the underlying issues to drive the search for creative solutions (Duncker, 1945). Problem exploration is necessary for design contexts as these problems are considered ill-structured; therefore, they must be articulated and reframed throughout the process. Well-structured problems, on the other hand, have articulated problem descriptions that lead to straightforward solutions. These routine problems generate ordinary solutions that may be effective but not creative (Cropley, 2015). With ill-structured problems, where the solution path and resulting solution is unknown, problems must be explored to form novel solutions, resulting in creative and innovative solutions (Reitman, Grove, & Shoup, 1964).

Understanding problem exploration and how it affects learning and creativity can positively impact design education and design practices in the industry. Vasconcelos, et.al. (2016) states that "…although the design literature often promotes the importance of problem exploration activities, the benefits these activities bring have not previously been investigated in depth" (p.89). Research has shown the importance of problem exploration in design, however little is known about how problems are discovered and formulated (Getzels, 1979).

Problem Definitions

Significant research of the problem exploration space is evident in the field of psychology, however, empirical research within the design domain is scarce. Since there lacks research, the definition of problem exploration varies across academia. Several sources define problem exploration as a research phase involving such things as data collection (Archer, 1968; Kruger & Cross, 2006; Shneiderman, 2000), feasibility studies (Asimow, 1968), and market research (Vasconcelos, et. al, 2016). However, these sources do little to explain how to use the research collected to effectively explore the problem in order to generate innovative solutions. For this paper, 'problem exploration' is considered the first stage of the design process prior to idea generation encompassing three distinct processes: problem finding, problem framing, and problem defining. The definitions of these processes, synthesized from prior research, are provided in Table 2.1.

Table 2.1 Synthesized definitions of problem finding, problem framing, and problem defining

	Definition	*Sources*
Problem Finding	Changing the way problems are envisaged, posed, formulated, and created	(Getzels, 1975, 1979; Getzels & Csikszentmihalyi, 1976; Hoover, 1994; Mumford, Reiter-Palmon, & Redmond, 1994; Okuda, Runco, & Berger, 1991; Runco, 1994; Wakefield, 1985)
Problem Framing	Altering perspectives about a problem description to reveal patterns of reasoning and problem solving that are associated with a particular way of "seeing" the problem, and leading to the possibility to "act" within the situation	(Kees Dorst & Cross, 2001; Dzbor & Zdrahal, 2002; Schon, 1984; Stumpf & McDonnell, 1999; Tversky & Kahneman, 1981; Wright, Silk, Daly, Jablokow, & McKilligan, 2015)
Problem Defining	Considering the goal or ideal state desired in order to define how much of the problem exists, whether it is worth solving, and even whether or not there is a problem	(Higgins, Maitland, Perkins, & Richardson, 1989)

The first process, problem finding, is considered a vital component of creativity and the first step of thought towards solutions (Dillon, 1982; Getzels, 1975; Getzels & Smilansky, 1983). The second process, problem framing, provides an opportunity to alter the perspective for novel responses to a problem (Dorst, 2010; Seevinck & Lenigas, 2013). The third process, problem defining, is the cumulation of finding and framing the problem. Once the first two processes are complete, the problem can then be defined for idea generation (Higgins et al., 1989).

Problem Exploration in Design Education

Most of the work that has been conducted around problem exploration processes and heuristics within design education is developed from Studer, et.al. (2017), Wright, et.al. (2015), and Yilmaz, et.al. (2010). These papers conducted case studies to first gain knowledge on how engineers and industrial designers framed problem statements. Through a large collection of verbal transcripts and written statements, they were able to analyze the data and find common characteristics among the responses to develop heuristics. Through the synthesis of these problem exploration heuristics, this study will identify if they are effective in restructuring problem statements.

This paper is important for design education as it will provide a unique lens to further understand the role of innovation in the design process. Everyone has potential to innovate; it is just a matter of providing the necessary resources in order to confidently design and solve problems. This work is also significant not just in the design field because these strategies could be implemented across a variety of disciplines at a systematic level of thinking.

Current Problem Exploration Techniques

Some design texts and popular books offer techniques to help guide designers in framing and redefining design problems, however they do not provide empirical evidence. All of the existing problem exploration techniques, shown in Table 2.2, propose trigger questions that may assist the student in critically assessing the presented problem and further defining it. One approach offered by MacCrimmon and Taylor (1976) identified complexity as being a limitation in problem formulation and provided four decision strategies: 1) determining problem boundaries, or examining the assumptions; 2) examining changes, or focusing on any alterations changes in the problem description; 3) factoring into sub-problems, such as using methods including morphological analysis (Hall, 1962) and attribute listing (Rickards, 1975); and 4) focusing on the controllable components, or selective focusing (Shull, Delbecq, & Cummings, 1970). Fogler and LeBlanc (Fogler & LeBlanc, 2008) proposed strategies for defining "the real problem" underlying a given engineering problem. The "5 Whys" (Bulsuk, 2011) technique, used by the Toyota Motor Corporation, repeatedly asks "Why?" question in order to explore the cause and effect relationships underlying a problem. Abstraction laddering (Autodesk, 2017), is also used to better understand the problem space based on the data gathered from stakeholders. It focuses on asking a series of 'how' and 'why' questions to describe the design problem at increasing or decreasing levels of abstraction. Parnes' (1967) restatement method varies how the problem is stated using prompts, such as 'vary the stress pattern by placing emphasis on different words and phrases in the problem', and finally, the Kepner-Tregoe (Kepner & Tregoe, 1981) pushes the designers to distinguish what the problem 'is' and 'is not'.

Table 2.2 Problem Exploration Techniques

Technique	*Description*	*Sources*
Present state/desired state analysis and Duncker diagram	Means to determine the real problem by first describing the present state (where you are) and then describing the desired state (where you want to go)	(Duncker, 1945; Higgins et al., 1989)
Critical Thinking Algorithm	Process to recognize underlying assumption, scrutinize arguments, and assess ideas and statements using Socratic Questions to prompt the designer	(Fogler & LeBlanc, 2008; Paul & Elder, 2006)
Parnes' statement-restatement method	Method to evolve the problem statement to its most accurate representation of the problem using different triggers such as "place emphasis on different words and phrases"	(Parnes, 1967)
Kepner-Tregoe problem analysis technique	Technique that determines the "four dimensions of the problem" including identify, locate, timing, and magnitude by determining the distinction between "is" and "is not"	(Kepner & Tregoe, 1981)
5 Whys	Technique that involves asking questions ("Why?") until you get to the root cause of the problem	(Bulsuk, 2011)
Attribute listing	Method that involves listing attributes of the problem space, considering the value of each attribute ("what does this give?"), and modifying attributes to increase value, decrease negative value or create new value	(Rickards, 1975)
Selective focusing	Technique that focuses on the problem components that can be manipulated	(Shull et al., 1970)
Spradlin's Problem-Definition Process	Process that includes establishing the need for a solution, justifying the need, contextualizing the problem, and writing the problem statement	(Spradlin, 2012)

All of these techniques propose trigger questions that may assist designers in further defining the presented problem; however, they are lacking the empirical evidence of their use in creating innovative solutions. In order to understand the impact of heuristics within the problem exploration space, two studies using empirical data were conducted (Chapter 3 and 5). Study 1 coded reframed statements from design students to uncover evident strategies, whereas Study 2 used 12 identified strategies to see how it impacted the students' reframed statements.

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CHAPTER 3. STUDY 1: STRATEGIES TO REDEFINE THE PROBLEM SPACE FOR DESIGN INNOVATION

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Abstract

Designers used to solving problems that are given to them leading them to focus on creating feasible solutions rather than exploring novel perspectives on the presented problems. Creative innovations in problem understanding may lead directly to more innovation solutions. Although problem exploration has been identified as a key process in design thinking, how designers restructure and reframe the problem is not fully examined. The present work aims to understand how designers intentionally explore variants of problems on the way to solutions. Through an empirical study industrial design students, we document a high degree of variation in the problem perspectives between designers working on the same problem. Analysis of qualitative changes in problem perspectives reveals systematic patterns. The results showed a causal relationship between the number of strategies used in reframing the problem and the quality of the solution generated. Evidence for the utility of problem exploration strategies in the problem defining stage is examined and suggestions for their use in design pedagogy are provided.

Introduction

Design education often focuses on developing solutions rather than a facilitation for broader explorations of the problem that may lead to consideration of a more diverse set of potential solutions. The process of problem exploration allows the designer to discover the essential properties of the problem, along with the creation of an appropriate solution. When faced with complex problems with many potential directions to take, asking different questions to explore the problems than the ones presented may lead to innovation [4]. True innovation requires looking beyond the problem as presented in order to “discover” the true problem, a process we call problem exploration. Problem exploration includes restructuring problems as it defines the set of possible solutions and is crucial to search for innovative solutions of this constrained set.

As the design work progresses from the initial presented problem through concept ideation and development, and on to the prototype stage, desired features and constraints are modified, leading to a redefined problem. Past research shows that design experts simultaneously, and iteratively, ‘explore’ a problem while searching for solutions [7]. More rich and varied problem descriptions occurs with greater levels of expertise [2], with superior depth and detail, more interconnections, and more actions. Paton and Dorst [14] describe the ability to “frame a problematic situation in new and interesting ways” as one of the key characteristics of design thinking. This ability is also seen as a longer-term predictive for reputation and financial success [9].

Further, empirical studies have documented that problem statements change as the design process progresses, termed as co-evolution [5-7]. This oscillation between the solution and problem suggests a process where a stated problem is subject to restructuring as solutions are considered, leading to simultaneous and iterative explorations by the designers while searching for possible solutions. Although there are many studies examining the evolution of the solutions space, there are fewer studies examining how designers explore stated problems to have a full analysis of the problem space. While the importance of problem exploration has been evident in the literature, there is a lack of empirical evidence on problem exploration [16].

To address this gap in the evidence about how designers successfully explore problem, through an empirical study, we documented design students' problem explorations as they created new opportunities for their solutions. This empirical study provides evidence about how designers intentionally alter the stated problem in the course of generation novel solutions. Rather than beginning with a search for solutions to a given problem, we propose an initial search to find the problem [16].

Problem Exploration Strategies

We propose that problem exploration is a vital contributor to the creation of innovative solutions. Some design texts and popular books offer techniques however they don't provide empirical evidence. One approach offered by MacCrimmon and Taylor [12] identified complexity as being a limitation in problem formulation and provided four decision strategies: 1) determining problem boundaries, or examining the assumptions; 2) examining changes, or focusing on any alterations changes in the problem description; 3) factoring into sub-problems, such as using methods including morphological analysis [10] and attribute listing [15]; and 4) focusing on the controllable components, or selective focusing [17]. Fogler and LeBlanc [8] proposed strategies for defining "the real problem" underlying a given engineering problem. The "5 Whys" [3] technique, used by the Toyota Motor Corporation, repeatedly asks "Why?" question in order to explore the cause and effect relationships underlying a problem. Abstraction laddering [1], is also used to better understand the problem space based on the data gathered from stakeholders. It focuses on asking a series of 'how' and 'why' questions to describe the design problem at increasing or decreasing levels of abstraction. Parnes' [13] restatement method varies how the problem is stated using prompts, such as 'vary the stress pattern by placing emphasis on different words and phrases in the problem', and finally, the Kepner-Tregoe [11] pushes the designers to distinguish what the problem 'is' and 'is not'. All of these techniques propose to trigger questions that may assist designers in further defining the presented problem; however they are lacking the empirical evidence of their use in creating innovative solutions.

Experimental Approach

This study seeks to understand how cognitive strategies promote exploration of the problem space while the design students' were working towards the goal of innovative outcomes. Based on our prior work on problem exploration strategies [18-20], we hypothesized that design students use such strategies although they may not be deliberately conscious or elaborate about this process. Do these changes in problems occur naturally in the design process? Can problem exploration strategies be identified in students' design problem definitions? How does the use of strategies differ among the design students?

Participants

Fifty-four junior industrial design students (43 males and 11 females) taking the same project-based course focusing on systematic design methodology at a large Midwestern university participated in the study. This 6-credit course is the third required studio course in the industrial design curriculum after completing the core program in the first year. The students are not considered as novices as they had an entire year of industrial design education before their junior year. Although, they were not exposed to problem framing as a concept before their junior year.

Data Collection and Analysis

This study was conducted in a classroom setting. As part of their ongoing project, students were given a broad design problem based on an international houseware competition. Students then were given two weeks to gather user insights on potential problems to target and create their own problem statements which varied from designing new organizers to ergonomic razors. They were then asked to generate up to five concepts addressing the issues stated in their own problem definitions. Then, in a new task, we asked them to go back and define the problem they had addressed within each of their solutions: “For each of the solutions you generated, write a problem statement that would allow other students to come with the same solution”. This was challenging for the students but allowed them to identify their own view of the important differences between their original stated problem and their innovated problem they solved. This session took about 20 minutes which seemed to be sufficient as most students were done writing the corresponding problem statements, to their design solutions. The data reported in this paper compares the original problem statement students submitted while they were generating the design solutions and the four innovated problem statements they generated based on the concepts they developed.

The original problem statement and the innovated design problems based on the solutions created were analyzed by two coders trained in industrial design. These coders (first and second author) scored the evidence of problem exploration strategies observed in each problem statement and documented the difference between the original statement and the new statements. Each statement was initially reviewed individually through several steps of design criteria, such as, . The initial component that was coded was the context to understand what the individual was designing for. The outcome was then identified as well as its functionality or motivation. Afterwards, the rest of the statement was analyzed to identify any other supporting information that further provided any descriptors. Once all statements were mapped with strategies, they were crosschecked with previous statements to ensure that the usage of each strategy was consistent. After the original problems and reframed problem statements were analyzed by each participant, their respective concept sketches were explored to understand how the new problem framing impacted the outcome.

Results

Fifty-four participants generated three to five unique problem statements based on the solutions they generated. This resulted in an analysis of 218 innovated design problems.

RESEARCH QUESTION 1: Can problem exploration strategies be identified in students' design problem definitions?

Using an inductive thematic analysis (Boyatzis, 1998), we were able to identify the commonly used patterns design students used in diversifying their problem framings, to generate new and innovative solutions. We were able to extract strategies that pushed the initial problem statement to a different direction in all 218 problem statements generated. Of the 218 problem statements, all showed evidence of more than one strategy use. Table 3.1 shows two design solutions and accompanying problem statements where P39 shows one strategy use in problem reframing, while P51 demonstrates multiple strategy use for problem exploration strategies. In the reframed problem statements and the associated solutions where multiple strategies were evident, the concepts showed signs of more developed or complex ideas. For example, participant P39 generated a problem statement that only utilized two types of strategies, whereas P51 used six strategies. After looking at the concepts they drew for their corresponding statement, P51 generated a more complex and in-depth idea. This suggests that more detailed strategies used in the problem statements results in more innovative solutions.

Table 3.1 Problem-Solution example demonstrating two participants' data

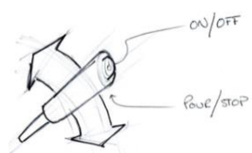
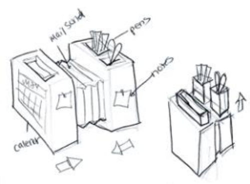
Participant	Problem Statement	Concept Solution	Concept Description
P39	Make an easy access coffee maker.		Design a coffee maker: Handle that implements both on and off and pouring tap
P51	Organize office supplies like pencils and scissors, emphasize and organize key notes to self and family members and store and sort mail, all while saving counter top space in a family home.		Design home organization: When the pieces push together, the pencil supplies compartments pop up to allow

Table 3.2 shows the sixteen strategies observed in this dataset, collected from design students, with an example demonstrating potential applications for a backpack design.

Table 3.2 List of sixteen strategies observed

#	Strategies observed	# of times observed	Example application in the problem statement
1	Define the product/service	148	backpack
2	Define the primary function	87	to house photography equipment
3	Define the context	84	in rainy regions
4	Product specification	73	has a rugged shell
5	Define attributive characteristics of the product/service	54	outdoors
6	Define user interaction characteristics	42	access camera gear in a simple manner
7	Define the user	40	young adults who enjoy hiking
8	Define efficiency characteristics	39	easy to carry
9	Describe an unwanted situation	32	isn't bulky
10	Describe a potential use scenario	29	when hiking in a downpour
11	Describe the user sentiment state (think, progress, motivate)	21	enforces safety of the equipment
12	Define mobility characteristics	17	portable
13	Define perceived materialistic attributes	15	lightweight, breathable
14	Define emotional characteristics	14	hassle-free
15	Define spatial characteristics	10	space saving
16	Insert a limitation	6	only houses necessary equipment

The most commonly observed strategy among the 218 problem statements was 'Define the product/service' (68%), followed by 'Define the primary function' (40%). This is expected as the design students tend to label what the product would be, such as, manual razor, or an office accessory, with a focus on the primary functions, such as trimming, or organizing. The three least observed strategies were ‘Define emotional characteristics’ (6%), ‘Define spatial characteristics’ (5%), and ‘Insert a limitation’ (3%). Overall, this table serves as a guideline to showcase designers’ priorities to identify design problems. After observing the strategy ranking in order from most to least prominent, it is apparent that the strategies increase in specificity and detail as the usage amount decreases. This is also acts as a hierarchy as the strategies needed to be expressed first were the most commonly stated.

RESEARCH QUESTION 2: How do the use of strategies differ among the design students?

How did different students apply the same strategy across problem contexts?

In order to understand how one single strategy can be applied to different problem statements, we chose three participants’ data, as they applied ‘Define perceived materialistic attributes’ to their original problem statement in order to shift their problem-solution exploration (Table 3.3).

Table 3.3 Example of Material strategy across two different problem statements

Participant ID	Original Problem Statement	Reframed Problem Statement
P17	How to improve small kitchen appliances for college students that have little to no cooking experience and results in overall better performance?	Create a smart, durable kitchen appliance that stresses simplicity and elimination of food waste.
P7	How might we design a disposable razor that gives users the freedom to choose the length at which they cut their facial hair?	Design a manual razor that allows the user to adjust the length to which they cut their hair, and provides the comfort and flexibility provided by other manual razors.

This material-focused strategy is used by the designer to understand and integrate what the material could look and feel like. For example, P17 reframed the ‘better performance’ as ‘durable’, making an assumption that if the appliance was durable, it’d increase its performance. P7 used this strategy in a way to bring comfort and flexibility to the user. Figure 3.1 shows the corresponding solutions for each of the reframed statements in Table 2, with the explanations provided by the students.

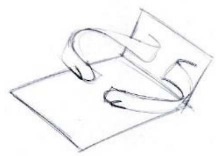
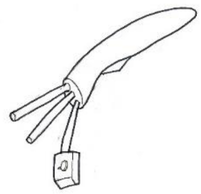
	
P17: Design a kitchen appliance	P7: Design a manual razor
Adjustable arm scan the cup to get a measurement of liquid	To increase flexibility in trimming, the head can be attached to one of the three different necks.

Figure 3.1 Concept solutions solving reframed problems

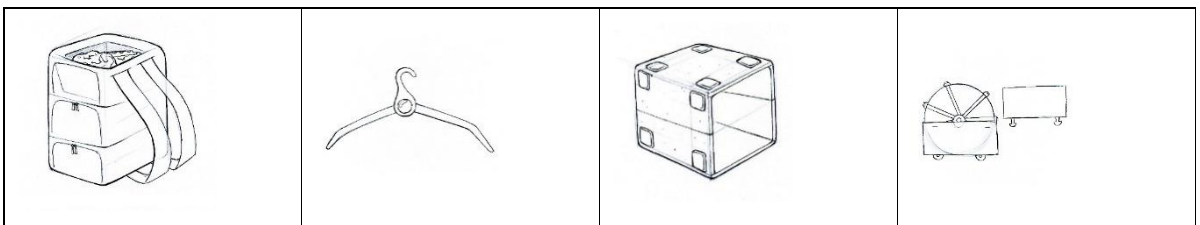
How did different strategies, when applied to the same problem, lead to different problems?

In order to explore how the use of different strategies lead to different problem statements, we traced the evolution of problem statements generated by the same participant, using the same original problem statement as the initial prompt. Each statement, created by Participant 13, utilized a unique set of strategies that lead him explore new solutions with diverse characteristics and features. The participant used home organization, specifically storage, as the main category for developing problem statements. For the analysis (Table 3.4), each statement was broken down into short phrases and then labelled with its respective strategy. For each statement, there was also a concept that resulted from the reframed problem. Because the statements were diverse and broad enough, the concepts differentiated from each other, dramatically, supporting the prior findings on the relationship between problem-solution spaces, how a new problem could lead to exploring a new solution (Author; Dorst & Cross, 2001).

Table 3.4 Reframed problem statements generated by P13, and the observed strategies corresponding to the characteristics of these statements

	Reframed problem statement	Strategies observed
1	Create a portable, segmented, and rotatable wardrobe piece	Define mobility characteristics; Define flexibility of use; Change the context of use
2	Simplify the process of hanging clothes	Define the process of use; Change the context of use
3	Create a modular and collapsible way of segmented storage spaces	Define mobility characteristics; Define spatial characteristics;
4	Reduce clutter and rummaging with many pairs of footwear	Describe an unwanted situation; Define the product in context

Figure 3.2 shows the varied concept solutions generated by the design student (P13), focusing on different reframing of the same problem. For example, the concept for problem one was a portable organizer similar to a backpack, whereas the concept generated from problem three was a flat-pack, cube organizer. Since problem one focused on mobility characteristics and perceived materialistic attributes, the participant created a sturdy backpack form to account for these strategies. For problem three, the participant focused on spatial and user-interaction characteristics to generate a solution for modular and collapsibility criteria. Because P13 used a variety of differentiating strategies for each concept, they visually and conceptually resulted in very different ideas.



Instead of being stuck in a wardrobe, this concept could be used for hiking. As a result, the top can be turned into a container for holding interesting things found along the way.	The arms use less material so they’re smoother.	Other than magnets, this concept is made out of a durable, recyclable material… maybe some sort of high density cardboard or mat board?	The packaging container for the shoe wheel is split into two halves; the bottom half has cut outs for the wheels and can be used to store more things.

Figure 3.2 Concepts generated by P13, based on reframed statements in Table 3.4

Discussion

The results from this exploratory case study showcased that there is evidence of commonly observed strategies that the design students use in exploring the problem space. They do this as they create new solutions or iterate on their prior solutions. These strategies varied in frequency of incidents observed, as well as the level of specificity. For example, ‘Define the product/service’ was observed 148 times whereas ‘Insert a limitation’ was only seen 6 times, in the data set of 218 problem statements. Although the difference among the quantities is rather noticeable, it seems to be reasonable as some of these strategies are more advanced, meaning they require more elaboration and intentional thinking regarding how the problem could vary to target different aspects of the problem space. These ‘more advanced’ strategies are not required to build the essential structure of the problem statement; however they seem to diversify the solutions in unique ways.

Another finding observed is the relationship between the number of strategies used in reframing the problem and the quality of the solution generated. The number of strategies observed in each problem statement varied between two and five. Compared to the solutions generated with five strategies applied, concepts with two strategies are very similar to the prior solutions the student created. This tells us that the more diverse strategies explored, the richer the problem statements will become and the more unique the solutions will be. Although this is a hypothesis based on a small sample size and an exploratory study, the patterns seem to show evidence of these outcomes. This is because students who used more diverse strategies as they explored the problem space expanded their thought process past the typical, basic requirements.

The case studies discussed in this study emphasize the importance of the designers’ conscious strategy use in identifying and reframing a diverse set of problem statements. The strategies that were evident in the participants’ problem statements were consistent with the strategies previously identified in other studies (Author; Author; Author). This is an important finding because it builds a case that many of these strategies are applicable independently of the specific problem context. While some may be more applicable than others depending on the context, the use of these strategies is consistently observed across problems.

This exploratory case study examined only 218 problem statements generated by fifty-four design students, and so is limited in the conclusions that can be drawn about the efficacy of problem exploration strategies in the design problem definition and framing process. This study was also limited by the constraints for the time, and task definition, which may not reflect typical working conditions for designers. Additionally, problem definition and framing may occur more often in a team environment. Nonetheless, even this small set of data showed evidence of strategies existing in problem exploration and framing. The evidence of the contribution of these strategies to generating diverse design problems suggests a direction for design training that will enable students to gain the needed expertise in understanding the potential alternatives in design problems.

Conclusion

The goals of this study were to document how design students explore problems as they create new opportunities for their solutions and uncover what strategies they use in developing new problem framings of the presented problem. The research questions sought to determine whether problem exploration strategies can be identified in students’ design problem definitions and how the use of strategies differ among design students. Understanding and enhancing design education through the inclusion of problem finding, formulation and reframing is critical. Exposure to a list of strategies that could expand design students’ thinking on problem exploration and framing would benefit concept generation, success of the design process, and ultimately the innovation that may be brought into the market. This research study suggests that utilizing a diverse range of strategies in formulating new problem statements can lead to countless new concepts. This research provides the rudimentary building blocks of observed strategies with design students. Further research will continue to develop and refine the strategies that most benefit designers within design education.

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CHAPTER 4. DESIGN OF THE TOOL

Overview

While Study 1 uncovered 16 prominent strategies in the students' statements, Study 2 provided certain strategies to the students for implementation (Creeger, et. al., 2018). Study 1 conducted great exploration into the key characteristics students used as potential strategies. The results were valuable as it helped to understand that a smaller set of strategies were observed and there was more overlap in strategies than anticipated. Although Study 1 was insightful, the strategies used in Study 2 were referenced from two previous studies (Studer et al., 2018; Studer et al., 2017). Previous research with coded strategies were compiled and analyzed to methodically use for Study 2 described below.

Process of Synthesizing Heuristics

The heuristics used in Study 2 were a compilation from two studies that initially began in 2015. The first phase investigated existing problem statements that derived from design competitions that provided open source briefs, such as open IDEO. This was a content analysis of what people relied on and how they reframed the original problem statements with many variables and constraints (Studer et al., 2018). The second phase was a protocol study that collected data from 35 engineering practitioners and students, as well as 15 Industrial Design practitioners and students. In the pilot study, the researcher provided the participant with a problem statement and was asked to reframe the statement in a different way. The study showed that the participants were unable to accomplish the task because they did not know what it meant by 'reframing the statement'. Since the method for the pilot study was too complex, a new protocol was suggested. This version gave the students a problem statement and were first asked to solve the problem. Based on the solution they generated, they described the problem they were solving. The participants repeated this process five times, which translated into problem-solution co-evolution (Studer et al., 2017). Through these two papers, a content analysis and protocol study, the data led to 67 heuristics in total (individual data shown in Table 4.1). Both sets of data were analyzed and compared to one another, however, it was noticed that there was inconsistency in language and specificity. This incongruency led to the next step, which resulted in taking all of the heuristics to compile into different categories. These were then narrowed down for newly phrased versions. The goal of Study 2 was to create a set of heuristics from the two studies that would resonate with design and engineering students: language wise, definition, and specificity. Afterwards, the next step was to put it into a tool that tested the quality of it, as well as the impact of the tool on the problem generation space.

Through various stages of thematic analysis of thirty-five identified problem exploration heuristics from Studer et.al (2017) and thirty-two identified heuristics from Studer, et.al (2018), twenty-eight heuristics were methodically narrowed down. Heuristics from both papers were organized by themes. Once the heuristics were categorized, a new proposed list was created. The observations supporting this set of 28 strategies are shown in Table 4.1. An important feature of this compilation of strategies across studies is that each heuristic was observed multiple times. Even though the design problem and setting changed with each study, a great number of previously identified heuristics were observed in each study. This suggests the identification of heuristics had reached a point of saturation across the entire set of concepts in this compiled dataset. The data observed led to twenty-eight strategies across the two studies.

Table 4.1 Observations of heuristics observed across studies

	Study A	*Study B*	
	Content Analysis	Protocol Study	Compiled List
	35 Heuristics JEE 2017	32 Heuristics AIEDAM 2018	28 Heuristics
Needs/Goals	Describe the Users' Need (56)	Determine the end user and detail their needs (19)	Determine stakeholders' needs
		Break down the desired outcome (15)	
		State the desired outcome (20)	
	State the Primary Need (114)		
	Break Down the Primary Need (129)		
User/Stakeholder	Determine the Primary User (28)	Describe the primary stakeholder (4)	Describe the characteristics of the stakeholders
	Break Down the Primary Stakeholder Group (19)	Break down the primary stakeholder group (2)	
	Substitute an Individual Stakeholder for a Group (3)	Substitute the individual primary stakeholder for a group (8)	Substitute the primary stakeholder with another stakeholder
	Expand the Primary Stakeholder Group (5)	Expand the primary stakeholder group (5)	Expand the primary stakeholder group
		Substitute the primary stakeholder group for an individual (6)	
Function	Detail the Required Functions (16)	Detail the required functions (40)	Describe the characteristics of the presented functions
	Describe Secondary Functions (14)	Describe secondary functions (17)	Describe secondary functions
			Describe how the functionality will be fulfilled
	Integrate Existing Products to Address Secondary Functions (4)	Integrate existing products to address secondary functions (12)	
	Find the Root Cause (1)	Find the root cause (20)	Determine the underlying issue
Setting	Describe the Setting (87)	Define the characteristics of the setting (9)	Describe the characteristics of existing conditions
	Expand the Setting (1)	Expand the setting (16)	Expand the problem setting beyond existing conditions
	Describe Environmental Conditions (15)	Describe the environmental conditions (7)	

Table 4.1 (continued)

		Prioritize use cases (21)	
	Focus Setting/Scenario (48)		
Scenario	Incorporate More Scenarios (12)		Describe a use scenario / setting / context
			Add unexpected use scenarios
User Interaction	Integrate Mobility (22)		Describe user's interaction with the functionality
	Include Multiple Ways to Interact (1)		
		Include multiple ways to interact (39)	
Physical Product Considerations	Describe the Required Dimensions (24)	Describe the required size and space attributes (2)	Describe dimensional attributes
		Integrate mobility (24)	Describe mobility characteristics
	Describe Material Characteristics (48)	Describe material characteristics (14)	Describe material characteristics (tangible and perceived)
			Describe perceived materialistic attributes
	Describe the Required Maintenance Needs (8)		Describe maintenance needs
	Describe the Desired Appearance Attributes (8)	Describe the desired visual attributes (13)	Describe desired aesthetic attributes
Operational Considerations	Determine the Required Costs (20)	Determine the required cost (17)	Describe cost constraints
		Describe the required manufacturing process and its limitations (7)	
		Incorporate user customization in manufacturing process (6)	
	Detail the Operational Requirements (34)		
Inspiration	Utilize Existing Solutions (28)	Describe an existing solution to use as conceptual inspiration (12)	Rely on existing solutions
	Modify Existing Solutions (12)		Modify existing solutions

Table 4.1 (continued)

	Describe an Existing Solution to Use as Conceptual Inspiration (7)	Consider existing solutions (2)	Use existing solutions to build analogies
Limitation	Add Potential Limitations (5)	Add potential limitations (19)	Add potential limitations
		Break down the addressed limitations (19)	
Cultural	Elaborate on a Method/Means (60)	Focus on eco-friendly solutions (14)	Describe environmental footprint
	Focus on Eco-Friendly Solutions (15)	Shift focus to cultural issues (2)	Shift focus to cultural issues
	Shift Focus to Cultural Issues (2)		Examine assumptions
	Examine Assumptions (2)		Extend the product's influence beyond its use
		Describe the brand values (5)	
	Prioritize Use Cases (13)		
	Expand the Scope (5)		
	Focus on Education (2)		

Although there were twenty-eight strategies identified, not all could be used for Study 2 due to restrictions of time and resources. To begin the process of understanding the impact of heuristics, only twelve strategies were methodically chosen based what would be the most relevant to the given problem statement (Chapter 5). Several identified heuristics were combined to provide simplicity. For example, in Table 4.1, the heuristics within functionality theme were merged into one strategy in Table 4.2 under Strategy 8. The idea was to provide broad enough thought-starters that were helpful to generate statements but were not too prescriptive in nature. The twelve strategies used for Study 2 are described in Table 4.2.

Table 4.2 Strategy Number, Name, and Questions prompting problem exploration

Strategy #	**Title**	**Questions prompting problem exploration**
1	Describe the Characteristics of the User and their Needs	What are the needs, tasks, and environments of the people to design a playground? What are the characteristics and attributes of the people using the playground?
2	Substitute the Primary Stakeholder with Another Stakeholder	Who are the others who might replace the primary users of the playground? Who else will be affected by the design? In what capacity? Consider both the individuals and the groups.
3	Describe Cultural Implications	How can the solution move beyond its functionality to serve other purposes and support the entire context of use? What requirements does the marketplace impose on the playground design?
4	Rely on Existing Solutions	What are similar existing solutions that target solving the playground? How can these solutions be used in exploring different problem directions? How can you modify an existing solution to shape the problem definition? What are comparable solutions or problems, and how can they help you build analogies on them?
5	Describe Visual Attributes	How does the problem determine aesthetic qualities of the playground? What are the material choices that will be visible to the people using the playground? What is the desired size in relation to other solutions around and the environment it will function in?
6	Describe the Context	What are potential scenarios where this playground could occur in? What are unique or unexpected ways the playground could be interacted with beyond its primary function or scenario? What is the context which the problem takes place?
7	Describe the Users' Interaction	How does the user(s) interact with the playground? How can their interaction be integrated into the solution?
8	Describe the Functionality	What are the main functions the design of the playground has to focus on? How do you characterize these functions?
9	Examine Assumptions	What are the items or actions that are already known to be true for the design of the playground? How can you challenge them? How can you narrow the scope of the playground?
10	Determine the Underlying Issue	Does the design of the playground solve the right problem at the right level?
11	Describe Mobility Characteristics	How do the mobility features or concerns affect the playground?
12	Describe Maintenance Needs	How will the playground be tested during design and fabrication? To what extent of testing is needed? What kinds of tests are needed?

Identifying a Digital Platform for the Tool Development

The entirety of the study revolved around a customized tool that each student utilized when reframing their statements. The tool took place on a digital platform so that each student could complete the study on their individual laptops or computers. A customized website was created using Visual Studio Code for the programming and GitHub pages to host the website. Multiple mock-ups and prototypes were created before the digital tool was released for the study. The website also went through several iterations to ensure seamless accessibility and usability for the students.

Pilot Testing

Before the study began, a Usability Test was created to ensure that the tool itself did not confuse or distract the student from the tasks at hand (Dumas & Redish, 1999). The student chosen for this test had experience in digital applications and was able to provide helpful suggestions to generate another round of revisions before conducting the study. A think-aloud protocol was used for the Usability Pilot Testing before the study. A think-aloud protocol was a necessary research method for this study because it allowed the participant to verbally process their thoughts aloud while they were performing the task (Fonteyn, et.al., 1993). It has been observed that think-aloud protocols do not alter cognitive processes when asked to verbalize their thinking (Cooke, 2010). This was very important so that their cognitive process and honest thoughts would be understood while they were naturally going through the study. One significant edit from the pilot study was to coordinate the page numbers in the provided packet with the task on the website. The page number was then referenced on each task for ease and simplicity.

Approach of Tool

An explanation of the digital tool is provided in chronological order for the study. Once the student entered their provided URL into a web address, the student landed on an introductory slide shown in Figure 4.1. This page provided a brief of the study and the importance of the problem generation space. This information also helped the student understand what tasks they were expected to accomplish.

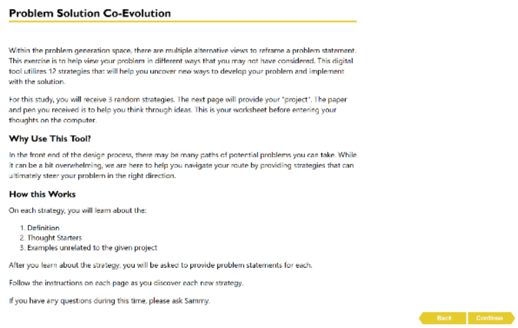

Figure 4.1 Introductory Website Page

The second slide displayed the provided problem statement shown in Figure 4.2. All students received the exact same scenario to ensure cohesive coding. At the bottom of the page, the students were asked to provide an initial problem statement that reflected the original statement. This step was important to understand how they phrased their statement without any influence on the strategies. Although this data was collected, it was not used for this study.

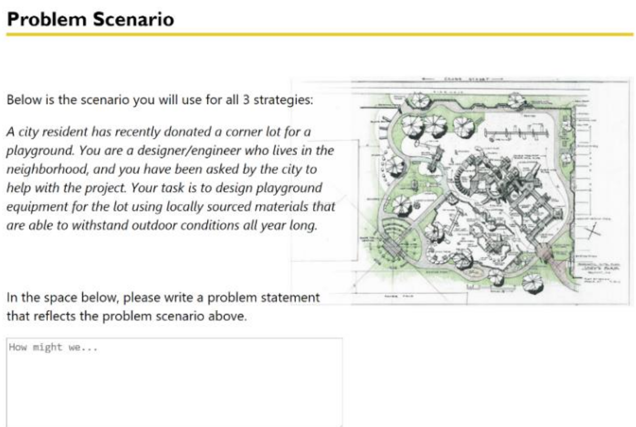

Figure 4.2 Original Problem Statement

Once the student entered a problem statement, they were directed onto the Strategy Generator page in Figure 4.3. The page instructed the student to press on the compass to receive a random strategy, however the three strategies were already pre-determined based on the URL they entered. This page also prompted the student to reference their packet in case they needed to write any thoughts or notes while they were working.

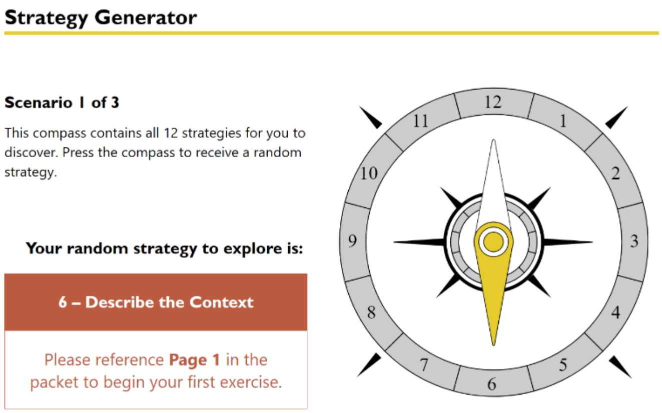

Figure 4.3 'Random' Strategy Generator

The next step of the study was learning about that provided strategy in Figure 4.4. There were three steps to this page: questions prompting problem exploration, thought starters, and examples unrelated to the given project. The prompted questions stemmed from previous research (Studer et al., 2018; Studer et al., 2017). Thought starters were broad descriptors to aid the student to think of how this strategy could be implemented. Finally, the three examples were created to help them see how it could be used. The examples, shown in Figure 4.5, were unrelated to the provided statement to further understand how each strategy could be applied to a potential problem.

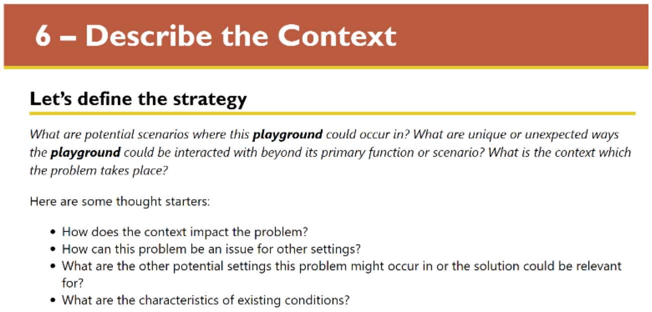

Figure 4.4 Definition Page

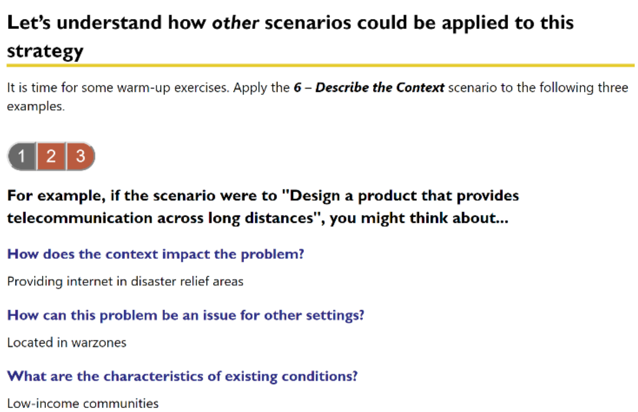

Figure 4.5 Examples to Familiarize Strategy

When the student felt comfortable to continue, they were then asked to generate as many problem statements using that particular strategy. A 'plus' button was clicked to allow for more submissions in Figure 3.6. Although they were encouraged to use the packet, the students were asked to enter all their reframed statements in the text fields on the website. This page provided the name of the strategy as well as the provided problem statement. When the student felt content with the submissions, the tool repeated to the Strategy Generator in Figure 3.3 to repeat the same steps for two more strategies.

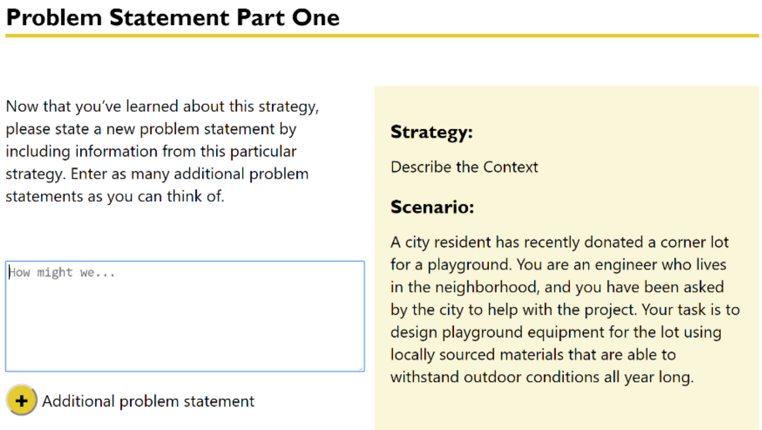

Figure 4.6 Forum to Enter Statements

Once the student completed all three strategies, a results and feedback page were provided, shown in Figure 4.7 and 4.8. Various demographic, quantitative, and qualitative questions were asked to further understand the effectiveness of the tool. When the student completed all questions, they were asked to digitally submit or print their results.

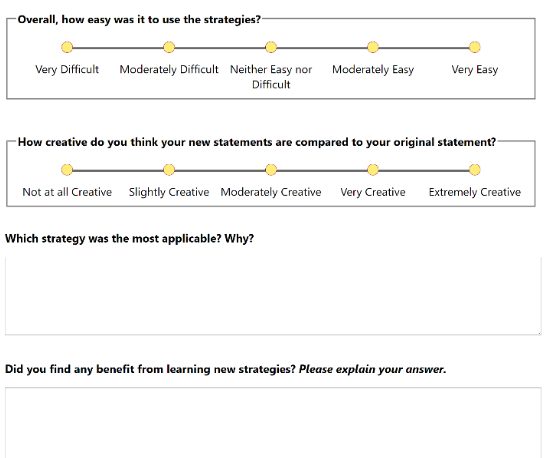

Figure 4.7 Results Page

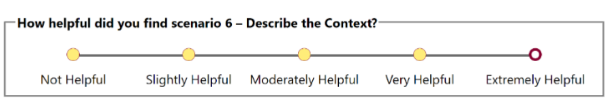

Figure 4.8 Example of Likert Scale

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CHAPTER 5. STUDY 2: EXPLORING THE PROBLEM SPACE WITH PROBLEM EXPLORATION STRATEGIES

Overview

In Study 1, sixteen strategies were observed through open coding of students' statements (Creeger, et al., 2018). Afterwards, a comparative synthesis was conducted with two previous studies to ultimately test twelve strategies for Study 2. The impact of these heuristics was tested on a design problem task in an instructional activity. Since it is unknown what tools are most beneficial, the study seeks to establish which heuristics promote divergent exploration of the problem space. This study will be guided by the following questions:

Q1: Did the students utilize the strategies provided?

Q2: How did the students perceive the benefit of using the strategies?

Q3: How did the students use each?

Q4: How much diversity is created among the new problems after strategy use?

Data Collection

For this study, participants focused on reshaping the problem provided to them into other potential problems, which may be more important to solve. They were encouraged to describe their written thoughts as they formed ideas for design problems in their provided packet (Appendix C), and then typed their statement into the digital forum. Each participant was given the same initial problem brief as well as the same format for the digital tool. Twelve problem exploration heuristics were methodically chosen, referenced by the work, Studer et. al (2017), and Studer et al. (2018).

This study was conducted in a classroom setting under the supervision of the instructors. Students of the same major were gathered together to ensure consistent directions and explanation. Each participant was asked to rewrite the given problem statement using three heuristics on their laptop or provided computer. The problem alterations were iterations of the previous problems, or entirely new ones. Participants were asked to work individually on their own devices. The participants only focused on understanding the true problems, not on solving the actual problem.

Before the study, each student was provided a packet (Appendix C), which included a unique URL and paper to write thoughts and notes for each strategy. The URL took the student to the main page of the tool. Four different URLs were provided in the packet as the students were randomly assigned to one of four groups: Group A, Group B, Group C, and Group D. Each group received three strategies that were different from the other groups. Since twelve heuristics were generated, all strategies would ensure for equal use.

Students were initially provided a brief and problem statement to understand the context of the study. “A city resident has recently donated a corner lot for a playground. You are a designer that lives in the neighborhood and you have been asked by the city to help with the project. Your task is to design playground equipment for your neighborhood.” This problem was chosen from Studer et al (2018).

For each strategy, the student had an opportunity to learn all necessary information about that strategy. Once they felt comfortable understanding the material, they were asked to generate as many statements as possible relating back to the provided strategy. From there, the process was repeated using two more strategies. The following data was not collected for this particular study; however, students were also asked to generate as many concepts from their statements within five minutes. Afterwards, the students used their recent solutions as inspiration to produce new problem statements. This in turn created a model of problem solution co-evolution (Dorst & Cross, 2001).

Participants

In total, 43 Industrial Design and Engineering students of varying experience and gender from Iowa State University participated in the study. The students were recruited to allow for robust, emergent themes during data analysis. Of the 43 that participated, only 40 of the participants' data were collected due to incomplete or missing data. All the students in Industrial Design were Junior status or higher as all have been exposed to problem framing before their Junior year and have experience to the design methodology. Students in Human Computer Interaction with engineering backgrounds are of Master's or Doctorate status. 9 students in Human Computer Interaction (HCI) (3 female, 6 male), 17 seniors in Industrial Design (8 female, 9 male) and 14 juniors in Industrial Design participated (8 female, 6 male). The overall average age was 22.92, SD=3.13. Figure 5.1 shows the number of participants in each group.

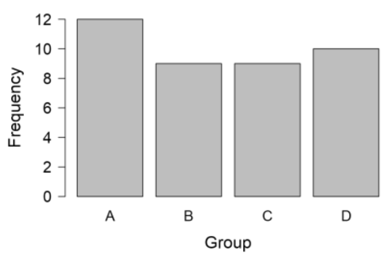

Figure 5.1 Number of Participants in each Group

Method

The methods used for data collection were an online protocol for gathering their statements, as well as retrospective questions in the form of a survey. Participants were asked several questions to understand their interpretation and experience during the problem exploration tasks. Utilizing a retrospective lens is used so that they are explaining their past experience and final opinions from the study. These questions helped further develop a case for understanding the thoughts and strategies behind the designer in redefining design problems (Gant, 1977).

Data Analysis

Discourse analysis was optimized to analyze the participants' typed and written information. Students were asked to print or digitally send their responses, which were then transcribed into a file. Each problem statement used a coding method where the statement was broken down into sub-components to identify which part of the statement was influenced by the strategy. Since participants in each group received the same design problem and strategies, the statements generated were compared against other participant's responses to see how effective that strategy was in helping them generate diverse statements. Group A received strategies 1, 6, and 10. Group B received strategies 2, 5, and 9. Group C received strategies 3, 8, and 12. Group D received strategies 4, 7, and 11. The answers to final retrospective survey were used to complement the analysis.

Results

This portion of the chapter answers each research question in detail. The type of analysis differs among each question and is supplemented with various tables and figures. Table 5.1 is provided as a reference guide when mentioning the strategy numbers. Forty participants generated unique problem statements, resulting in an analysis of 275 innovated design problems.

Table 5.1 Strategy Number and Name

Strategy #	Title
1	Describe the Characteristics of the User and their Needs
2	Substitute the Primary Stakeholder with Another Stakeholder
3	Describe Cultural Implications
4	Rely on Existing Solutions
5	Describe Visual Attributes
6	Describe the Context
7	Describe the Users' Interaction
8	Describe the Functionality
9	Examine Assumptions
10	Determine the Underlying Issue
11	Describe Mobility Characteristics
12	Describe Maintenance Needs

Q1: Did the students utilize the strategies?

In order to analyze all the research questions, the first step was to determine if the students successfully utilized each given strategy. If most of the students did not implement the strategy within their statement, the data would suggest a representation of an incoherent tool on the researcher's part, not the students. To avoid this error, a usability test was initially conducted to ensure that the tool itself would not distract the student from completing all tasks. The student was asked to conduct the study using a think-aloud protocol so that the student's thoughts and concerns could be recorded to improve the tool. A think-aloud protocol is an effective way to test usability for a digital tool (Cooke, 2010).

There were two parts to demonstrate there was evidence the participants utilized each strategy. The first step was to code each statement individually, rating if the student did or did not utilize the strategy given to them. If the student correctly used the strategy, a '1' was marked next to the statement. A '0' was given if the student did not accurately use the strategy. The rating was based off the codebook, which consisted of the definitions and thought-starters provided in the tool. Table 5.2 showcases the percentage of participants successfully using the strategy. The strategies with the highest percentage were Describe Mobility Characteristics (93.75%), Describe the Functionality (93.55%), and Rely on Existing Solutions (90%). The strategies with the least successful implementation were Determine the Underlying Issue (65%), Describe Visual Attributes (68.75%), and Substitute the Primary Stakeholder with Another Stakeholder (73.08%).

Table 5.2 Percentage of statements using each strategy

	Total	**YES (1)**	**NO (0)**	**% Used**
Strategy 11	16	15	1	93.75
Strategy 8	31	29	2	93.55
Strategy 4	20	18	2	90
Strategy 3	32	28	4	87.5
Strategy 6	24	20	4	83.33
Strategy 12	22	18	4	81.82
Strategy 1	26	20	6	76.92
Strategy 9	17	13	4	76.47
Strategy 7	25	19	6	76
Strategy 2	26	19	7	73.08
Strategy 5	16	11	5	68.75
Strategy 10	20	13	7	65
	275			

In order to ensure that the data was correctly interpreted and reduce bias, it was recommended to include a method to protect the quality of the research (Lincoln, Guba, & Pilotta, 1985). Since qualitative data is interpretive in nature, there are not standardized methods to ensure complete accuracy. However, any method used seeks to mitigate an interpretive bias of a single researcher. One way to analyze qualitative research is through coding, which captures phrases or an idea of the data and associate it to a general issue or topic (Rossman & Rallis, 2012). A method to maintain consistency in the coding and visualize the reliability of the coding is through the Inter-Rater Reliability testing. Inter-rater reliability is a numerical measure of the degree of agreement among the raters. This creates a percent agreement statistic. Multiple coders were asked to independently rate each statement so that the reliability between all codes could be evaluated (Gwet, 2014). Various researchers have various percentages of what is considered minimal or sufficient agreement among multiple coders. While Miles, Huberman, & Saldaña (2014) state that 80% is the minimum acceptability, other researchers like Hartmann (1977) and Stemler (2004) state that 75% is acceptable. The reliability was calculated by taking the number of agreements divided by the total number of agreements and disagreements. For this paper, a 75% acceptability was determined for minimum agreement.

Two coders with experience in research and generating problem statements were used to verify the data. Each student was given the same codebook and data within an Excel file. The codebook included the definition of each strategy, the same that all students were given for the study. All statements from each student were coded using a ‘1’ or ‘0’; ‘1’ being the student sufficiently used the strategy and ‘0’ being the student did not accurately use the strategy. For example, students were given a ‘0’ if they were too vague and used the name of the strategy verbatim. As an example, Participant 38 said “How might we build a playground that promotes interaction” when using Strategy 7, Describe the Users’ Interaction. This participant did not actually describe what the interaction was, simply saying that there should be interaction. The coders were given the same instructions and asked to complete the task individually. Table 5.3 shows the number of disagreements for each coder. Once the results from each coder were received, the data was cross-referenced with the lead researcher’s data. The number of discrepancies between the original coding data was recorded under each coder. That number was then averaged to uncover the agreement percentage, shown in Table 5.4. The strategies are ranked in order from highest percentage agreement to lowest.

Table 5.3 Coder Disagreement Results

		Disagreement #		
	Total	**Coder 1**	**Coder 2**	**AVG**
Strategy 1	26	3	9	6
Strategy 2	26	1	0	0.5
Strategy 3	32	2	3	2.5
Strategy 4	20	3	8	5.5
Strategy 5	16	3	6	4.5
Strategy 6	24	3	7	5
Strategy 7	25	6	6	6
Strategy 8	31	2	4	3
Strategy 9	17	1	6	3.5
Strategy 10	20	2	5	3.5
Strategy 11	16	1	1	1
Strategy 12	22	0	0	0

Table 5.4 Inter-Rater Reliability Percentage

	Total	**AVG 0**	**% Agreement**
Strategy 12	22	0	100
Strategy 2	26	0.5	98.08
Strategy 11	16	1	93.75
Strategy 8	31	3	93.55
Strategy 3	32	2.5	92.19
Strategy 10	20	3.5	82.5
Strategy 9	17	3.5	79.41
Strategy 6	24	5	79.17
Strategy 1	26	6	76.92
Strategy 7	25	6	76
Strategy 4	20	5.5	72.5
Strategy 5	16	5	68.75

The strategies below the 75% inter-rate reliability were below minimal agreement. Since strategies 4 and 5 were below the minimal agreement, inter-rater reliability is unacceptable.

Strategy 5, Describe Visual Attributes, had the lowest average agreement percentage at 68.75%. Although this strategy would be expected to have a higher agreement rate, there are a couple reasons why that was not the case. The first could be due to a lack of clarity in either the title or definition of the strategy. This strategy encompassed all components of visualization, being tangible characteristics and theoretical descriptors. For example, Participant 1 stated "How might we design durable playground equipment using locally sourced material?" The two coders gave a 0 to this statement most likely because it did not provide a physical characteristic. However, the word 'durable' suggests a potential material descriptor for is visual attribute. This strategy was also ranked low for implementation, shown in Table 5.2. This shows that the students had a difficult time utilizing the strategy successfully. This could either be a result of study fatigue due to the lowest number of statements provided and/or confusion of the prompted questions provided.

Strategy 4, Rely on Existing Solutions, was the other strategy with less than minimal agreement at 72.5%. This strategy asked to utilize analogies, case studies or past experiences as inspiration. There is reason to believe this received a low reliability percentage due to it being more subjective in nature compared to the other strategies given. Since this one asks for personal opinions and experience, the coders may have used their bias to suggest a different outcome. For example, Participant 35 stated "Design a reading game that encourages users to speak when using it." The coders did not agree this participant used the strategy; however, the statement suggests an existing game to be implemented within the playground. The statements were more open-ended and less obvious to uncover, resulting in a disagreement. 90% of the statements generated from Strategy 4 accurately used it, which showcases that there was more confusion on the coders' end, not the students.

Overall, the large amount of disagreement could be due to varying interpretations of the codebook. Due to the disagreement, this shows that the definitions should be narrowed upon further development to ensure consistency. It was noticed that strategies with clear and concise definitions, such as Describe Maintenance Needs, were obvious to spot if the student did or did not uses the strategy. When comparing the primary researcher's results to Coder 1, there were not any strategies below 75% agreement. However, when both coder's data was averaged, there were two strategies below the minimum agreement threshold. Due to the extensive number of statements to code, there was not enough time to appease each disagreement. If more time provided, all coders would have discussed the coding disagreements to perform other iterations of coding. Instead, an inference was made to reason the disagreements.

Q2: How did the students perceive the benefit of using the strategies?

After participants completed the study, they received a final page titled 'Feedback and Results'. This page displayed all the statements generated for each strategy, as well as survey questions to gather feedback on how participants perceived the benefit for this tool. Since a retrospective interview could not be conducted for each individual student in a classroom setting, a survey with multiple questions was used to understand the student's opinions and thoughts regarding the study and strategies they were given. There were two portions of the survey; a Likert scale and short answer questions. Each student was asked the following questions on a five-point Likert scale, '1' being not helpful/easy/creative and '5' being very helpful/very easy/very creative. A visual of the questions are displayed in Figure 4.7 and 4.8:

- "How helpful did you find strategy X"

- “Overall, how easy was it to use the strategies?”
- “How creative do you think your new statements are compared to your original statement?”
- “Which strategy was the most applicable and why?”
- “Did you find any benefit from learning new strategies?

Since each group received different strategies, the Likert scale questions were analyzed individually. Group A received strategies 1, 6, and 10. Group B received strategies 2, 5, and 9. Group C received 3, 8, and 12. Group D received strategies 4, 7, and 11.

Table 5.5 and Figure 5.1 display the results for “How helpful did you find strategy X?”. The highest rated strategy was 6, Define the Context (4.00, SD=1.04). The lowest rated strategy was 5, Define the Visual Attributes (3.00, SD=1.5). Overall, the averages were close in rating.

Table 5.5 Descriptive Statistics of all Strategies

	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**S11**	**S12**
Valid	12	9	9	10	9	12	10	9	9	12	10	9
Missing	28	31	31	30	31	28	30	31	31	28	30	31
Mean	3.58	3.89	3.56	3.30	3.00	4.00	3.70	3.67	3.33	3.58	3.40	3.78
Std. Error of Mean	0.34	0.31	0.41	0.37	0.50	0.3015	0.34	0.33	0.47	0.26	0.22	0.28
Std. Deviation	1.17	0.93	1.24	1.16	1.50	1.04	1.06	1.00	1.40	0.90	0.69	0.83

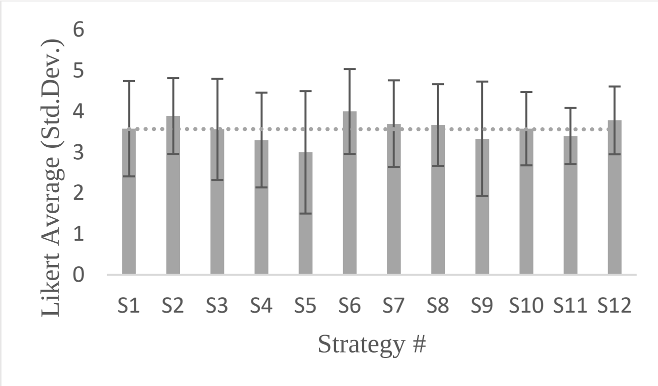

Figure 5.2 Averages of Likert Questions

The data was also used to compare between groups and cohort shown in Figures 5.2 and 5.3. Overall, the students in HCI rated 6 as the most helpful with the least as 5. Strategies 2, 12, and 8 were the highest ranked amongst the juniors, with 9 as the least helpful. The seniors equally ranked 10, 9, 5, and 7 as the highest and 8 and the least. The data among each group was mildly consistent in Figure 5.2. One data point of interest was Group B, Strategy 5 for HCI students. This data was the most extreme outlier, as it was significantly lower than the design students. On reason could be that the design students have a greater sense of visual attributes and have been trained on aesthetic appearance compared to the HCI students with engineering backgrounds, hence they might not have seen the value of such a strategy helping them.

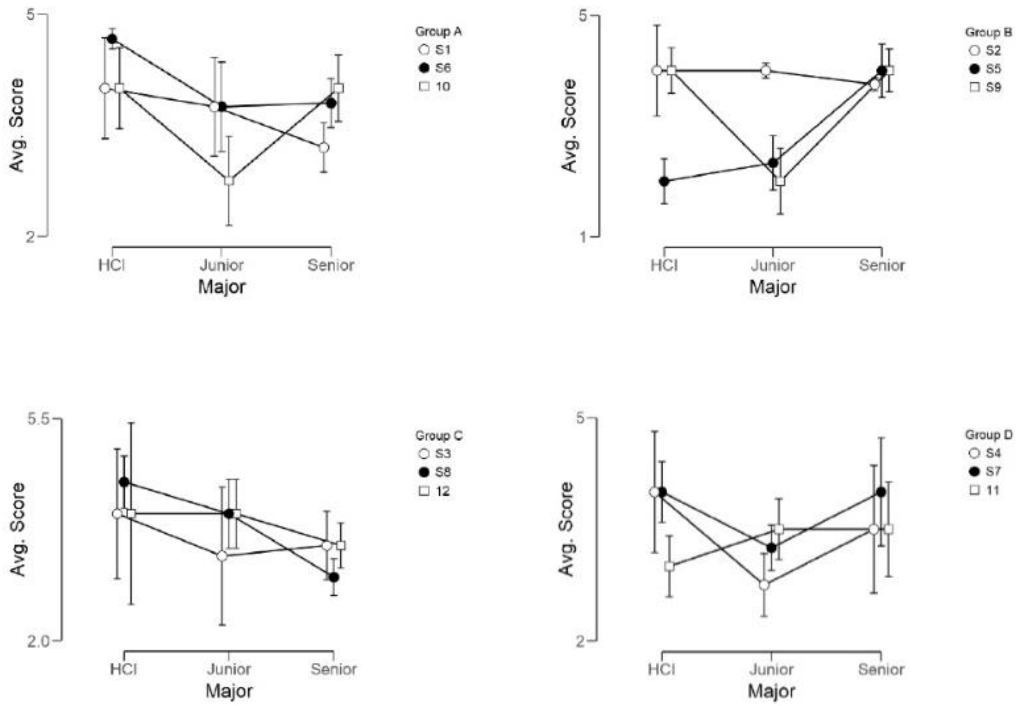

Figure 5.3 Visual Representation between group and cohort

Group A	Major	Mean	SD	N
S1	HCI	4.000	1.000	3
	Junior	3.750	1.258	4
	Senior	3.200	1.304	5
S6	HCI	4.667	0.577	3
	Junior	3.750	0.957	4
	Senior	3.800	1.304	5
10	HCI	4.000	1.000	3
	Junior	2.750	0.957	4
	Senior	4.000	0.000	5

Group B	Major	Mean	SD	N
S2	HCI	4.000	0.000	2
	Junior	4.000	1.000	3
	Senior	3.750	1.258	4
S5	HCI	2.000	1.414	2
	Junior	2.333	1.528	3
	Senior	4.000	1.155	4
S9	HCI	4.000	1.414	2
	Junior	2.000	0.000	3
	Senior	4.000	1.414	4

Group C	Major	Mean	SD	N
S3	HCI	4.000	1.414	2
	Junior	3.333	1.528	3
	Senior	3.500	1.291	4
S8	HCI	4.500	0.707	2
	Junior	4.000	1.000	3
	Senior	3.000	0.816	4
12	HCI	4.000	1.414	2
	Junior	4.000	1.000	3
	Senior	3.500	0.577	4

Group D	Major	Mean	SD	N
S4	HCI	4.000	1.414	2
	Junior	2.750	0.957	4
	Senior	3.500	1.291	4
S7	HCI	4.000	0.000	2
	Junior	3.250	0.957	4
	Senior	4.000	1.414	4
11	HCI	3.000	0.000	2
	Junior	3.500	0.577	4
	Senior	3.500	1.000	4

Figure 5.4 Data for Figure 5.2

For the other question “Overall, how easy was it to use the strategies?”, the overall average was 3.57, SD=0.90. Figure 5.4 shows the distribution plot of the responses. When looking at the difference among cohorts, the juniors rated the lowest values, although not significant.

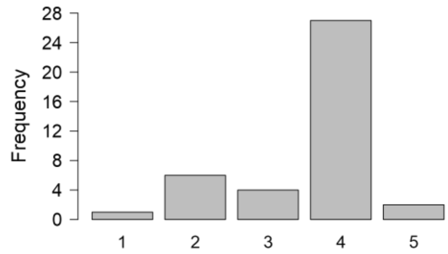

Figure 5.5 “Overall, how easy was it to use the strategies?”

The data was also compared against each group and major in Table 5.6 and 5.7. Group D voiced that their strategies (4, 7, 11) were the easiest (3.70, SD=.67), whereas Group C (3, 8, 12) had the most difficulty (3.56, SD=.73). The juniors had the most difficulty (3.00, SD=1.11) out of all the majors, which could reason that they had the least amount of experience reframing statements. Surprisingly, all HCI rated the ease of use at 4, SD=0. Their knowledge and years of school experience could be a reason they thought it was easy.

Table 5.6 Average response between Groups

	A	**B**	**C**	**D**
Valid	12	9	9	10
Missing	0	0	0	0
Mean	3.583	3.444	3.556	3.700
Std. Deviation	1.084	1.130	0.7265	0.6749
Minimum	2.000	1.000	2.000	2.000
Maximum	5.000	4.000	4.000	4.000

Table 5.7 Average among major

	HCI	**Junior**	**Senior**
Valid	9	14	17
Missing	0	0	0
Mean	4.000	3.000	3.824
Std. Deviation	0.000	1.109	0.7276
Minimum	4.000	1.000	2.000
Maximum	4.000	4.000	5.000

When asked “How creative do you think your new statements are compared to your original statement?”, the overall average was 3.375, SD=0.98 shown in Figure 5.5.

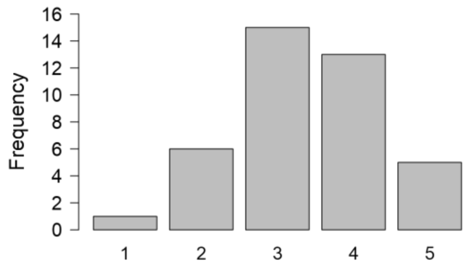

Figure 5.6 Creativity average

In Table 5.8, Group A (1, 6, 10) perceived their reframed statements to be the most creative (3.83, SD=.83), whereas Group D (4, 7, 11) perceived their results to be the least creative (3.00, SD=.94). One interesting note is that although Group D considered their strategies the easiest to implement in the previous question, they thought that it did not produce creative results. The juniors also ranked their perceived creativity the lowest in Table 5.9 at 3.07, SD=1.00). The seniors had the highest average score of 3.65, SD=.93.

Table 5.8 Creativity average among Groups

	A	B	C	D
Valid	12	9	9	10
Missing	0	0	0	0
Mean	3.833	3.222	3.333	3.000
Std. Deviation	0.8348	1.394	0.5000	0.9428
Minimum	2.000	1.000	3.000	2.000
Maximum	5.000	5.000	4.000	5.000

Table 5.9 Creativity average among Major

	HCI	Junior	Senior
Valid	9	14	17
Missing	0	0	0
Mean	3.333	3.071	3.647
Std. Deviation	1.000	0.9972	0.9315
Minimum	2.000	1.000	2.000
Maximum	5.000	5.000	5.000

When analyzing the question, "Which strategy was the most applicable?", the results were analyzed and ordered by each group. The results are shown in Table 5.10.

Table 5.10 Results of question, "Which strategy was the most applicable?"

Group A	#Students	%	Group B	# Students	%	Group C	# Students	%	Group D	# Students	%
#6	6	50%	#9	3	33.30%	#8	4	44.40%	#7	5	50%
#10	3	25%	#5	3	33.30%	#3	3	33.30%	#11	4	40%
#1	3	25%	#2	3	33.30%	#12	2	22.20%	#4	3	30%

Starting with Group A, fifty percent of the students mentioned that 6, Describe the Context, was the most applicable. Participant 39 said: “It made me think of not only playground in my own neighborhood but at other areas with different users and needs. That could have been because I had begun to be more creative at the different ways to look at designing a playground so it could have just been because it’s the last strategy I used.” Several participants mentioned that order was important when using the strategies. Participant 24 mentioned that “getting to strategy 1 after already using both other strategies allowed me the most time to think about the problem”. Participant 33 also said Strategy 6 was the most applicable because, “It is easier to relate to the context than finding the underlying issue. The thought of ‘finding an issue’ makes it harder to be creative and the thoughts get more complex than it has to be.”

For Group B, all three strategies were equally applicable. One design student said Strategy 5 was more applicable because it was more tangible and possibly more in the realm of what they were used to solving for. Participant 15 said, “I think the scenario 5 - Describe Visual Attributes was the most applicable simply because it was the easiest to translate directly into design criteria, whereas the other methods were a little more abstract.” However, Participant 31 preferred Strategy 2 because, “…it focuses on all of the people involved/around a playground, who could use it, and others affected. It allows one to make sure it is as inclusive as possible.” Finally, Participant 5 preferred Strategy 9, Examine Assumptions, because, “I felt like this really helped me to look at any biases I might have and push myself to think more creatively.”

For Group C, Strategy 8, Describe the Functionality, received the highest percentage of applicability: 44.4%. The students who preferred this strategy described as being the building blocks or quintessential piece of the problem statement. Participant 8 said that it “…is the most important thing on designing a product, being able to identify the functions helps a lot in solving problems.” Participant 23 also stated that, “I thought the functionality strategy was most applicable. It was key to understand how the playground equipment was going to function before anything else. If you don't know the purpose of the playground then it is more difficult to consider other factors.”

For Group D, half of participants said that Strategy 7, Define the Users’ Interaction, was the most applicable. Participant 3 had a unique insight saying that Strategy 7, “was the most applicable to design the best solution for a new playground, however, the mobility one helped me get the furthest away from my initial ideas and be the most creative.” Others who preferred the mobility strategy said it was the least restrictive which allowed them to think of many ideas.

There were several themes that emerged from the final question, “Overall, how easy was it to use the strategies?” (1) Critical thinking, (2) expanding perspectives and (3) helpful probes were 3 themes uncovered from all responses.

Critical thinking allowed the students to dig deeper about the problem at hand. Participant 15 from the HCI said, “… it got me thinking more critically about what I had written.” Participant 23 said, “It made me critically think about the key factors when it came to the design of the playground equipment.”

Expanding perspectives, discussed the ability to think in new ways they may never have explored before. Some students enjoyed the addition of the Thought Provokers section. “The Thought provokers are best for finding a divergent path to explore and generate concepts (P43).” Another student mentioned that, “I could see that my problem statements became more rich and creative after thinking about the strategies (P17).”

Helpful probes allowed the student to think in new ways they may have never explored before. Participant 42 considered this tool to be beneficial as, “… this approach gave me new avenues in which to frame my problem statements. Avenues in which I would not have thought to consider when reframing the problem.” Participant 19 said, “Sometimes it's difficult to keep all the different strategies in mind. It's nice being probed with the various strategies to help design thinking.”

Although many students praised the usefulness of the tool, there was critique for the strategies itself. One critique was that, “The culture strategy was a little less helpful and I felt like I was really reaching for solutions (P23).” Another participant also critiqued the medium of the tool itself: “I think just having a list of them would have been nice (P27).” As for the applicability of the tool, Participant 31 stated that, “I think using these strategies will have you focus on a specific problem but make you forget about the other design objectives/requirements needed for the playground."

Q3: How did the students use the strategies?

Question 1 showcases that the students successfully used the strategies, but how do they implement them within a statement? This question addresses the range of statements and how they differ among each other. For reference, Table 5.11 displays two examples of reframed statements for each strategy. Strategy 1 focused on defining who the user was for the playground and what their needs were. It was noticed that most students defined the user as children since it is the most obvious answer to provide. What did differ among the reframing was the extent of specificity for the user. In Example 1, the student simply stated the user were kids, whereas Example 2 defines the user as 'children with disabilities'. For Strategy 2, the students were asked to substitute the primary stakeholder with another stakeholder. Similar to Strategy 1, most student assumed that children were the primary stakeholder, so most of the statements revolved around the parents or caretakers, shown in Example 2. The only statement that did not define the playground for children or parents was Example 1, which created a playground for pets. Strategy 3, Describe Cultural Implications, was more open-ended and allowed the student to define 'culture' in their own terms. In this sense, the reframed statements varied in specificity and definition. In Example 1, the statement was more on the broader spectrum by creating an inclusive playground for varying cultures. Example 2, however, states that the cultural implications were creating an inclusive playground for varying generations of people. Strategy 4 asks the students to rely on existing solutions when reframing their statement. Many students described existing infrastructure as a method of inspiration, however students also specified unique examples. In Example 1, a student described a type of game to implement within the playground. Several students also used biomimicry as a way to generate statements, shown in

Example 2. Since this strategy heavily relied on a student's personal experiences, the results greatly varied in specificity. Strategy 5, Describe Visual Attributes, received statements with varying topics. Some students explained the physicality of the materials, whereas other students where very broad in their descriptions shown in Example 2. Instead of describing the tangible attributes, some described how it would look as a cohesive unit within its community and environment. For Strategy 6, students were asked to describe the context in which the playground took place. The statements varied in range since the type of scenario and setting was up to the student's interpretation. Example 1 discusses the weather in which it would take place, compared to Example 2 which discusses the safety and well-being of people using the playground. The students who reframed statements for Strategy 7, Describe the User's Interaction, where mostly similar in theme although they varied in specificity. While Example 1 discusses the playground to be engaging, Example 2 further demonstrates how the playground could be engaging through literacy. Strategy 8 greatly varied in topics as the students were asked to describe the functionality. In this sense, students were able to determine if they wanted to describe the functionality in terms of the playground itself, the user, or other external factors. For Strategy 9, students were asked to examine the assumptions. Since an original statement was provided to them, most students used the existing information from that statement as assumptions, shown in Example 1. The student mentioned using locally sourced materials which is mentioned in the initial statement provided. Strategy 10, Determine the Underlying Issue, also varied in topics as the students were able to determine how they wanted to discuss the issue at hand. In Example 1, the student describes lack of socialization a main issue compared to Example 2 which describes the price of manufacturing as an issue. Strategy 11 described the mobility characteristics which discusses how mobility affects the playground. Although many students reframed their statements around exercise, shown in Example 2, there were students who were able to push away from mobility just being for the user. In Example 1, the student describes features of the playground being mobile for changing seasons. Finally for Strategy 12, students described the maintenance needs of the playground. The reframed statements were limited in terms of range but varied in specificity. Many students simply stated that minimal maintenance is required, however some students discussed the types of testing or budgets required in Example 2.

Table 5.11 Examples of each Strategy

Strategy	Example 1	Example 2
1	How might we design a community playground using locally sourced materials that expands kids' imaginations and creativity all year round. (P39)	Design a playground that allows children with disabilities to be able to play? (P12)
2	How might we design a playground for pets and their pet owners that is durable and uses locally sourced materials? (P31)	How might we design a playground so that adults can enjoy the playground while their children play? (P19)
3	Design a long lasting playground equipment that brings together people of different cultures? (P34)	Design a playground experience that brings together people of different generations together? (P34)
4	Design a game that improves the current color matching game on the playground (P35)	How might we design playground equipment that is inspired by the durability of nature? (P29)
5	How might we design a durable, weather resistant playground made of locally sourced materials such as wood, stone, and recycled goods? (P37)	How might we create a playground that is visual representation of the community? (P5)
6	How might we make the playground equipment durable in harsh winters? (P26)	How might we design the park to encourage many positive uses, and discourage negative uses (e.g. every town has that one park where drug deals often occur). (P20)
7	How might we develop playground equipment that is fun and engaging? (P6)	How might we design playground equipment that promotes literacy and learning how to read? (P29)
8	How might we design a playground that does not become hot to the touch? (P42)	How might we allow kids to swing on equipment? (P23)
9	How might we design a playground using locally sourced materials that are durable? (P31)	How might the park fit within and complement the city's existent parks (P27)
10	How might we design a playground that helps kids socialize with one another? (P26)	How might we design cheaper playground equipment that is sustainable? (P43)
11	How might we design accessible playground equipment that can be switched out and replaced with different pieces of equipment from season to season? (P29)	How might we create a more action and exercise based playground with new equipment? (P3)
12	Design an equipment that requires minimal maintenance? (P34)	How can we design a playground that will require less than $1,000 in maintenance a year and last 30 years. (P18)

Q4: How much diversity is created among the new problems after strategy use?

The final question seeks to understand the distance in which the statements can be pulled apart. Another step in qualitative analysis after coding is to identify themes amongst the data by extrapolating examples to offer explanations in the findings (Creswell & Creswell, 2013). For this stage in the analysis, all of the statements that accurately depicted the given strategy were analyzed. In the first stage, the statements were grouped together by themes, such as 'Community Oriented' or 'Location and Safety'. Once all statements were grouped accordingly, it was noticed that common themes were emerging across multiple strategies. All statements regardless of strategy were combined to form more coherent thematic groups. Within each theme, the statements were then ranked based on how similar or different the re-written statements were compared to the provided problem statement. The statements closest to the original were placed on level one. As the more novel the statements were, the lower the level the statement was placed. After several rounds of iterations, the farthest level acquired was seven. Overall, there were eight themes ranging in size and complexity. Figure 5.6 shows the eight themes as well as an example of the levels used in bold. The themes on the right-hand side lacked depth and diversity compared to the themes on the left, which created more of a matrix with its complexity. When organizing the statements, the ones that were similar in topic and description were placed next to each other in rows. When a statement was of similar theme but provided more detail or explanation, that statement was then placed below on a new level. Table 5.13 includes the name of each level as well as a brief description.

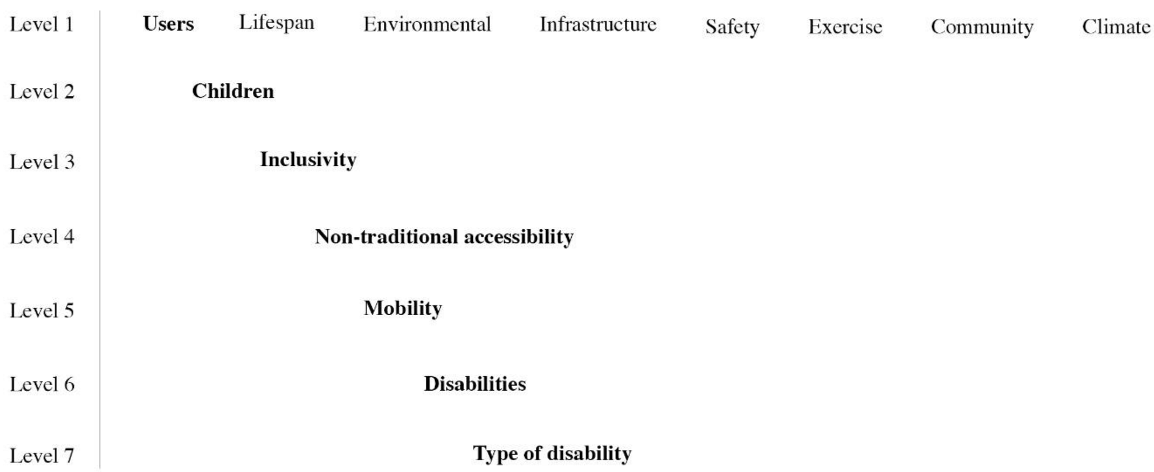

Figure 5.7 Titles of Themes and Levels of Diversity Tree

Table 5.12 Descriptions of each Level

	Title	Description
Level 1	Universal	Statement was almost verbatim with the given statement, while including the generic theme.
Level 2	Broad	Statement still used key words from the original statement while specifying the theme further.
Level 3	Collective	Further specifies the overall theme, providing more color to the statement.
Level 4	Particular	Information begins to delineate from the original statement.
Level 5	Clear	Further development from Level 4
Level 6	Distinct	Expands ideas upon Level 5
Level 7	Precise	The detailed specificity has a far relation to the original statement, typically accompanied with a specific example.

When organizing the statements, the ones that were similar in topic and description were place next to each other in rows. When a statement was of similar theme, but provided more detail or explanation, that statement was then placed below on a new level. An example of this tree is displayed in Figure 5.7. The particular theme shown in this figure is ‘User’. Each strategy represents a different color, which demonstrates the variety of strategies used within the same theme.

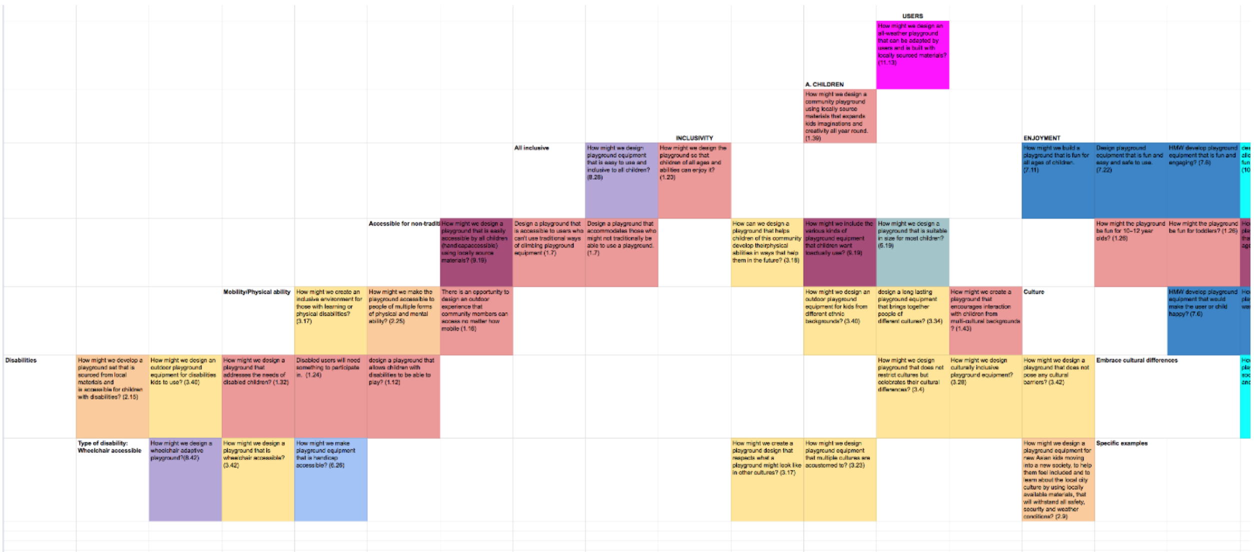

Figure 5.8 Example of hierarchy for 'User' theme

The number of strategies organized on each level were counted to analyze which strategies were most prominent on each level. Once the number of strategies were counted, the total amount of statements for each strategy were then converted into percentages. Table 5.13 highlights in grey which strategies had the greatest percentage of use on each level. Figure 5.8 is a visual representation of the number statements organized on each level.

Table 5.13 Percentage of Statements used on each Level

	% S1	% S2	% S3	% S4	% S5	% S6	% S7	% S8	% S9	% S10	% S11	% S12
L1	0	5	7	16	9	15	5	3	15	13	20	5
L2	10	10	11	16	18	25	21	13	20	20	20	0
L3	25	25	14	16	18	25	21	27	15	27	7	17
L4	30	30	14	5	9	10	0	10	46	20	13	28
L5	20	15	25	10	27	15	16	13	0	7	13	33
L6	15	10	18	26	18	5	10	27	0	13	20	17
L7	0	5	11	10	0	5	26	7	0	0	7	0

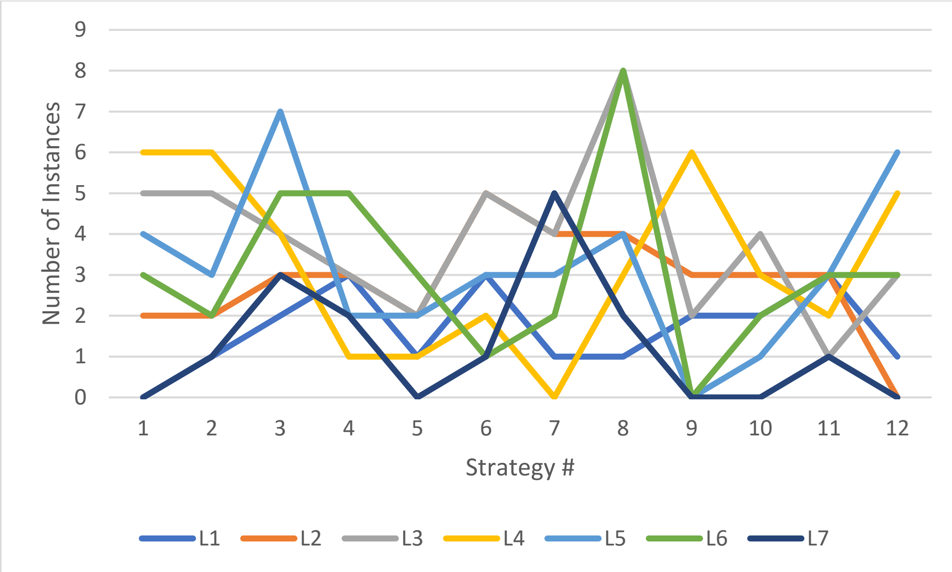

Figure 5.9 Graph showing number of instances for each Strategy

Strategy 11, Describe Mobility Characteristics, had the highest percentage out of all the strategies at Level One. One reason why this strategy had a higher representation among the lower levels could be due to its constraint in definition. Since Mobility was a more understood strategy people could can tended to have a limited frame of view. On the other hand, Strategy 7, Describe the Users' Interaction, received the highest percentage for Level 7. This means that statements from Strategy 7 were able to diversify to most from the original statement.

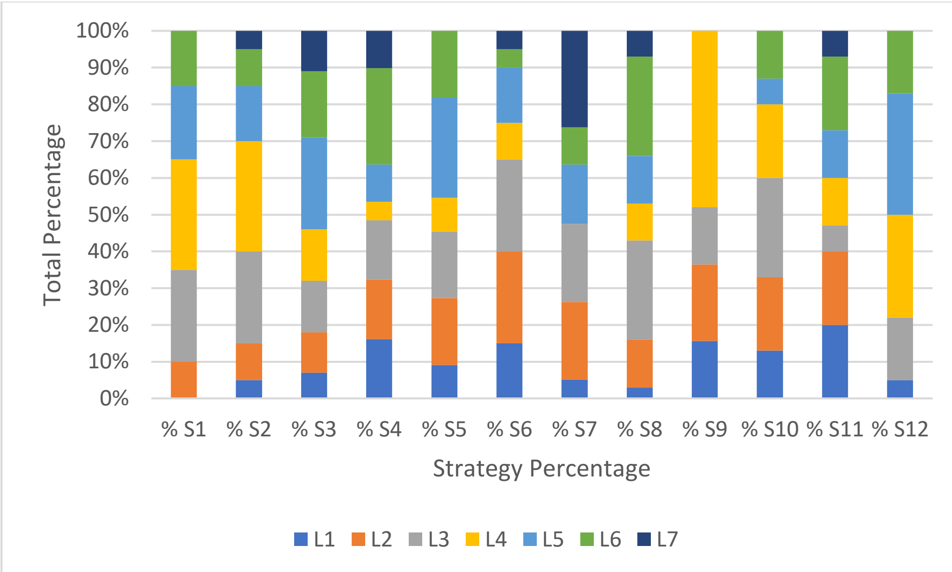

Figure 5.10 Bar graph displaying percentage of levels for each strategy

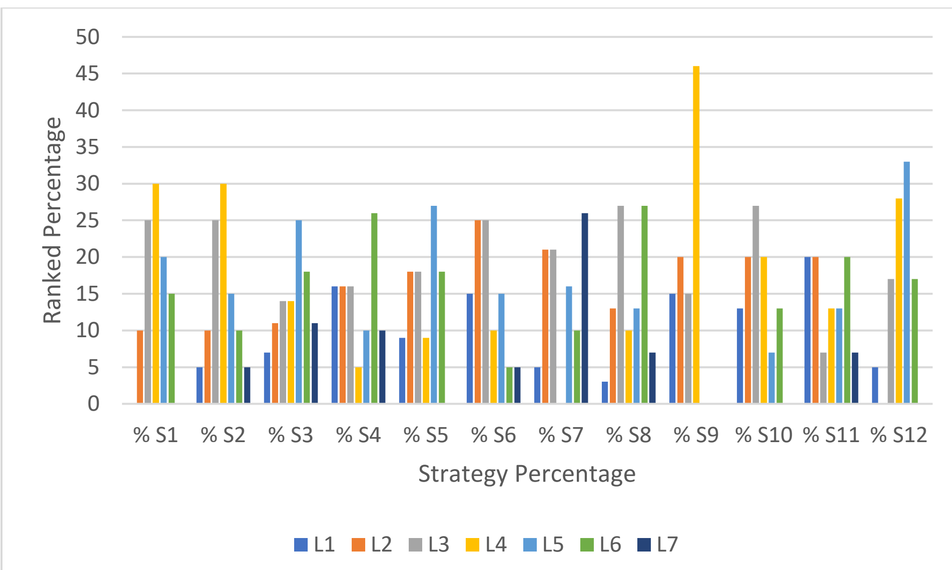

Figure 5.11 Another representation of level percentage across strategies

As seen in Figure 5.9 and 5.10, it is shown that Strategy 9 and 1, Examine Assumptions and Define the Characteristics of the User and their Needs, respectively, had the most representation for the central portion of the levels. For Strategy 9, students are asked to reference the original statement many times since they need to place judgement/assume what is going on in the situation. Since the statements are a complete reference to the original, it makes sense that most of the statements are located at Levels 2, 3, and 4. Strategy 1 asks for the student to define the user and their needs. It was noticed that a majority of the students generalized the user instead of specifying who it would specifically be, which resulted in most of the statements gathered around Levels 3, 4, and 5.

Our analysis included both the depth and the complexity of cross-pollination among themes. Statements from each strategy were examined to see where they were placed in relation to the tree. Did all statements gather in the same theme, or were they spread out amongst many? The strategies most prominent in staying together as a unit were 4, 11, and 12. A majority of their statements were only visible in one or two main themes. Figure 5.11 shows how the statements of Strategy 11 were closely placed together.

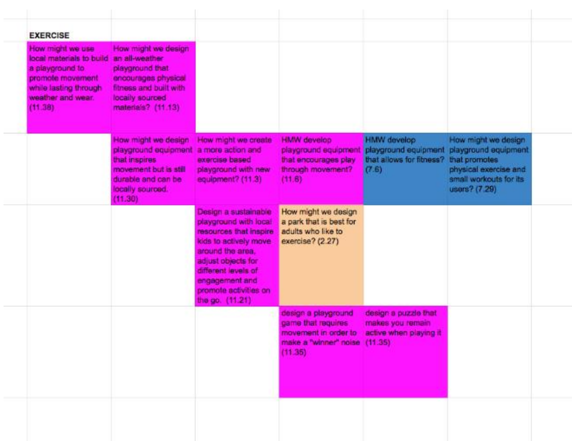

Figure 5.12 Example of Strategy 11

For example, the statements of Strategy 12 were only located in the theme ‘Lifespan’. Since this strategy prompts the students to describe the maintenance needs, the specification of the definition limits the student to think of other options outside the scope of public works for the city. In contrast, Strategy 3, Describe Cultural Implications, had the most significant cross-pollination across the tree. Strategy 3 had statements interspersed almost equally across all themes. Since the word 'culture' is a broad term, one could reason this allowed students to think of culture in different avenues. For example, Participant 34 described culture in two different ways. The first was a general use of culture, "design a long-lasting playground equipment that brings together people of different cultures" compared to "design a shared space that brings communities together". Strategies 6, Define the Context and 10, Determine the Underlying Issue, had a moderate cross-pollination. Since these strategies also provided broad enough definitions, the students in turn were able to generate statements in multiple different themes. Students using 'Define the Context' were given the freedom to determine in their own minds what 'context' they wanted to pursue if that was talking about the safety of the community or the weather in a particular location. When asked to create a statement for Determine the Underlying Issue, the students reached all aspects of the themes from creating an opportunity to socialize with other kids to creating cheaper and sustainable playground equipment.

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CHAPTER 6. CONCLUSION

The aim of this thesis was to address the impact of design problem with the use of cognitive heuristics. This was accomplished by directly observing and analyzing the participant data when reframing a given problem statement. Study 1 was an introduction to understand what strategies could be observed in students' reframed problem when they were not given any aid. This was a great initial exploration of potential strategies. Study 2 was a comprehensive analysis into the impact of twelve provided strategies. In total, forty participants collectively generated two hundred and seventy-five unique problem statements based on the original statement. Throughout the study, each statement was coded and clustered together to generate a cohesive analysis of the strategies. Four questions were answered to understand the application of all perspectives in depth: Q1: Did the students utilize the strategies? Q2: How did the students perceive the benefit of using the strategies? Q3: How did the students use each? Q4: How much diversity is created among the new problems after strategy use?

The first step was to determine if the students could accurately use the strategies provided. If so, this translated that the strategies were clear to understand and easy to implement. The highest percentages were 11, 8, and 4, and the lowest were 10, 2, and 5. To reduce any bias, an Inter-Rater Reliability test was conducted with two coders. The strategies with maximum agreement were 11, 12, and 2. The two strategies below the 75% minimum agreement were 4 and 5. This initial data set confirms that 11 had the greatest clarity on the student's side to implement but also understandable on the researcher's side. The data also indicates that Strategy 5, Describe Visual Attributes, was the most difficult for coder agreement, as well as implementation by the students.

Although the data can suggest certain outcomes, it is important to understand the student's perspective about how they really felt about the effectiveness of the study and strategies in particular. When asked how helpful each strategy was, the highest overall strategy was Strategy 6, Define the Context. The lowest overall was Strategy 5, Describe Visual Attributes. When asked how easy the strategies were to use as well as their perception of creative outcomes, the juniors both had the lowest average ranking. This explanation could be due to a lack of experience completing tasks of this nature. Although the HCI students do not have much experience formulating problem statements, their ranking as master's students and a supposedly greater world-view could explain this. The students were also asked which was the most applicable strategy they used. For Group A, the most applicable was 6. Group B had tied results and Group C's most applicable was 8 with the lowest being 12. Group D's most applicable was 7 with 4 as the least applicable.

The preliminary findings from the diversity tree showcase eight key themes emerging from the data: user, lifespan, environmental, infrastructure, finance, exercise, safety, community support, and climate. These were considered to be the overarching characteristics to determine particular perspectives. The statements were organized on a hierarchal level to determine the distance apart from the original problem statement. Seven levels were discovered through multiple iterations of organization and clustering. Statements in level seven were the farthest from the original problem statement, indicating the most diverse. The strategies with the highest percentage in level seven and six were 7 and 8, respectively. The strategies with the greatest prominence in level one and two were 11 and 6, respectively. The statements were also examined to see how many themes each strategy could cross-pollinate. The strategies with the greatest cross-pollination were 3, 6, and 10. The strategies that were closely clustered together were 4, 11, and 12.

Through this cumulative analysis, there were several key takeaways. Strategy 8 was a strong contender for applicability, clarity, helpfulness, and diversity. Strategy 6 was overall considered the most helpful and applicable for Group A. Although it was ranked for low diversity, it did have a large presence of cross-pollination. Strategy 5 was consistently ranked the lowest for accurate implementation, reliability, and helpfulness. This suggests that this strategy has the most improvement to make for future work. Strategy 11 generated the most amount of statements on level 1 and had a significant amount clustered together. This indicates it generates little diversity and cross-pollination of ideas.

Since the heuristics chosen were initial ways of evolving design problems, it is not conclusive that these strategies are most beneficial for problem reframing. Further research needs to be conducted to identify what strategies improve innovative solutions. The next step for continued research would be to cross reference the identified heuristics that were most beneficial and allow the participant to generate concepts. This way, the solutions can be analyzed to see if the use of problem exploration heuristics were impactful in diverse solution generation. There were also several more problem exploration strategies that were not used in this study, so it is imperative to not ignore the ones that have previously been identified. Overall, it was noticed that people can interpret the strategies in different ways. Within the same strategy, the range of diversity among the statements can greatly differ. The research demonstrates that design in both domains can use the problem exploration strategies effectively with minimal training as a tool for problem exploration.

Limitations and Recommendations for Future Work

Some limitations to the study could be the genre or wording of problem that was initially prompted to the participant. Since the students were seeing the design problem for the first time, there could be a possibility of misunderstanding, although the participant was allowed to ask any questions for clarification. Their perspectives and experience reframing problems could also affect the results. An external limitation could be the lack of research and studies similar to the work of this study. Since there is little research on the effectiveness of problem exploration heuristics, personal bias could steer towards a particular conclusion. Although the limitations are recognized, personal bias and experience will ultimately have a beneficial impact on the study.

There are many opportunities for future revisions and work within the problem generation space. It is shown that without the strategies, people do not know how to rewrite problems. Since only twelve strategies were analyzed for this study, there is an opportunity to study the effectiveness of other possible strategies. The study also showed that semantics is extremely important, so re-wording the titles and prompted questions would be beneficial for the students. It would also be helpful to test more engineers and different years in their college career. Another opportunity is to analyze the second half of the data for problem solution co-evolution. The process of coming up with ideas that propel multiple cycles of iteration is a way to uncover possible strategies. A final opportunity would be to create another study comparing the data when using the digital tool, traditional paper format, and a control group.

The future implications of this work can help guide future researchers in the design education space. Although there were key themes identified through this study, this is the beginning of identifying heuristics that are most practical and useful for problem generation.

APPENDIX A. IRB APPROVAL

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 10/10/2017

To:

From: Office for Responsible Research

Title: Tackling the 'right' problem: Investigating Cognitive Strategies Used in Understanding Engineering Problems

IRB ID: 15-435

Approval Date:	10/10/2017	**Date for Continuing Review:**	7/20/2018
Submission Type:	Continuing Review / Modification	**Review Type:**	Expedited

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use only the approved study materials** in your research, **including the recruitment materials and informed consent documents that have the IRB approval stamp**.
- **Retain signed informed consent documents for 3 years after the close of the study**, when documented consent is required.
- **Obtain IRB approval prior to implementing any changes** to the study by submitting a Modification Form for Non-Exempt Research or Amendment for Personnel Changes form, as necessary.
- **Immediately inform the IRB of** (1) **all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.
- **Stop all research activity if IRB approval lapses,** unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.
- **Complete a new continuing review form** at least three to four weeks prior to the **date for continuing review** as noted above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. **Approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **IRB approval in no way implies or guarantees that permission from these other entities will be granted.**

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 202 Kingland, to officially close the project.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.

APPENDIX B. INFORMED CONSENT DOCUMENT

INFORMED CONSENT DOCUMENT

Title of Study: Tackling the 'right' problem: Investigating cognitive strategies used in understanding engineering problems

Investigators: Seda McKilligan, PhD and Samantha Creeger, MS

This is a research study. Please take your time in deciding if you would like to participate. Please feel free to ask questions at any time.

INTRODUCTION

The purpose of the study is to investigate problem exploration heuristics— strategies used to identify and refine problem definitions (also called problem finding or framing). You are being invited to participate in this study because you contacted us about your willingness in taking part in this research, where we explore cognitive heuristics used defining design problems. You should not participate if you are under 18.

DESCRIPTION OF PROCEDURES

If you agree to participate, you will be given a problem statement describing a problem and its context in a written format, and asked to work on it for 30 minutes. The problem statement will be developed based on existing problems in engineering, inspired by the Grand Challenges. In addition, you'll be introduced to a series of heuristics or strategies that we extracted from practicing and student designers and engineers during their problem solving processes. After the problem statement and the heuristics are provided, you will be asked to reshape that problem into other potential problems using the heuristics, which may be more important or feasible to solve. While you are working on this activity, we will ask you write any thoughts down on provided sheets of paper.

At the end of the session, we will ask you to walk us through your process in using these heuristics and explain how you used them and how they assisted in exploring the problem and solutions spaces. The entire session will be transcribed later for analysis.

The entire study will take about an hour and you will not be asked to spend time on studies in addition to what you will be asked.

RISKS

While participating in this study you may experience the following risks: Minor psychological discomfort; however, we will provide a short think-aloud exercise at the beginning to minimize the discomfort of talking aloud while working on the task.

BENEFITS

If you decide to participate in this study there is no direct benefit to you. However, a possible benefit is that you will become more aware of problem exploration heuristics and how to use them in understanding underlying problems and how they would help you in solving problems.

PARTICIPANT RIGHTS

Your participation in this study is completely voluntary and you may refuse to participate or leave the study at any time. If you decide to not participate in the study or leave the study early, it will not result in any penalty or loss of benefits to which you are otherwise entitled. You can skip any questions that you do not wish to answer.

CONFIDENTIALITY

Records identifying participants will be kept confidential to the extent permitted by applicable laws and regulations and will not be made publicly available. However, federal government regulatory agencies, auditing departments of Iowa State University, and the Institutional Review Board (a committee that reviews and approves human subject research studies) may inspect and/or copy your records for quality assurance and data analysis. These records may contain private information.

To ensure confidentiality to the extent permitted by law, the following measures will be taken: the coding of the data will be done by the researchers who will be blind to the project. Participants' information will be removed and replaced by ID codes. These ID codes will be matched by participants, but will only be available to the PI. No identifiers will be provided to researchers for data analysis. The identifiers will be kept in PI's office, in a locked cabinet. The data will also be kept there, and will be taken out when the researchers analyze them.

If the results are published, your identity will remain confidential.

QUESTIONS OR PROBLEMS

You are encouraged to ask questions at any time during this study.

- For further information about the study contact Dr. Seda McKilligan at 515.294.716.
- If you have any questions about the rights of research subjects or research-related injury, please contact the IRB Administrator, (515) 294-4566, IRB@iastate.edu, or Director, (515) 294-3115, Office for Responsible Research, Iowa State University, Ames, Iowa 50011.

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PARTICIPANT SIGNATURE

Your signature indicates that you voluntarily agree to participate in this study, that the study has been explained to you, that you have been given the time to read the document, and that your questions have been satisfactorily answered. You will receive a copy of the written informed consent prior to your participation in the study.

Participant's Name (printed) ____

______________________________________ ______________________

(Participant's Signature) (Date)

APPENDIX C. PROTOCOL TEMPLATE

DESIGN PROBLEM

A city resident has recently donated a corner lot for a playground. You are an engineer/designer who lives in the neighborhood and you have been asked by the city to help with the project. **Your task is to design playground equipment for your neighborhood.**

STRATEGY 1: ____________________

DESIGN PROBLEM STATEMENTS: Part One

Generate an alternative problem statement based on the original problem.

Design a…

STRATEGY 1

CONCEPT GENERATION

Generate as many concepts as you can relating to Strategy 1.

Please provide a description for each concept.

Concept 1

Description

Concept 2

Description

STRATEGY 1

DESIGN PROBLEM STATEMENTS: Part Two

Generate alternative problem statements based on the concepts you just generated.

Design a… *I used Concept #_____*
Design a… *I used Concept #_____*
Design a… *I used Concept #_____*