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DEALING WITH LOSS: HOW DO DESIGNERS' RESILIENCE AND PERCEPTIONS OF SCARCITY AFFECT PERCEPTIONS OF DESIGN PERFORMANCE?

Grace Sibley
Department of Mechanical Engineering
The Pennsylvania State University

Cynthia Letting
Department of Mechanical Engineering
The Pennsylvania State University

Jessica Menold
Department of Mechanical Engineering
School of Engineering Design and Innovation
The Pennsylvania State University

ABSTRACT

Resources are an essential aspect of individual problem solving and their availability is critical for success. Resource scarcity is common in many industries and can affect the resources available to prototype, design creatively, and work freely. We argue that designers face scarcity and short timelines on engineering teams, and it is uncertain how these constraints may affect design outcomes and strategies. We also argue that designers must be resilient to overcome challenges faced during problem-solving. In this work, we study the interactions between resilience and perceived resource scarcity and how they affect perceptions of design performance. A controlled study was conducted to understand the linkages between resource scarcity, resilience, and scarcity mindset. We found that a perceived general scarcity of time in day-to-day life, significantly predicted perceptions of design performance. Further, we found that participants with higher resilience scores were less likely to have their design idea affected by the induced resource scarcity. Our work builds foundational knowledge regarding the interactions between individual resilience, general perceptions of scarcity and resource constraints in the context of engineering design. Further work may require more longitudinal based studies to better understand resilience and resource scarcity over longer periods of time.

Keywords: Engineering Design, Resilience, Resource Scarcity, Design Performance

1. INTRODUCTION

Plato famously wrote, "our need will be the real creator" [1]. Empirical research has demonstrated some truth to this proverb, finding that a scarcity of resources can increase innovative output, particularly for small to mid-sized enterprises [2]. For example, [3] found that a scarcity of financial resources promoted the success of incremental innovations. Yet, the literature remains split on the effects of resource scarcity when studied in the context of design. Most design processes necessitate an abundance of resources to facilitate uncertainty reduction through iterative design activities. For example, prototyping efforts often require design teams to devote a significant amount of time and money [4]–[6].

Engineering design is a fundamentally iterative process, and multiple iterations are essential to drive innovation and product development [7]. Iteration can be particularly challenging in resource constrained environments, as designers are required to adapt to changing resource constraints and emergent design knowledge simultaneously [cite]. Winkens et al. [8]define resilience as the ability to not only cope with but learn from highly ambiguous and complex problems. As design is often categorized as a complex form of problem solving with high levels of uncertainty, we argue that resilience is critical to successful design efforts, particularly in the context of resource scarcity. Resilience can enable individuals to personally grow and adapt to adverse or difficult situations such that in the process they not only persist, but develop the personal tools and self-efficacy to have resilience in other scenarios [9]. Richtner et al. [10] found that organizational resilience positively predicted organizational creativity, particularly during times of turbulence. Further, Do et al. [11] found that when small to mid-sized enterprises leveraged resource-based management approaches, firms became more resilient and more innovative. Within engineering education, researchers hypothesize that students that do succeed and thrive in engineering disciplines develop not only high levels of engineering self-efficacy but also resilience in the face of trials [12], [13].

While resilience and resource scarcity has been well-studied at the organizational level, resilience and resource scarcity has not been investigated withing the context of engineering design. In the current work, we aim to close this critical gap, and investigate the fundamental linkages between resilience and design performance in the context of resource scarcity. Findings from our controlled study suggest that individual designer resilience may not be related with design performance but may be related with designers' *perceptions* of performance. Prior to reviewing the experimental protocol and emergent findings, we begin with a review of relevant theories.

2. BACKGROUND

2.1 The Role of Resilience in Design

Resilience refers to a person's ability to positively adapt to thrive despite stress and adversity [14]. As humans are exposed to stress frequently, it is essential to understand how resilience affects the natural response to stress and adversity. Experimental studies have found that resilience is based upon multiple variables, including biology [15], genetics [15], psychology and psychiatry [16], and one's environment [17]. Additionally, resiliency is associated with numerous other psychological constructs like Dweck's theory of growth mindset, which postulates that individuals can grow their ability to adapt to adversity and challenges and apply that strength in future events [18]. Research has been conducted on the application of resilience in the military [cite], athletics [19], psychological capital, and nurturing high human potential [20].

Adversity is an inevitable reality for individuals, teams, and organizations in all subject areas, and resilience will always be necessary to overcome these challenges. Engineering design firms currently face an increasingly competitive market characterized by rapid change and high complexity with regard to technology and policy [21]. Prior work has found that employees with high resilience may be more productive in difficult work environments, as compared to peers with lower levels of resilience [22]. Further, studies indicate that increased levels of resilience at the individual level can contribute to improved mental health and worker well-being [23], which in turn can improve worker retention and organizational buy-in. Within engineering education, resilience is often studied as an outcome of improved engineering self-efficacy [24]. Previous work has determined that the inability to cope and bounce back from the challenges of engineering education can result in a decrease in student motivation and increase in burn out [25], [26]. More recently, researchers have begun exploring interventions aimed at increasing students' resilience [23], [27], often through authentic or project-based experiences.

Within design, the construct of resilience has predominately been studied from a systems perspective in the context of natural or man-made disasters [28]. However, few studies have investigated resilience as an individual designer trait or ability. For example, Blizzard et al. [29] defined resilience as a key trait of designers engaged in Design Thinking practice. Gerber and Carroll [30] found a qualitative link between resilience and team self-efficacy in their seminal work on the psychological experience of prototyping. The found that company climates that supported rapid low-fidelity prototypes were more likely to reframe failure as a learning opportunity, increasing team resilience and self-efficacy. McComb et al. [31] investigated team response to sudden and significant changes in design problems, finding distinct patterns of behavior in high and low-performing teams. While not explicitly studying resilience, we hypothesize that individual resilience likely affected the ability of the team to adapt and respond to sudden design changes.

2.2 Resource Scarcity in Design

Shah et al. [32] demonstrated that human behavior is adversely affected by a scarcity of resources due to a "scarcity mindset" describing "a perceived discrepancy between ones' current level of resources, and a higher more desirable reference point" [33]. In behavioral economics, this theory explains counterproductive behaviors of individuals living in poverty (such as excessive borrowing) [32], [34], [35], resulting in higher levels of stress [36], [37]. Importantly, scarcity can lead to attentional shifts, such as a tendency to focus more on immediate expenses at the detriment of longer-term outcomes (e.g., taking high interest short-term loans) [32], [33]. The effects of this mindset extend beyond poverty. For example, busy individuals suffering from perceived time scarcity tend to focus on new and upcoming deadlines intensely, procrastinating important tasks to serve urgent ones [38].

A scarcity mindset and the psychological stress that accompanies it can come from a lack of resources including products, time, and money [39]. When people perceive that a resource is "scarce", they employ strategies to cope in order to accomplish previously determined goals in spite of the scarcity [40] [39]. Resource scarcity and its effects have been studied in a variety of contexts. For example, startup companies struggle to prototype effectively as prototyping represents a significant sunk cost, that can be detrimental to the startup due to the constrained time, funding, and skills that the start-up possesses [41]. Consumers face resource scarcity, and it can affect their decision making and willingness to take risks or delay gratification [42]. A study in Nigerian factories identified multiple obstacles that occur in a team setting as a result of resource scarcity, including unclear boundaries, poor attitudes, improper utilization of workers, and worker demoralization [43]. Camison-Zornoza et al. [44] demonstrated that firms with significant resources were more capable of producing and supporting innovative products, systems, or services to market. However, several scholars point to the positive effects of resource scarcity, particularly for creative or innovative endeavors [45]. For example, [46] found that resource scarcity actually contributed to the development of innovative products for startups operating in low-resource environments.

The central idea of scarcity theory is that scarcity produces a mindset that affects how people think and make decisions, thereby influencing the way that people behave [47]. Applied to design, if a designer is engaged in a task, and an additional demand on the designer's cognitive system is made (such as processing novel design information), this additional demand can feel urgent, particularly if the designer perceives themselves to be "overloaded", increasing the stress and decreasing the effectiveness of the designer. Attentional shifts due to perceived scarcity may cause the designer to miss critical design information or fixate on non-critical tasks.

We know from prior work that design constraints have been shown to benefit individuals and teams and can provide freedom to view them as opportunities [48]. Resources or more precisely, the availability of resources, can be viewed as a constraint of the design process. Constraints have been previously studied in engineering design teams [48]–[51]. Constraints can both limit and improve creativity in the engineering design process. Onarheim [49] observed the implementation of constraints at different points in the design process of a project; some introduced early and some introduced late. Findings suggested that the establishment of a constraint can begin a new type of creative process, and the introduction of constraints in later stages of design processes may pose a significant problem for designers, as the start of a new creative process so late in the design's trajectory, may not be feasible.

Prototyping in industry and its economies can have immediate effects on the profitability of a project or proposal [52].The financial implications of prototyping make the cognizance of its economics pertinent to companies, designers, and researchers. [52]

We argue that designers face scarcity and short timelines on engineering teams, and it is uncertain how these constraints may affect design outcomes and strategies. We also argue that designers must behave with resilience in order to overcome challenges faced during the problem-solving process and prototyping stages of the engineering design process. Exploring the relationship between these variables and their influence on design performance will further our understanding of resource scarcity and resilience in the context of engineering design. This research seeks to investigate the implications of perceived resource scarcity on engineering design performance from an individual perspective.

3. RESEARCH OBJECTIVES

The goal of this paper is to understand how perceptions of scarcity and individual designer resilience may influence design performance and design behavior. As a first step towards this goal and to address associated gaps in the literature, this study aims to answer the following research questions:

RQ1*: *What is the relationship between designers' resilience, individual perceptions of scarcity, and perceptions of design performance?

While the literature remains split on the effects of resource scarcity on individual or team problem solving performance, we hypothesize that a designers' level of resilience will positively predict design performance. Further, we know from psychology that when faced with a scarcity, individuals will sacrifice long-term outcomes for short-term gains. As such, we argue that greater perceptions of resource scarcity will negatively affect design performance.

RQ2: How does designers' resilience affect design behavior?

We hypothesize that designers' level of resilience will affect how designers react to sudden changes in available resources. Based on prior literature, we know that resilience can improve and individual's ability to adapt to challenges or obstacles. Further, we hypothesize that individuals with higher levels of resilience will perceive their performance during the design task more favorably as compared to individuals with lower levels of resilience.

The remainder of this paper is organized into 6 sections. Section 3 details the experimental design and methodology. Section 4 presents the quantitative results of the study. Section 5 synthesizes the results to offer an understanding of the implications of study. Finally, Sections 6 and 7 conclude with limitations of the study, proposed areas for future work, and a summary of the major findings.

4. METHODS

In pursuit of these research questions, a controlled mixed-methods study was conducted. Data was collected during a two-hour design thinking workshop. Participants were randomly paired, and were tasked with individually redesigning the seating experience for their partner. The overarching aim of the workshop was to teach participants the fundamentals of design thinking and human-centered design practice through an authentic design challenge. To understand the role of resource scarcity in design, the research team introduced a material constraint at the start of the design challenge, specifically participants were tasked to with the following statement:

"How might we redesign the seating experience for our partners using only cardboard?"

The research team constrained participants to cardboard to enable the introduction of a material resource scarcity half-way through the design challenge. The workshop followed the generalized flow of design thinking: empathize, define, ideate, prototype, test. Participants were first tasked with interviewing their partners to determine their partner's seating preferences. Participants were then asked to organize their notes and observations regarding their partners seating preferences using a four-quadrant empathy map. Following this, participants were asked to generate ideas novel ideas to enhance the seating experience for their partner. Prior to idea generation, participants were shown the amount of cardboard available to manufacture their idea and were explicitly told that they would construct whichever idea they believed best met their partner's needs. No other materials were provided for the construction of the chair, and the provided amount of cardboard was physically presented to the participants at the beginning of the ideation stage of the workshop. Participants were instructed to sketch as many ideas for a cardboard chair as they could, using physical idea sheets with space for verbal description. After ten minutes of sketching, participants were given 5 minutes to evaluate their ideas and were asked to select the best idea to move forward with.

Once idea generation was complete, the researchers informed the participants that they would half as much cardboard as was originally promised. This intervention was done to induce a perceived scarcity of material resources. Participants were then given 5 minutes to redesign their chair as needed to accommodate this new resource constraint. Following this, participants were given 30 minutes to physically construct their cardboard chairs, using the cardboard provided. The timeline of the study is outlined in greater detail in Figure 1 below.

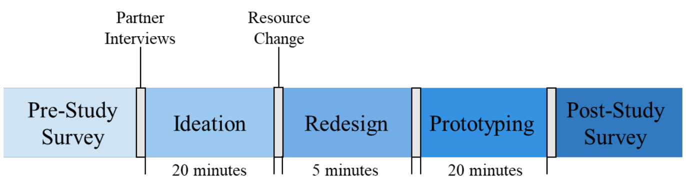

FIGURE 1: TIMELINE OF DESIGN-THINKING WORKSHOP

4.1 Participants

A total of 19 students participated in this study. Participants were full-time students enrolled in the Pennsylvania State University College of Engineering. Participants were recruited in accordance with the Institutional Review Board practices. Students ranged from first year undergraduate students to fourth year graduate students (Figure 2). The distributions of participant's race and gender are presented visually in Figure 3.

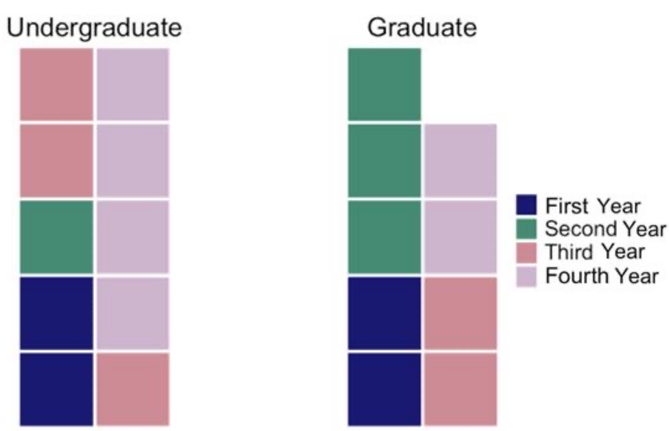

FIGURE 2: DISTRIBUTION OF PARTICIPANT'S ACADEMIC STANDING

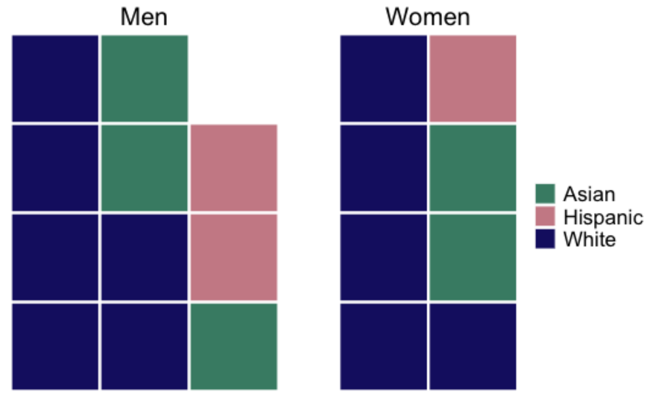

FIGURE 3: DISTRIBUTION OF PARTICIPANT'S RACE

4.2 Data Collection

Prior to the start of the workshop, participants were asked to take a brief pre-survey study. The pre-study survey collected demographic data, participants' level of resilience, and participant's perception of scarcity.

Measuring Perceptions of Scarcity: Both undergraduate and graduate engineering students face immense amount of stress [53], and often struggle to deal with competing demands on limited resources, such as time or money. As such, six items were crafted to measure participants' perceptions of resources. Items were determined by synthesizing findings from qualitative interviews with engineering students, reported here [54], and literature in engineering education and psychology [42], [43], [47], [50], [55]. An initial set of items were pilot-tested using think-aloud protocol with 10 engineering students. Member-checking was also leveraged to understand how accurately items represented internal constructs. Final items are listed in table 1. Participants were asked to rate their agreement with each of the six statements, on a scale from 1, completely disagree, to 5, completely agree.

Table 1. Pre-Survey Items: Perceptions of Resources

Item	References
There is not enough time in the day to accomplish tasks	[50], [51]
I lack the knowledge needed to successfully accomplish coursework	[56]
I do not have the funds I need to support my education	[36], [57]
I am consistently concerned about money	[50]
I do not have the resources I need to succeed	[42], [47]
I do not have mentors or advisors I can rely on for help	[55]

Measuring Level of Resilience: The Connor-Davidson Resilience Scale 10 (CD-RISC-10) was used to measure self-report of resilience [58]. Respondents answered items on a 5-point Likert Scale, with 4 being true nearly all the time, and 0 being not at all. The original CD-RISC has 25 items and was developed for use in general population, primary care, and psychiatric outpatient, and clinical trials. However, the researchers selected the shorter 10 item scale for time purposes and to decrease cognitive load during the pre-survey for participants. The abridged 10-item version of the original CD-RISC has been found to have strong psychometric properties and can be used to assess resilience [58].

Perceptions of Design Performance: In a post-workshop survey, participants rated their perceptions of their own performance. Ratings were used as a measure of perceived performance on the design task; example items included "my final design was a success", "my final design effectively used the available cardboard", and "my final design met the needs of my partner". Participants rated their agreement with each statement on a scale from 1, completely disagree, to 5, completely agree.

Design Behavior: Design behavior was captured via quantitative survey items paired with open-ended survey questions. A single item asked participants, "Do you feel your design concept was affected by the decrease in cardboard?". Participants could answer either "Yes" or "No" to this item. Participants were also asked to rate their agreement to the following item "I significantly altered my design due to the limits on available cardboard", using a five-point Likert-type scale. In addition, the post-survey included the following open-ended questions to prompt reflection and gain qualitative data on experiences during the workshop:

- Please describe your experience during the design challenge today.
- How did the change in resources influence how you approached the design problem?
- Please describe why the decrease in cardboard did/did not affect your design concept.

These items were crafted to capture general experiences of participants engaged in the workshop and understand how participants perceived the change in resources and the affect this change had on final design outcomes.

Design Artifacts: In addition to the survey items, the research team collected all idea sheets produced during the workshop and collected photographs of each prototype produced. While this data is not used in the current work, two examples of participant's final cardboard are pictured below in Figure 4, to provide context for final output.

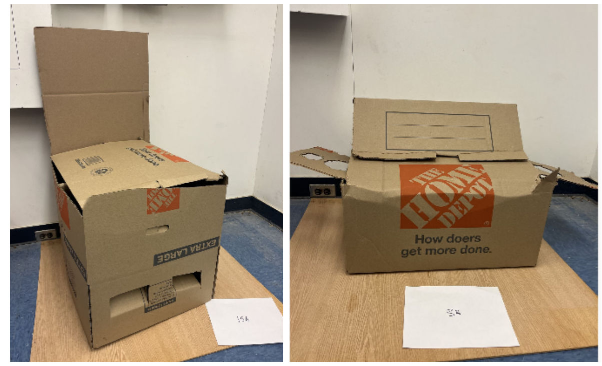

FIGURE 4: EXAMPLES OF PARTICIPANTS FINAL PROTOTYPES

5. RESULTS

This section presents the results of the research questions. Statistical analyses were computed using R CARN v. 4.1.3. A significance level of $p = 0.05$ was used in all analyses. Effect sizes less than 0.4 were considered small, sizes between 0.4 and 0.8 were considered moderate, and sizes greater than 0.8 were considered large. Figure 5 provides an overview of the distribution of participants' perceptions of scarcity across all six items. Figure 6 provides an overview of the distribution of resilience scores. Figure 7 depicts the distribution of average perceived design performance ratings.

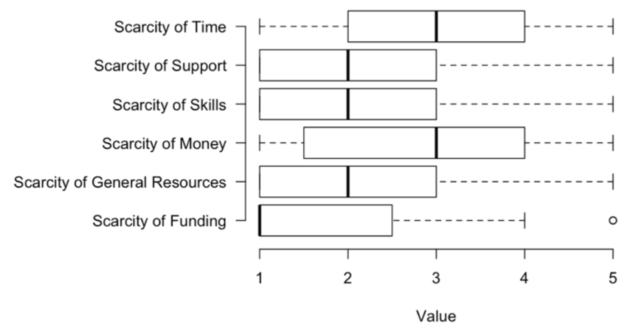

FIGURE 5: PARTICIPANTS' PERCEPTIONS OF SCARCITY

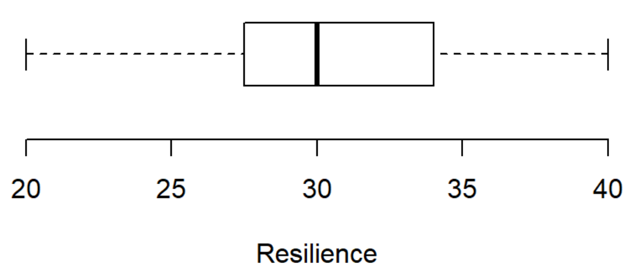

FIGURE 6: PARTICIPANTS' RESILIENCE SCORES

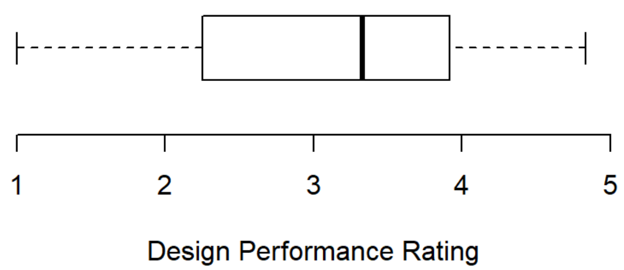

FIGURE 7: PARTICIPANTS' PERCEPTION OF DESIGN PERFORMANCE RATING

5.1 Effect of Resilience and Resource Scarcity on Perceptions of Design Performance

For research question 1, *what is the relationship between designers' resilience, individual perceptions of scarcity, and perceptions design performance,* linear regressions were conducted. Self-reported resilience was used as the independent variable and the dependent variable was design performance. We note, here design performance was rated by the participant's partner, who was representative of their final customer. Academic standing was used as a covariate as prior work suggests that as engineers progress through their academic careers, resilience may increase due to increased experiences overcoming academic obstacles [59]. However, no significant differences were found for the CD-RISC-10 across academic standing, and therefore it was removed from the model. After removing academic standing from the model, linear regressions were computed with the independent variable being each perceived scarcity item and the dependent variable being the self-perception of successful design performance.

The results of the linear regressions showed that only perceived scarcity of time could be used to predict perceptions of design performance. To assess linearity, a scatterplot of perceived scarcity of time against the perceptions of design performance with a superimposed regression line was plotted and is shown in Figure 8. Visual inspection of this plot indicated a linear relationship between the variables. There was homoscedasticity and normality of the residuals. There were no outliers in these data.

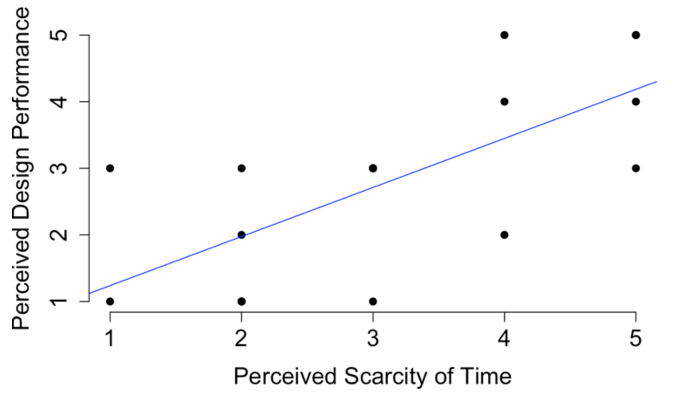

FIGURE 8: SCATTERPLOT OF PERCEIVED SCARCITY OF TIME AND PERCEPTIONS OF DESIGN PERFORMANCE. THE REGRESSION LINE IS SHOWN IN BLUE.

The prediction equation was: perceived design performance = 0.50 + (0.74*perceived scarcity of time). Perceived scarcity of time statistically significantly predicted perceived design performance, $F(1, 18) = 16.39$, $p<0.001$, accounting for 49.1% of the variation in perceived design performance with adjusted $R^2 = 46.1\%$, a moderate effect size according to Cohen [60]. For each 1-point increase in perceived scarcity of time, there is a 0.74 (95% CI, 0.35 to 1.32) point increase in perceived design performance. This finding indicates that participants' perceived scarcity of time moderately predicts their perceived design performance. Thus, a designer's perception of their ability to cope with time deficits can predict how they think they performed during a design task.

5.2 Resilience and Design Behavior

In pursuit of RQ2, *how does designers' resilience affect design behavior*, we used participants' responses to the survey item "Do you feel your design concept was affected by the decrease in cardboard?". Fourteen participants indicated that they felt their design was significantly altered by the decrease in cardboard, and five participants indicated they felt their concept was not changed. To understand how individual levels of resilience may differ between these groups, an independent unpaired t-test was performed. Statistically significant differences between groups were observed on two items of the CD-RISC-10. The first item, coded as *Resilience-Humor*, asked participants to rate their agreement with the following statement: "I try to see the humorous side of things when I am faced with problems." The second item, coded as *Resilience-Deal*, asked participants to rate their agreement with the following statement: "I can deal with whatever comes my way."

Figure 9 shows the distribution of scores to the Resilience-Humor item across both groups, those affected by the resource change and those unaffected by the resource change. Figure 10 shows the distribution of scores to the Resilience-Deal item across both groups.

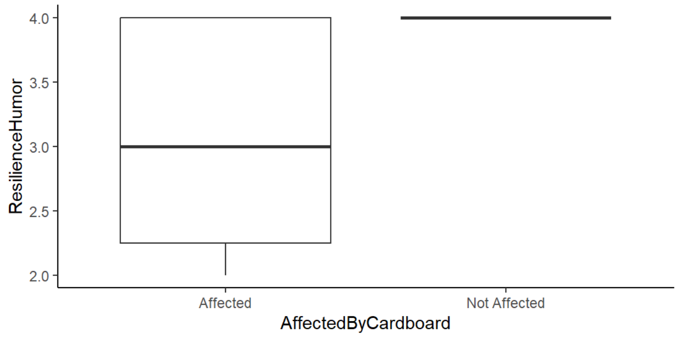

FIGURE 9: *RESILIENCEHUMOR* FOR EACH CONDITION

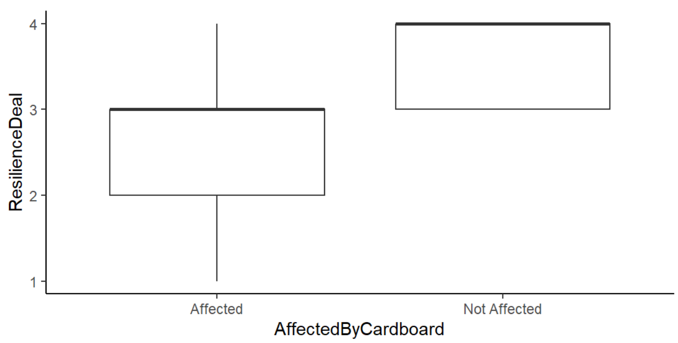

FIGURE 10: *RESILIENCEDEAL* FOR EACH CONDITION

Homogeneity of variances for both items was checked and was not met for the Resilience-Humor item, but was met for the Resilience-Deal *l* item. No outliers were identified in each group using boxplots.

A Welch t-test was run to determine if there were differences in the Resilience-Humor item between participants that felt their design was significantly altered by the decrease in cardboard and those that did not, as assessed by Levene's test for equality of variances ($p = 0.008$). The differences in Resilience-Humor were statistically significant, $t(13) = -4.19$, $p = 0.001$, $d = 1.58$. The effect size for this analysis was large as $1.58 > 0.8$. These results indicate that participants in the group that changed their design concept due to the induced scarcity ($M = 3.07$, SD = 0.83) presented lower levels of resilience tied with humor than participants that did not change their design concept ($M = 4$, $SD = 0$).

The t-test to determine if there were differences in the Resilience-Deal item based on if the participant felt their design was significantly altered by the decrease in cardboard was also found to be statistically significant, $t(17) = -2.61$, p = 0.02, d = 1.46. The effect size for this analysis is large ($1.46 > 0.8$). These results indicate that participants in the group that changed their design concept due to the induced scarcity (M = 2.64, SD = 0.745) presented lower levels of resilience tied with dealing with obstacles than participants that did not change their design concept (M = 3.6, SD = 0.54).

6. DISCUSSION

The main goal of this study was to investigate the ability of resilience and perceived scarcity of resources to predict perceived design performance. The main findings from the study are as follows:

1) Resilience did not predict self-perceived design performance
2) Significant differences were observed across items of the resilience scale between individuals that adapted their design based on the resource deficit and those that did not.
3) General perceptions of a scarcity of time in day-to-day life, positively predicted perceptions of design performance.

The first finding from this study indicates that student's self-reported resilience does not predict self-perceived design performance. This contradicts prior work in other fields outside of engineering design, which suggest that resilience can help support people in difficult working environments [22]. Another study found that academic resilience resulted in higher academic performance during the challenges of the COVID-19 pandemic. [61]. In the current work we sought to understand the linkages between resilience and perceptions of design performance, as prior work in engineering education has demonstrated a strong link between self-efficacy beliefs and resilience. However, our study found no significant link between resilience and perceptions of design performance. We do acknowledge that this work relied on quantitative methods, and with in-depth qualitative analysis of participant responses, differences in design performance could be understood in further detail. We highlight this as an area for future work.

Previous work has found that time pressure can increase productivity, yet creativity can be compromised by a scarcity of time [51]. Our results show that an increase in perceived scarcity of time predicted an increase in self-perceived design performance. This in an interesting finding as other resources such as funding, mentors, skills, money, and general resources did not predict perceptions of design performance. Perhaps longer time-based metrics could be employed in future studies to better understand this relationship between perceived scarcity of time and design performance. Additionally, these findings can help us to better understand how controlled application of time constraints may be able to facilitate more successful design performance. [51] While other scarcity items may not have a significant influence on design performance, these findings present that perceived scarcity of time do.

We found individual items in the CD-RISC-10 to be linked with designer behavior. Specifically, items were found to be significantly different across groups of designers; namely, those that adapted their designs based on the sudden resource deficit and those that did not. Individuals that self-categorized their design processes as being unaffected by the sudden resource constraint, introduced in this study, generally felt they were more likely to see the humor in things when faced with challenging situations, and were more likely deal with whatever obstacles came their way, as compared to those individuals that self-categorized their design processes as affected by the resource deficit.

To understand how students evaluated their design task experience and perceived how the resource scarcity affected their design outcome, we report on preliminary trends observed in the open-ended responses from the post-survey. We note, however, that qualitative analysis is on-going, and preliminary results are reported here. Open-ended responses were separated into groups by participants that changed their design concept due to the induced scarcity and participants that did not change their design concept due to the induced scarcity. Both groups reported that the design task was "fun", "challenging", "difficult", and "a little stressful".

The group of participants that was affected by the decrease in cardboard reported that generally, the resource scarcity caused them to focus on structure and support and abandon extra features. Another common theme observed in this group was that the extra cardboard that they thought would be provided would have made their final prototype "sturdier and stronger", and that there was a shift in focus to functionality over user needs after the resource constraint was introduced. Overall, the group affected by the resource scarcity experienced a struggle to fulfill their original design idea and needed to cut corners to complete a final prototype. Largely, open-ended responses in this group are marked by trade-offs.

The group of participants that were not affected by the cardboard reported that the resource scarcity did not affect their design because their design idea did not require a lot of material to begin with. Participants stated that there "design was already small" or that they "had not taken the material amount into consideration" when ideating. Two participants noted that the resource scarcity affected the scale and size of their final prototype but not their design idea. Though the group of participants that were not affected by the cardboard (N = 5) was significantly smaller than the group that were affected (N = 14), there were similar trends amongst the group that asserted that the material was not a factor they had either considered or was imperative to the success of their design.

7. LIMITATIONS AND FUTURE WORK

This work was limited by a relatively small sample size. Additionally, the sample was geographically clustered in the northeastern United States at one public university. Prior work suggests that the geographic location may affect cultural customs and accessibility of resources [63]. Future work should seek to contrast results with a larger depiction of geographic locations across the United States. The sample consisted of only engineering students at Pennsylvania State University but contained both undergraduate and graduate students in the College of Engineering. Therefore, the nature of the sample may have biased findings, and future work should seek to compare these results with more general populations of students. Additionally, it is possible that self-selection bias may have influenced the results of the study. Participants that chose to participate in the design workshop could present different traits than those who opted not to sign up for the workshop. Future work could seek to randomly select engineering designers for this study to reduce self-selection bias and find more representative results.

8. CONCLUSION

Iteration and adaptation in engineering design is crucial and can be an essential skill in the design process when faced with a variety of constraints. In this work, we aimed to understand the influence of designer's resilience and perceived scarcity of resources on their design performance in a resource constrained environment. After performing quantitative analysis of pre and post survey results, we found significant effect of perceived scarcity of time on design performance. No significant effects were found for perceived scarcity of funding, mentors, skills, money, and general resources on design performance. Additionally, there was no significant effect of individual resilience on design performance, which contradicts prior work on the effect of resiliency on other performance outcomes in different fields such as engineering education and problem-solving. However, large effect sizes were found for two resilience items between the group of designers that changed their concept as a result of the induced scarcity and the group of designers that did not. Future work should consider a more in-depth qualitative analysis of the final prototypes rather than relying on quantitative post-survey results to confirm if there are differences in design concept outcomes between the two groups. Further work may require more longitudinal based studies to better understand resilience and resource scarcity over longer periods of time.

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