IASDR 2019

International Association of Societies of
Design Research Conference 2019
DESIGN REVOLUTIONS

Manchester School of Art
Manchester Metropolitan University
02-05 September 2019

Exploring the problem space with Problem Exploration Strategies

Creeger, Samantha[a]; McKilligan, Seda*[a], Seifert, Colleen[b]

[a] Iowa State University, Ames, USA
[b] University of Michigan, Ann Arbor, USA
* seda@iastate.edu

The problem generation space is a critical stage in the design process impacting the quality of the outcomes. However, there's limited research on how to explore the problem space. This research reports on designing a tool for problem exploration strategies identified in a prior study and its impact on student designers' problem formulations. This research uncovers how these strategies were used and how certain strategies led to diversity in the newly formulated problem statements.

Keywords: problem exploration; cognitive strategies; design education

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, students are taught the fundamentals of the design process from beginning with a design brief to eventually resulting in a technical and thoughtful solution. 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 strategies 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 strategies and which ones are most effective.

This paper 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 strategies that are most influential to problem generation.

2 Literature Review

Design solution space has been explored in detail by design cognition researchers, however there is little emphasis on the design problem space and how exploring the problem space influence solution space creativity. It is important for designers to generate a thoughtful problem statement as it is the foundation for the rest of the design process. 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 mostly needs to focus on the solution. This means that the problem space gets little attention and neglects 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". Research has shown the importance of problem exploration in design, however little is known about how problems are discovered and formulated (Getzels, 1979).

2.1 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). Through a large collection of verbal transcripts and written statements, researchers were able to analyse the data and find common characteristics among the responses to develop heuristics. This research 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.

2.2 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 1, 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 (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 1 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	Technique that determines the "four dimensions of the problem" including identify,	(Kepner & Tregoe,

analysis technique	locate, timing, and magnitude by determining the distinction between “is” and “is not”	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 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.

3 Synthesizing Problem Exploration Strategies

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

For the study reported in this paper, we chose 12 strategies to test with a tool, to observe their impact. Several identified heuristics were combined to provide simplicity and accessibility. The twelve strategies used are described in Table 2.

Table 2 Strategy Number, Name, and Questions prompting problem exploration

	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?

An online tool was designed and developed for each student to complete the study on their own laptops. A customized website was created using Visual Studio Code for programming and GitHub pages to host the website. Multiple mock-ups and prototypes were created before the tool was released for the study. The website also went through several iterations to ensure seamless accessibility and usability for the students. The figures below demonstrate part of the tool in chronological order. The introductory 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. The second slide displayed the provided problem statement shown in Figure 1. All students received the exact same scenario to ensure cohesive coding.

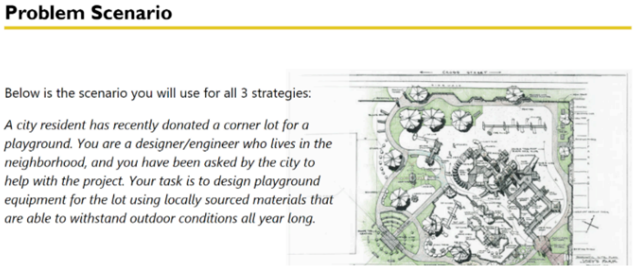

Figure 1 Original Problem Scenario

The student was then directed onto the Strategy Generator page in Figure 2. 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.

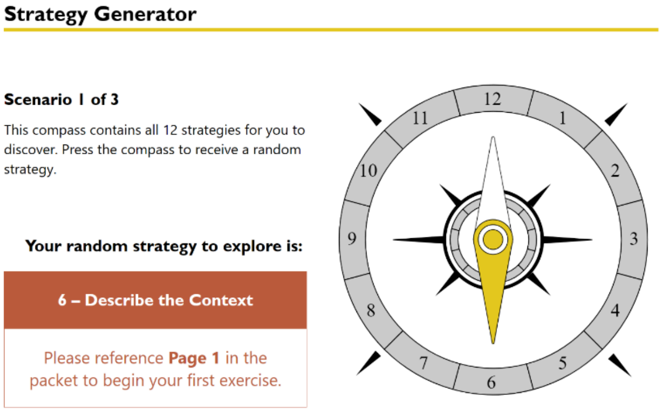

Figure 2 'Random' Strategy Generator

The next step of the study was learning about that provided strategy in Figure 3. 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, were unrelated to the provided statement to further understand how each strategy could be applied to a potential problem.

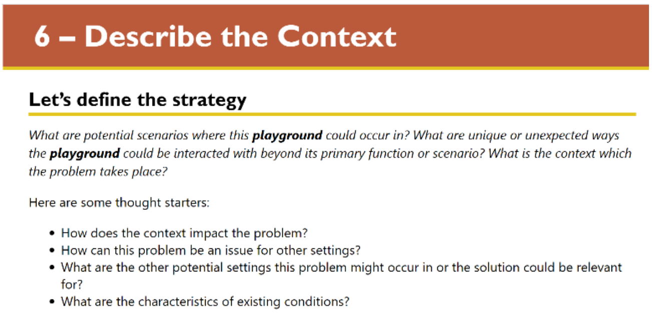

Figure 3 Definition Page

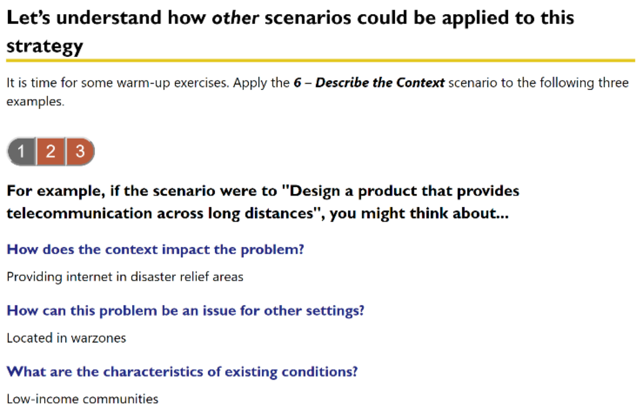

Figure 4 Examples to Familiarize Strategy

When the student felt comfortable to continue, they were then asked to generate as many problem statements using that strategy. A 'plus' button was clicked to allow for more submissions in Figure 5. When the student felt content with the submissions, the tool repeated to the Strategy Generator in Figure 2 to repeat the same steps for two more strategies.

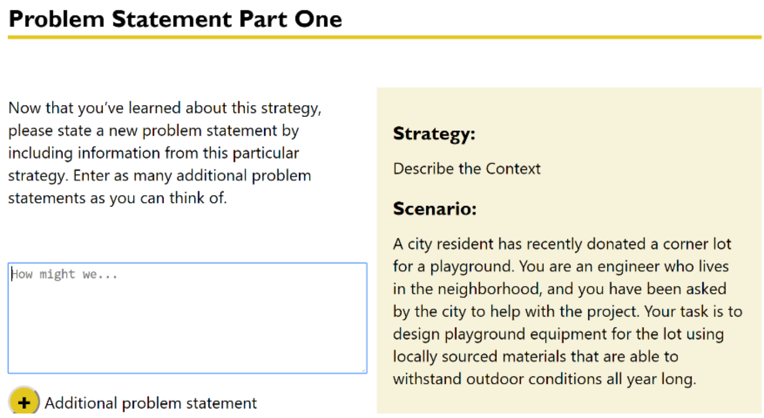

Figure 5 Forum to Enter Statements

4 Experimental Method

In this study, we extend our previous work to design and engineering students working on a new design problem, using the digital tool as an intervention to expand their problem spaces. Our goals were to gain evidence that the problem exploration strategies indeed assist in this expansion, and if so, how they were used and the outcomes they led the students to. The research reported here examined the problem exploration strategies in classroom settings. The students were given the online tool that introduced them a subset of strategies and were asked to work on an open-ended design problem, using the strategies introduced with the tool. We collected their reformulated problem statements after they applied each strategy.

The research questions led this study are:
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?

4.1. Participants

In total, 43 students studying industrial design or human computer interaction with engineering background participated in the study. Of the 43 that participated, 40 of the participants' data were collected due to incomplete or missing data. Students in Human Computer Interaction with engineering backgrounds were pursuing a graduate degree (3 female, 6 male). 17 student Industrial Design were seniors (8 female, 9 male) and 14 were juniors (8 female, 6 male). The overall average age was 22.92, SD=3.13.

4.1 Data Collection and Analysis

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 strategies on their laptops. The newly formulated problems were either 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, 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 neighbourhood and you have been asked by the city to help with the project. Your task is to design playground equipment for your neighbourhood." This problem was chosen since no participant should be limited by lack of knowledge when designing playgrounds and was considered an optimal brief to code mentioned in 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. Students' newly formulated problem statements, after applying each of three strategies, in addition to a short survey asking for their perception of the value of these strategies on their problem space exploration, were collected.

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 3, 8, and 12. Group D received strategies 4, 7, and 11. The answers to final retrospective survey were used to complement the analysis.

4.2 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.

Q1: Did the students utilize the strategies?

We coded each statement individually, rating if the student did or did not utilize the strategy given to them. 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. 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 use the strategy. The disagreements between the coders were discussed until arrived at a consensus.

Table 3 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 3 Percentage of statements using each strategy

	Total	YES	NO	% 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	223	52	

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: “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?

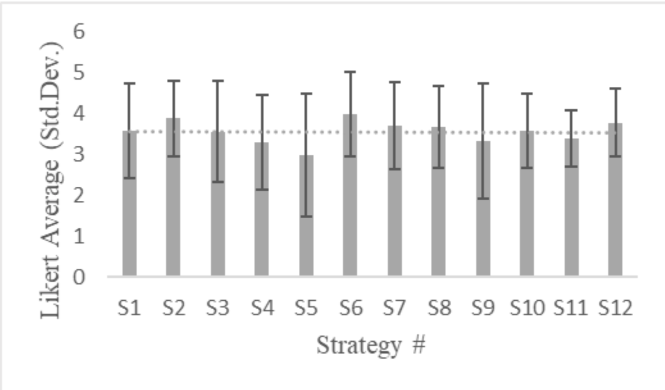

Figure 6 Survey responses for ‘How helpful did you find strategy X?’

The data shown in Figure 6 responds to the question “How helpful did you find strategy X.” 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. 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.

For the other question “Overall, how easy was it to use the strategies?”, the overall average was 3.57, SD=0.90. Figure 7 shows the distribution plot of the responses. When looking at the difference among cohorts, the juniors rated the lowest values, although not significant.

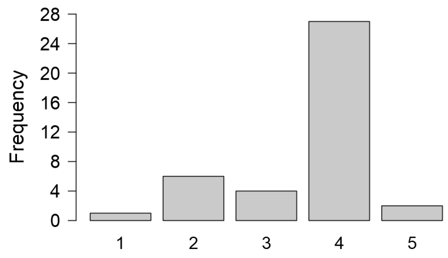

Figure 7 Overall, how easy was it to use the strategies?

The data was also compared against each group and major. 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. 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 8.

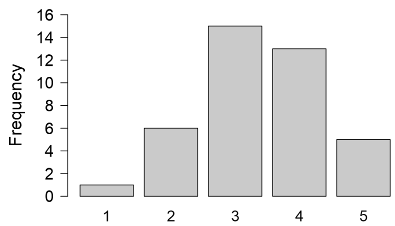

Figure 8 Creativity average

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 at 3.07, SD=1.00). The seniors had the highest average score of 3.65, SD=.93.

When analysing the question, "Which strategy was the most applicable?", since all groups received different strategies, the results were analysed and ordered by each group. 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 neighbourhood 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 said: "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 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 richer and more 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 also 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. 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?

In Table 4, we provided two distinct examples of the application of each strategy. The goal was to understand how the students implemented each strategy within a problem statement.

Table 4 Examples of each Strategy

	Example 1	Example 2
Strategy 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)
Strategy 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)
Strategy 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)
Strategy 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)
Strategy 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)
Strategy 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)
Strategy 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)
Strategy 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)
Strategy 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)
Strategy 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)
Strategy 11	How might we design accessible playground	How might we create a more action

	equipment that can be switched out and replaced with different pieces of equipment from season to season? (P29)	and exercise-based playground with new equipment? (P3)
Strategy 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)

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. Like 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 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.

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. For this stage in the analysis, all of the statements that accurately depicted the given strategy were analysed (Creswell & Creswell, 2013).

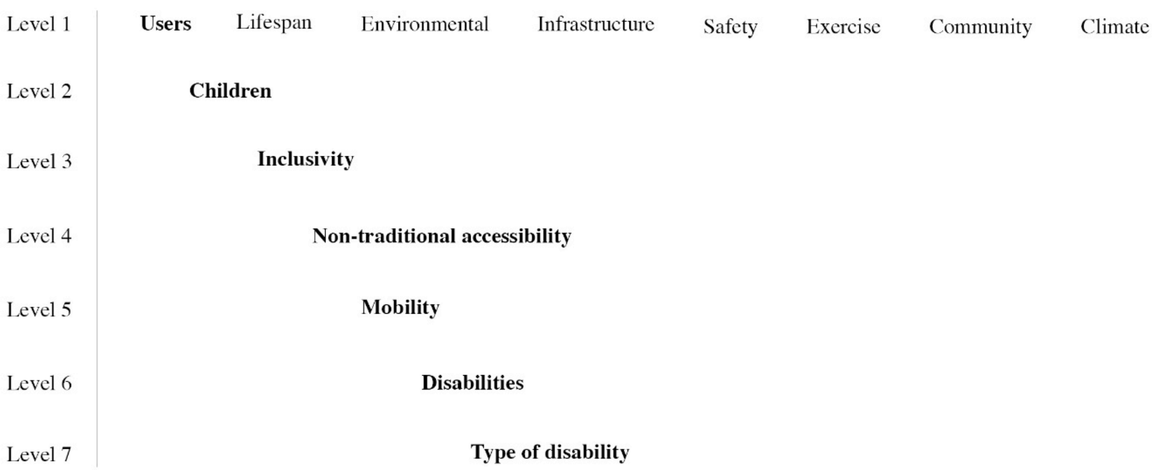

Figure 9 Titles of Themes and Levels of Diversity Tree

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 9 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 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. The number of strategies organized on each level were counted to analyse 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 highlights in grey which strategies had the greatest percentage of use on each level.

Table 5 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

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.

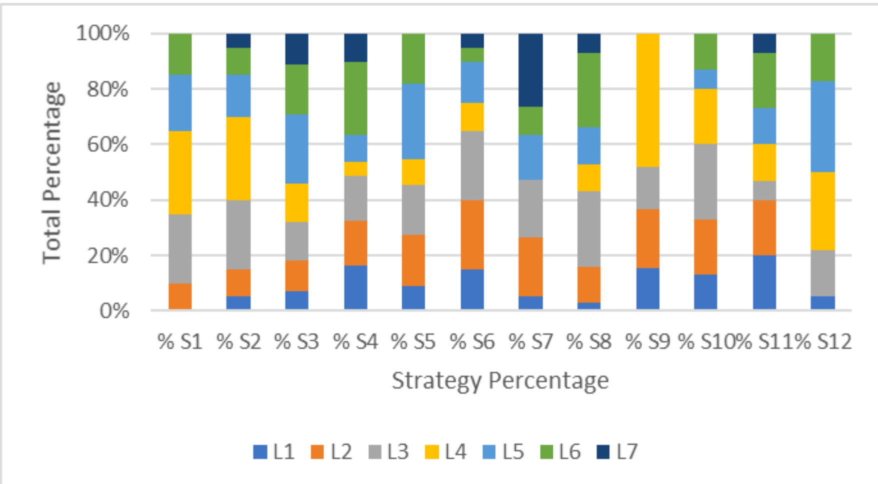

Figure 10 Bar graph displaying percentage of levels for each strategy

As seen in Figure 10, 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 many 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. Most of their statements were only visible in one or two main themes.

5 CONCLUSION

The study explored the impact of problem exploration strategies on student designers' exploration of diverse reformulations of the problem statement. Although students were introduced to problem exploration strategies for the first time, in addition to an online tool to apply them, there was clear evidence of their use (81%). Students' perception of the value of such a tool in their process was also promising with over average highlighting its potential contribution. The strategies, as demonstrated and applied as a digital tool, helped students to diversify their problem statements while giving them a chance to explore new problem spaces that may not have been investigated before.

Even though there are differences in education and training, students with industrial design and engineering backgrounds were able to use the problem exploration strategies tool to generate diverse and unique problems. This research demonstrates that designed in both domains can use the problem exploration strategies effectively with minimal training as a tool for problem space exploration.

6 References

Autodesk. (2017). *Understanding the abstraction laddering*. Retrieved from https://www.autodesk.com/industry/manufacturing/resources/mechanical-engineer/abstraction-laddering

Bulsuk, K. (2011). *An introduction to 5-why*.

Creswell, J. W., & Creswell, J. W. (2013). *Qualitative inquiry and research design: choosing among five approaches* (3rd ed). Los Angeles: SAGE Publications.

Cropley, A. J. (2003). *Creativity in education & learning: a guide for teachers and educators* (Repr). London: Kogan Page.

Cropley, D. H. (2015). Promoting creativity and innovation in engineering education. *Psychology of Aesthetics, Creativity, and the Arts*, *9*(2), 161–171. https://doi.org/10.1037/aca0000008

Dorst, Kees, & Cross, N. (2001). Creativity in the design process: co-evolution of problem–solution. *Design Studies*, *22*(5), 425–437. https://doi.org/10.1016/S0142-694X(01)00009-6

Duncker, K. (1945). On problem-solving. (L. S. Lees, trans.). *Psychological Monographs*, *58*(5), i–113. https://doi.org/10.1037/h0093599

Einstein, A., & Infeld, L. (1938). *The evolution of physics from early concepts to relativity and quanta*. New York; London; Toronto [etc: Simon and Schuster.

Fogler, S., & LeBlanc, S. (2008). *Strategies for Creative Problem Solving*. Massachusetts: Peason Education Inc.

Getzels, J. W. (1979). Problem Finding: a Theoretical Note. *Cognitive Science*, *3*(2), 167–172. https://doi.org/10.1207/s15516709cog0302_4

Getzels, J. W., & Csikszentmihalyi, M. (1976). *The Creative Vision: A Longitudinal Study of Problem Finding in Art*. New York: Wiley.

Hall, A. (1962). *A Methodology for Systems Engineering*. New York: Litton Educational Publishing Inc.

Higgins, J., Maitland, G., Perkins, J., & Richardson, S. (1989). Identifying and solving problems in engineering design. *Stud High Educ*, *14*(2), 169–181.
Kepner, C., & Tregoe, B. (1981). *The New Rational Manager*. Princeton: Princeton Research Press.
MacCrimmon, K., & Taylor, R. (1976). Decision making and problem solving. *Dunnette MD, Ed. Handbook of Industrial and Organizational Psychology*.
Parnes, S. (1967). *Creative Behavior Guidebook*.
Paul, R., & Elder, L. (2006). *The Thinker's Guide to the Art of Socratic Questioning*. Dillon Beach: Foundation for Critical Theory.
Reitman, W. R., Grove, R. B., & Shoup, R. G. (1964). Argus: An information-processing model of thinking. *Behavioral Science*, *9*(3), 270–281. https://doi.org/10.1002/bs.3830090312
Rickards, T. (1975). *Problem Solving through Creative Analysis*. Essex: Gower Press.
Shull, F., Delbecq, A., & Cummings, L. (1970). *Organizational Decision Making*. New York: McGraw-Hill Book Co.
Snider, C. M., Culley, S. J., & Dekoninck, E. A. (2013). Analysing creative behaviour in the later stage design process. *Design Studies*, *34*(5), 543–574. https://doi.org/10.1016/j.destud.2013.03.001
Spradlin, D. (2012). Are you solving the right problem? *Harvard Business Review*, *90*(9).
Studer, J. A., Daly, S. R., McKilligan, S., & Seifert, C. M. (2018). Evidence of problem exploration in creative designs. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, *32*(4), 415–430. https://doi.org/10.1017/S0890060418000124
Studer, J., McKilligan, S., Seifert, C., & Daly, S. (2017). Problem Exploration Strategies during Engineering Design. *Journal of Engineering Education*.
Vasconcelos, L. C., Crilly, N., Chen, C. C., Campos, F., & Kelner, J. (2016). What's the benefit of problem exploration. *DS 84: Proceedings of the DESIGN 2016 14th International Design Conference*.
Wright, S., Silk, E., Daly, S., Jablokow, K. W., & McKilligan, S. (2015). Exploring the Effects of Problem Framing on Solution Shifts: A Case Study. *ASEE Annual Conference & Exposition*.
Yilmaz, S., Daly, S., Seifert, C., & Gonzalez, R. (2010). A Comparison of Cognitive Heuristics Use between Engineers and Industrial Designers. *Design Computing and Cognition*, 16–35.

About the Authors:

Samantha Creeger: earned her Master of Science degree in the interdisciplinary Human Computer Interaction graduate program. Her research brings her design experience into the UX context where she develops digital interfaces for design pedagogical improvements.

Dr. Seda McKilligan: research focuses on identifying impacts of different factors on ideation of designers and engineers, developing instructional materials for design problem and solution spaces, and exploring foundations of innovation.

Dr. Colleen Seifert: research interests lie in complex human cognition, including memory, learning, problem solving, and creativity. With her collaborators, she is currently investigating cognitive accounts of creative thinking, and ways to improve the creative process.