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Applying design thinking principles to support resiliency in engineering graduate students

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Abstract

Graduate students in engineering often face significant uncertainty in research, particularly in the early stages of their thesis work. Many are accustomed to structured assignments and clear solutions from their undergraduate coursework, making the transition to independent research, where timelines are often shifting and undefined, particularly challenging. This study explores the impact of our half-day design thinking workshop developed to support graduate student resilience by helping Ph.D. and M.S. thesis students in engineering navigate ambiguity and build confidence in their research process. The workshop framed graduate research as a design activity and introduced five principles drawn from contemporary design literature: rapid prototyping, soliciting feedback, divergent and convergent thinking, avoiding fixation, and design by analogy. To demonstrate how these principles could be applied in the research process, we designed interactive activities such as brainstorming ideas and then sorting them on an impact versus feasibility axis to demonstrate divergent and convergent thinking. Ten participants completed all surveys before the workshop, immediately after, and three months later, allowing us to assess workshop impacts over time. Likert-scale ratings across the three surveys show that participants felt significantly more confident in their ability to navigate research uncertainties after the workshop and particularly valued the process of iterating multiple solutions. Qualitative analyses show that participants connected most with the principle of soliciting feedback, while expressing some hesitation toward rapid prototyping as a means to improve research resiliency. Additionally, participants emphasized the benefits of sharing their experiences with other graduate students. We show that the design workshop effectively engaged graduate engineering students with the five design thinking principles, fostering their integration into research practices immediately and three months after the workshop. This paper presents an overview of the workshop, the embedded design principles, and recommendations to support the development of resilient researchers.

1 Introduction

Graduate students navigate a great deal of uncertainty and ambiguity throughout the research process, which is typically not extensively taught at the undergraduate level. Many engineers struggle with this uncertainty [1, 2], especially at the beginning of their thesis research when they are accustomed to having structured assignments and defined solutions throughout their undergraduate coursework. This struggle could be particularly problematic for first generation and minority students that experience higher rates of imposter syndrome [3].

One approach that explicitly supports navigating uncertainty to work towards solutions is *design thinking.* Design thinking is a human-centered approach to problem solving that emphasizes understanding stakeholder needs, reframing problems, generating ideas, and learning through iterative cycles of prototyping and feedback [4, 5]. Rather than prescribing a linear process for solutioning, design thinking acknowledges the ambiguity, experimentation, and reflection required for one to navigate complex, open-ended challenges [6]. Importantly, design thinking provides a mindset and tools to support resilience when tackling ill-structured problems [7]. A core mindset in design thinking is a "bias towards action," which emphasizes trying-by-doing and frequent feedback. As a result, design thinking trainings are commonly applied across organizational and professional contexts to support employees' problem solving, collaboration, and teamwork [8, 9].

In order to investigate whether lessons from design thinking principles could be applied to help graduate students become more comfortable with uncertainty in the research process, we implemented a half-day workshop for engineering graduate students at University of Colorado Boulder. Here, we discuss the workshop implementation, including introduction of design thinking principles, hands-on group activities focused on student implementation of different principles, and a faculty panel discussing their non-linear career trajectories. In addition, we present student participant survey data immediately before and after, as well as three months following the workshop demonstrating workshop outcomes and attendees' biggest takeaways.

2 Theoretical Foundations

Contemporary design research has advanced both theory and method to better support individuals in engaging in core elements of design thinking, such as mitigating fixation and encouraging synthesis through iterative prototyping, gathering feedback, analogical thinking, and divergence and convergence [10].

Design scholars describe *synthesis* as a central cognitive activity in which designers construct problem-solution representations by integrating disparate pieces of information, including constraints, available assets, and emerging solutions [11]. Synthesis is not a linear aggregation of data, but an iterative process of mentally structuring and reframing the "problem space," *i.e.*, the theoretical representation of needs, goals, constraints, and contextual factors, and "solution space," *i.e.*, the theoretical set of possible artifacts, concepts, or strategies that could address the problem [12].

Feedback and iteration are critical to synthesis, and design thinking encourages individuals to treat early ideas as provisional and subject to refinement [13]. One way scholars characterize iteration is through *convergent and divergent thinking* [14]. Divergent thinking involves intentionally expanding the solution space by considering multiple interpretations, alternatives, and possibilities. Alternatively, convergent thinking involves narrowing this space through evaluation, prioritization, filtering, and decision making.

Core to design thinking is iterative *prototyping* and *soliciting feedback*. Prototypes are defined as any representation of an idea or design [15], which serve as "boundary objects" that enable communication, negotiation, and shared understanding between individuals [16]. Research shows

that prototypes help externalize one's assumptions and support the realization and communication of abstract ideas [17]. Adapting the fidelity, form, and purpose of prototypes helps to gather useful feedback and relevant critique that supports the development of the idea, solution, or problem framing [18]. Thus, design thinking encourages iterative cycles of rapid prototyping and feedback, so that one can refine their understanding of both the problem and emerging solutions.

Prototyping and feedback are also encouraged to reduce *fixation*, a well-documented cognitive phenomenon studied by design scholars. Fixation occurs when individuals become overly attached to ideas, examples, or problem framings, limiting their ability to explore alternative solutions [19, 20]. Because fixation is a common and unconscious human tendency, designers must actively employ strategies to counteract it. One common strategy is *design by analogy* (or, analogical thinking), which describes how new ideas are almost entirely constructed by drawing on prior experiences, existing solutions, or examples from other domains [21]. Designers who are skilled in analogical thinking can identify productive sources of inspiration and adapt them thoughtfully for their application or context.

3 The Resilient Researchers Workshop

Building on the theoretical foundations described above, we sought to support graduate engineering students with resilience in the uncertain, sometimes ill-defined research process. Supported by key principles of design thinking, we developed a workshop that introduced participants to these principles through a series of hands-on activities and reflections. The 3-hour workshop (Table 1) focused on developing resiliency and comfort with uncertainty in research through the application of design thinking principles and approaches. This workshop was developed and facilitated by the second, third, and fourth authors of this paper. All facilitators identify as women and hold doctoral degrees in various engineering fields. The third and fourth authors are early-career tenure-track faculty in the mechanical engineering department at University of Colorado Boulder, while the second author participated as a guest facilitator.

Table 1: Summary of the Resilient Researchers 3-hour Workshop Activities.

Workshop Activity	**Time Frame**
Introductions	15 minutes
Design Thinking Activity	45 minutes
Facilitated Reflection	30 minutes
Lunch and Faculty Panel	1 hour
Wrap-up and Close-out	15 minutes
Breaks and buffer time throughout	15 minutes

3.1 Introduction

To open the workshop, the facilitators introduced themselves and briefly articulated the motivation for the event. To establish a supportive and reflective tone, each workshop facilitator shared a personal example of a significant "failure" in their research practice, including data

collection errors, grant rejections, and accidentally publishing grammatical mistakes. These examples were intentionally presented with humor to normalize failure, reduce perceived power differentials, and build psychological safety among the workshop participants. Following these reflections, participants engaged in a pair-share activity guided by two prompts: "Tell your partner about a time you felt like you failed in research," and "Tell your partner about a time in the last month when you felt stuck in your research."

Table 2: List of design thinking principles taught to participants during the workshop.

Principles	**Description provided to workshop attendees**
Rapid Prototyping	Rapid prototyping emphasizes quickly creating and testing early versions of ideas to gather immediate feedback and refine them. This iterative process allows researchers to explore multiple concepts, identify potential challenges, and make improvements before committing significant resources. This process often involves creating low-fidelity models or simulations to validate key assumptions and improve functionality. This promotes resilience through frequent cycles of design, testing, and revision.
Soliciting Feedback	Soliciting feedback builds resilience by fostering comfort with failure and vulnerability, allowing researchers to embrace critique as an opportunity for growth. This openness promotes continuous improvement and strengthens the ability to adapt and refine ideas.
Divergent and Convergent Thinking	Divergent and convergent thinking fosters resilience in research by encouraging both creativity and focus. Divergent thinking emphasizes ideation and withholding judgment to explore a wide range of possibilities, while convergent thinking organizes and filters these ideas to identify the most viable solutions.
Avoiding Fixation	Addressing fixation in research involves recognizing and overcoming attachment to initial ideas or solutions. By remaining open to alternative approaches and challenging preconceived notions, researchers can avoid stagnation and encourage innovative solutions.
Design By Analogy	Gathering inspiration from others (in your own discipline and outside of it) sparks creativity and broadens perspectives, enabling innovative approaches in your research.

3.2 Design Thinking Activity

After the introductions and warm-up activities, the facilitators prompted participants to assemble into teams of four to five. Each team was asked to brainstorm research challenges that they were facing using posters and sticky-notes. This was prompted with "generate as many research challenges that you face as possible and withhold judgment." Next, each team chose one research challenge on which to focus for the remainder of the workshop. With this research challenge as a starting point, teams brainstormed as many solutions as they could in ten minutes, with added "nudges" grounded in different design principles. Nudges involved one or more facilitators asking teams to consider new constraints or resources during their idea generation. Examples of nudges included: "You must now use your phones or laptops to find inspiration from the internet," "Your

next few ideas must incorporate AI," and "All teams must rotate to the team to your right and read their ideas to gather additional inspiration." Once teams generated many ideas, which were scattered on sticky-notes across large posters, the facilitators prompted them to use different sorting methods. First, teams plotted their solutions on a new poster with a 2x2 matrix of "feasibility (high/low)" versus "impact (high/low)." Next, teams were asked to select one solution from their high-impact, high-feasibility quadrant around which to rapidly prototype a one-minute pitch and concept sketch. All teams shared their pitches to the full group and answered questions from the other teams about their solutions.

3.3 Facilitated Reflection

After the design activity, which had participants moving around the room and sharing ideas, teams were asked to return to their seats for facilitated reflection. Participants were provided with a worksheet outlining design thinking principles that we derived from contemporary design research scholarship (Table 2). A facilitator walked through each principle and asked participants to reflect on ways they could practice the principles in their research day-to-day.

3.4 Lunch and Faculty Panel

Following the reflection, the facilitators invited three faculty members from the department to participate in a panel discussion facilitated by a member of the workshop planning team. The panel included one assistant professor and two full professors (one of whom served as department chair) and reflected diversity in gender and international background. During the session, the panelists responded to a set of guiding questions and answered additional questions posed by participants, drawing on their experiences and perspectives. The following guiding questions were asked:

- Please provide a brief introduction and background of your academic journey.
- What is an experience that was or felt like a "failure," but turned out to be an important lesson or pivotal moment that helped your career? (Or, a door-closing moment that turned out to open a new door)
- What are some strategies that have worked well to overcome feeling "stuck" in your research?
- How do you maintain motivation and confidence when facing prolonged uncertainty, setbacks, or rejection in your research (e.g., funding rejections, paper rejections, experiments not working, getting "writers block")?
- Can you share a time when feedback (either receiving or providing it) helped you navigate a particularly difficult research challenge?

3.5 Wrap-up and Close-out

To close the workshop, participants selected one brainstormed idea that they could test in their own research process and paired with an "accountability buddy" to check on each others' progress, in alignment with the "bias to action" mindset in design thinking.

4 Assessment Methods

We aimed to evaluate the outcomes of the workshop, which we designed to support graduate student resilience by encouraging participants to integrate design thinking principles into their research routines. Using survey responses collected before, immediately after, and three months following the workshop, we assessed participants' perspectives and learning outcomes related to their confidence with navigating uncertainty and with using the five design thinking principles. Ultimately, we sought to answer the question: *In what ways can design thinking principles support the development of research resilience among graduate students?*

4.1 Surveys

The study involved three surveys: Survey 1 (the "Pre-workshop survey") and Survey 2 (the "Post-workshop survey") were completed on the day of the workshop, and Survey 3 (the "Follow-Up survey") was sent to participants via email three months after the workshop. All surveys were designed to take between 10 and 15 minutes to complete and were administered via Google Forms.

Across all surveys, we asked the same set of nine questions (Table 3). Each question prompted participants to rate their agreement with a specific statement on a 7-point Likert scale (1 = not true at all, 7 = exactly true). These questions assessed participants' perceptions of the five design thinking principles, including their confidence in navigating research uncertainties, the importance of iterating and sharing unpolished results, the value they placed on generating multiple solutions, the importance of drawing inspiration from others' work, and the importance of developing their own innovative ideas.

Qualitative comments were also gathered in open-response questions in the Post-workshop and Follow-Up surveys to help contextualize the quantitative results of these surveys. Open-ended prompts included:

- Please describe your biggest takeaway(s) from the workshop in 1-2 sentences. (Post-workshop survey)
- When considering the five design principles to improve research resilience, which one feels most relevant and useful for you? And why? (Post-workshop survey)
- When considering the five design principles to improve research resilience, which one do you feel the most resistance towards (*i.e.*, least likely to implement in your work)? And why? (Post-workshop survey)
- Which design principle(s) have you implemented in your research? Please provide an example. (Follow-Up survey)
- Now that it has been a couple of months, please describe your biggest takeaway from the workshop. (Follow-Up survey)
- Is there anything else you wish to let us know about your experience or takeaways from the workshop? (Post-workshop and Follow-Up surveys)

Table 3: Likert-scale questions, associated design thinking principle(s), and participants' responses (mean ± standard deviation (SD)) from Pre-, Post-, and Follow-Up surveys. Each question prompted participants to rate their agreement with a specific statement on a 7-point Likert scale (1 = not true at all, 7 = exactly true). Cells marked with the same symbol (either † or *) indicate a statistically significant difference between the corresponding survey time points ($P<0.05$)

Likert Scale Questions: 1 (not true at all) to 7 (exactly true)	**Design Thinking Principle(s)**	**Rating (mean ± SD)**		
		Pre-	**Post-**	**Follow-Up**
I feel confident in my ability to navigate any uncertainties and learn the necessary skills required to conduct graduate-level research at this stage of my journey (Fig. 3).	Overarching Goal	4.64 ± 0.809 *†	5.36 ± 0.674 *	5.5 ± 0.527 †
When working on research, I believe it's important to identify many different potential solutions and/or pathways forward, before deciding which ones to try.	Divergent Thinking and Rapid Prototyping	5.82 ± 1.08	5.82 ± 0.982	6.20 ± 0.919
Throughout a project, I think it's helpful to create multiple iterations of solutions and/or results (Fig. 1).	Rapid Prototyping	5.73 ± 1.01 *	5.82 ± 0.751 †	6.50 ± 0.527 *†
I like to wait until the very end of a project to pull it all together; I think it is important to show my PI a finished, polished result before getting feedback (Fig. 2).	Rapid Prototyping and Avoiding Fixation	2.73 ± 2.00	2.00 ± 1.41 *	2.80 ± 1.75 *
I am comfortable showing unfinished/in-progress work to my labmates and/or PI.	Rapid Prototyping and Soliciting Feedback	5.73 ± 1.68	6.00 ± 1.18	6.00 ± 1.15
When considering alternative pathways or solutions, I believe it is important to organize the possibilities and consider the pros and cons of each before making a decision.	Convergent Thinking	5.72 ± 1.35	5.72 ± 1.10	5.90 ± 0.876
Once I come up with an idea, I like to stick to it and don't want to waste time considering alternatives.	Avoiding Fixation	2.64 ± 0.924	3.45 ± 1.86	2.70 ± 1.25
I think it's important to look at other researchers' work (e.g., in the literature, in the lab) to gather inspiration and ideas for how to conduct my own project.	Design by Analogy	6.45 ± 0.522	6.73 ± 0.467	6.70 ± 0.675
I think it's important to come up with my own innovative way to solve a problem, something that has not been seen before.	Design by Analogy	4.64 ± 1.63	3.73 ± 1.90	4.30 ± 1.49

To address our primary research question regarding ways in which design thinking principles support the development of research resilience among graduate students, we organized both qualitative and quantitative data into thematic categories. Qualitative comments were analyzed by grouping written responses into six categories: one for each design thinking principle and an additional category for other takeaways. All members of our research team participated in discussions regarding the groupings of responses and their corresponding themes. For the quantitative analysis, each of the nine Likert-scale survey questions was mapped to one of the design thinking principles. Responses from each participant were tracked across surveys, and paired t-tests were used to identify significant changes in group average ratings between surveys.

4.2 Participants

Fourteen graduate engineering students attended and participated in the workshop. The study was overseen by University of Colorado Boulder Institutional Review Board and determined *exempt level two* (Protocol #25-0005). Participant consent was gathered on the first page of each survey. Participation in the assessment study was voluntary; to encourage participation, attendees were informed that three participants who completed all three surveys would be randomly selected to receive $50 gift cards. Of the fourteen participants, ten completed all three surveys and were included in the analyses.

Demographic data were collected in the Pre-workshop survey and are reported for the ten participants included in the analyses. All participants were current doctoral students in engineering at University of Colorado Boulder, with seven in their first or second year of the PhD program. Most participants identified as female (n = 7), with the remaining participants identifying as male (n = 3). The sample identified predominantly as White (non-Hispanic) (n = 7), with additional participants identifying as Asian (n = 2) and Black or African (n = 1).

5 Results

The following subsections describe participants' perceptions of each design principle introduced during the workshop. The final subsection summarizes overall takeaways, including those that extended beyond the main workshop goals.

5.1 Rapid Prototyping

Across all three surveys, participants were asked to rate their agreement with the statement, "Throughout a project, I think it's helpful to create multiple iterations of solutions and/or results." Average scores were significantly higher three months following the workshop than in both the Pre-workshop ($p=0.011$) and Post-workshop ($p=0.023$) surveys (Fig. 1).

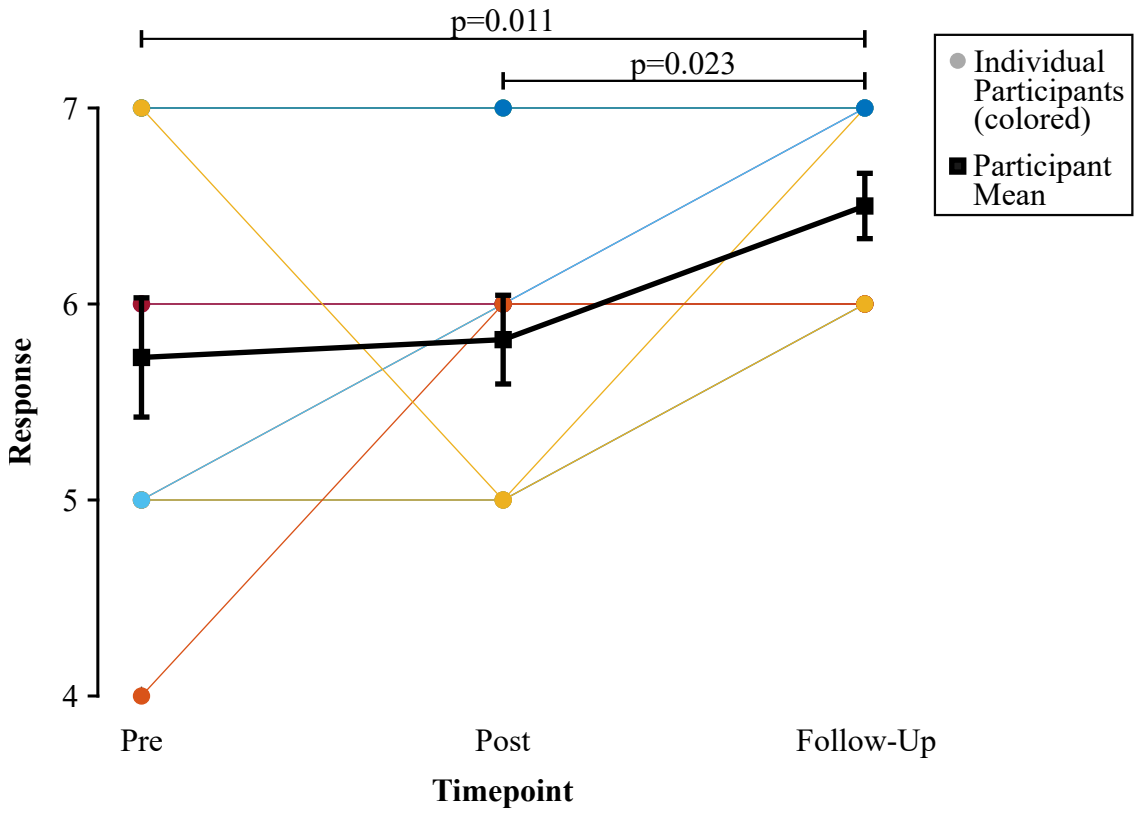

Figure 1: Participant ratings of agreement with the statement, "Throughout a project, I think it's helpful to create multiple iterations of solutions and/or results," measured on a 7-point Likert scale (1 = not true at all, 7 = exactly true). Ratings increased significantly at Follow-Up compared to both the Pre- and Post-workshop surveys. Black error bars indicate the group SD. Both individual responses and group means are shown connected across time points.

Despite this increased appreciation, some participants initially viewed rapid prototyping as difficult to implement in their research. Post-workshop responses revealed that participants found it "hard to apply" or "not beneficial" to current projects, noting limited time and unfamiliarity with iterative design. Some participants reported hesitating to apply rapid prototyping when their ideas felt unfinished or underdeveloped. For example, one participant noted, "Sometimes it's scary to try out new ideas. I don't want to fail or have them be half-baked."

Over time, participants reported greater implementation of rapid prototyping, as we found a significant increase in participants' responses regarding creating multiple iterations in the three-month Follow-Up survey (Fig. 1). In fact, while half of participants identified rapid prototyping as the principle they were least likely to implement in the Post-workshop survey, the same number (n = 5) reported applying it in some capacity in the Follow-Up survey.

5.2 Soliciting Feedback

Across all three surveys, participants rated their agreement with the statement, "I like to wait until the very end of a project to pull it all together; I think it is important to show my PI a finished, polished result before getting feedback." Average scores slightly decreased immediately after the

workshop and increased significantly at the three-month Follow-Up compared to the Post-workshop survey (p=0.019; Fig. 2).

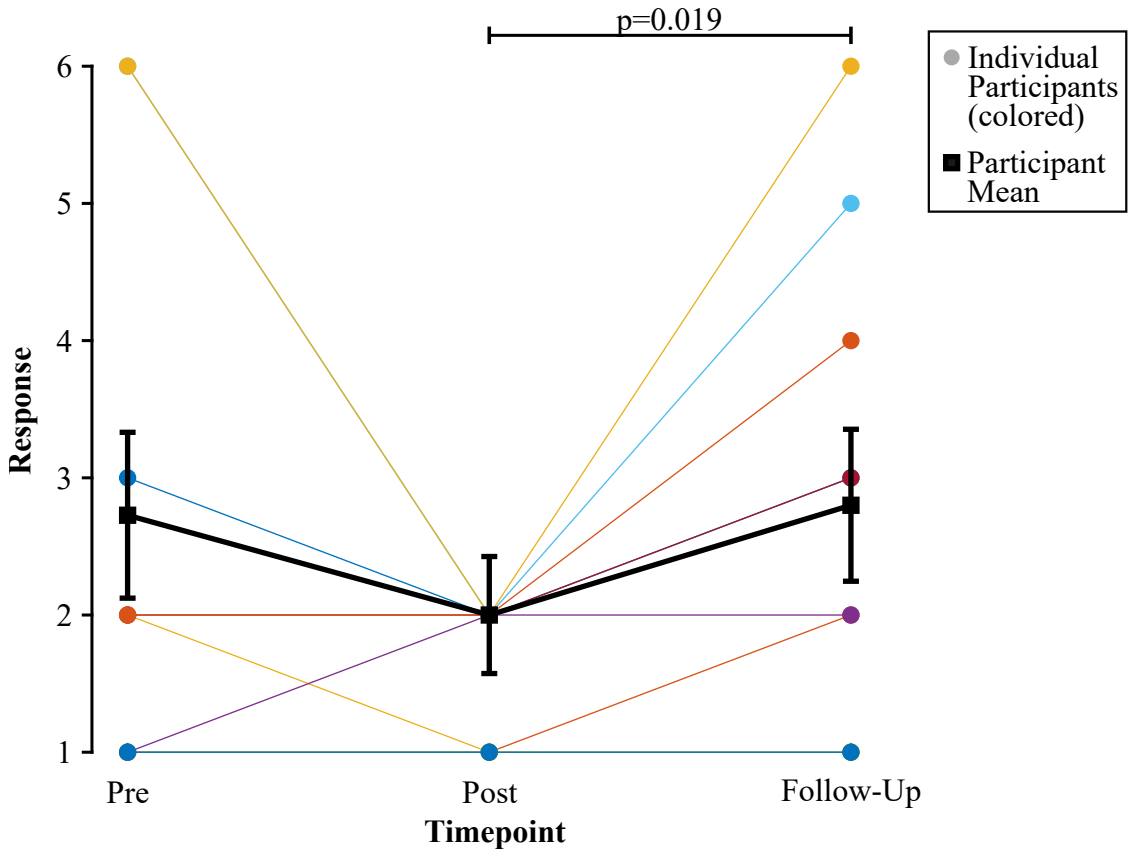

Figure 2: Participant rating of agreement with the statement, "I like to wait until the very end of a project to pull it all together; I think it is important to show my PI a finished, polished result before getting feedback," measured on a 7-point Likert scale (1 = not true at all, 7 = exactly true). Ratings slightly decreased between Pre-workshop and Post-workshop surveys, though this was not significant. Ratings increased between Post-workshop and three-month Follow-Up surveys. Black error bars indicate the group SD. Both individual responses and group means are shown connected across time points.

In the three-month Follow-Up survey, all ten participants reported using the soliciting feedback principle, and half identified it as the design principle they implemented most frequently. Participants reported seeking feedback from professors, lab members, and peers regarding project direction and progress.

Participants reported that soliciting feedback is an important way to make progress in their research. Three-month Follow-Up survey responses indicated that participants used feedback from peers and mentors to generate new ideas and overcome challenges. Several noted that discussing research with others helped them regain momentum when they felt "stuck" and provided a useful "sanity check" on their methods and results.

Many participants also emphasized the importance of receiving feedback within supportive and trusted communities. Some participants expressed a desire to strengthen their lab or peer

communities to make feedback exchanges more frequent and productive. They highlighted the value of honesty and vulnerability in creating spaces where feedback feels constructive.

5.3 Divergent and Convergent Thinking

In the three months following the workshop, participants appreciated the use of divergent and convergent thinking in helping them improve research resiliency. For example, one participant noted that "setting time up front to properly organize a project has been a really great way to maximize efficiency." Participants also noted that the use of convergent and divergent thinking prevented them from "getting overwhelmed when approaching a big problem."

Many participants felt that divergent and convergent thinking allowed for more creativity and less judgment. Furthermore, some participants felt that this principle was important in improving research resilience because it allows for the freedom to brainstorm new ideas without fear of judgment.

5.4 Avoiding Fixation

Many participants found avoiding fixation difficult to apply in practice. Post-workshop responses revealed that five participants, most of whom were early-stage doctoral students, were least likely to implement this principle in their research process. Participants noted that at the beginning of a project, they preferred to push through challenges to maintain focus and avoid distraction. Others described avoiding fixation as a "trap" or an area where they "lack self-awareness," acknowledging that they were not always able to recognize when fixation occurred.

Some participants, however, viewed avoiding fixation as a useful strategy for managing setbacks in their research. These participants described the principle as helping them remain "flexible" and "open-minded" during challenges. For them, avoiding fixation likely provided a way to adapt their approach and maintain progress when experiments or analyses did not go as planned.

5.5 Design by Analogy

Participants found that exposure to research both within and outside their field served as a key source of inspiration. Survey responses indicated that learning about work in other areas helped participants generate new ideas and make connections to their one projects. One participant explained that they applied this principle by "attending seminars and reading papers from other fields" which allowed them to "stockpile future ideas" to draw from later in their research.

Participants also viewed design by analogy as relatively easy to implement within their academic program. Some noted that opportunities to attend faculty talks, visiting speaker events, and student presentations made it easy to engage with ideas from other disciplines. This accessibility likely contributed to participants' willingness to apply the design by analogy principle in their research.

5.6 Overall Takeaways

Across all three surveys, participants were asked to rate their agreement with the statement, "I feel confident in my ability to navigate any uncertainties and learn the necessary skills required to

conduct graduate-level research at this stage of my journey," on a 7-point Likert scale (1 = not true at all, 7 = exactly true). Ratings significantly increased from the Pre-workshop to both the Post-workshop (p=0.007) and Follow-Up surveys (p=0.002; Fig. 3), indicating that participants' confidence improved immediately after the workshop and that gains were maintained over time.

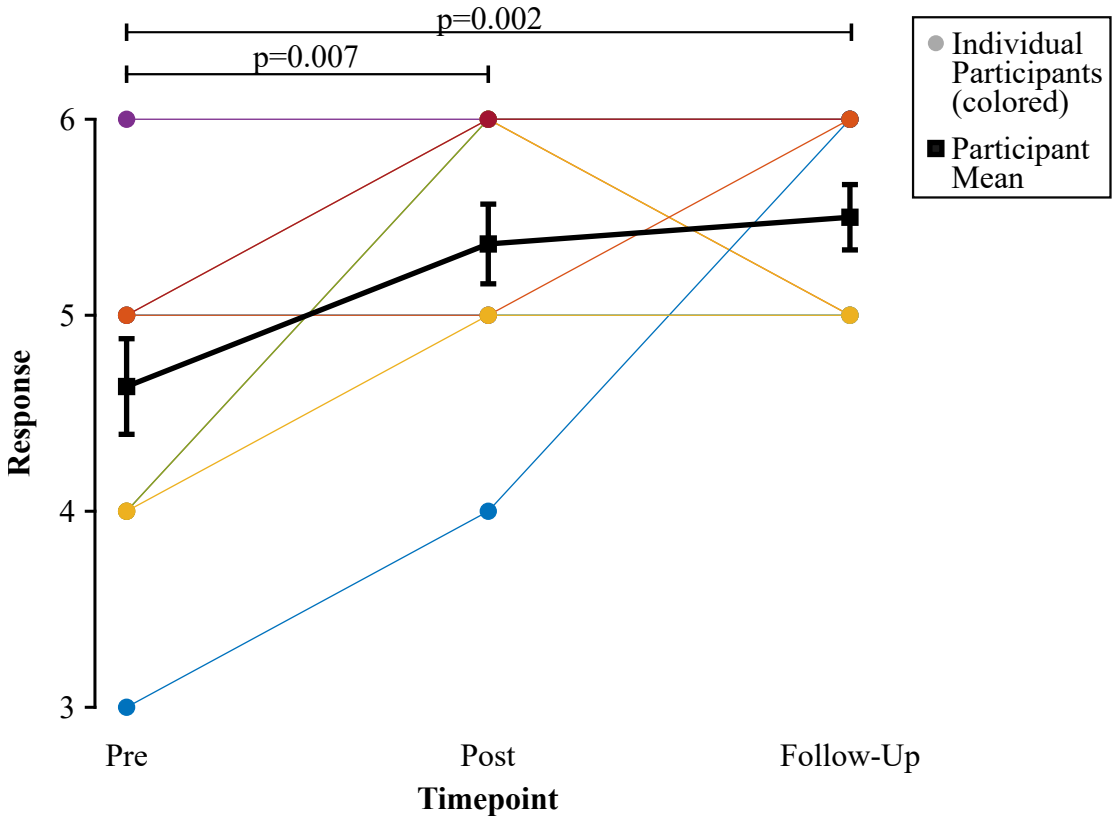

Figure 3: Participant rating of agreement with the statement, "I feel confident in my ability to navigate any uncertainties and learn the necessary skills required to conduct graduate-level research at this stage of my journey," measured on a 7-point Likert scale (1 = not true at all, 7 = exactly true). Ratings increased significantly between Pre-workshop and Post-workshop surveys and between Pre-workshop and Follow-Up surveys. Black error bars indicate the group SD. Both individual responses and group means are shown connected across time points.

Sharing research challenges with peers during the workshop helped participants feel more connected and supported. Many discovered that they were not alone in their struggles, with one participant noting "challenges in grad school are common and we can benefit a lot from sharing and building community." Others emphasized the value of simply chatting and laughing with peers to build resilience, highlighting the importance of empathy, understanding, and social connection during stressful times (note that the workshop took place in February 2025).

The emphasis of inclusion throughout the workshop also contributed to participants feeling engaged and welcomed. Many appreciated the representation of women and gender minorities, noting that this visibility encouraged participation and reinforced a sense of belonging. Participants additionally highlighted the support provided by faculty as an important factor in

creating an inclusive and supportive environment.

Finally, participants expressed a desire to continue discussions around research and personal challenges beyond the workshop. They suggested more opportunities to meet with peers, discuss academic and research challenges, and engage with supportive faculty, reflecting an interest in sustaining the collaborative and empathetic community fostered during the workshop.

6 Discussion

We investigated the impacts of a half-day workshop focused on how graduate students could apply design thinking principles in their research to improve resiliency. The workshop content focused on description and interactive examples of five design thinking principles: rapid prototyping, soliciting feedback, divergent and convergent thinking, avoiding fixation, and design by analogy. The workshop concluded with a faculty panel with questions designed to highlight nonlinear career trajectories and emphasize the lessons learned from failure in research.

Quantitative analysis from participant surveys demonstrated that the workshop had a significant positive impact on participants both in terms of overall research confidence and in specific design thinking principles, even months afterwards. Specifically, significant improvements were seen in the three-month Follow-Up survey compared to before the workshop in two of the nine questions, focusing on (1) overall confidence navigating uncertainty in their research and (Fig. 3) (2) the importance of rapid prototyping in their research (Fig. 1). Interestingly, although both responses were improved three months following the workshop, there was a difference in when the improvement occurred. Furthermore, participants' confidence in navigating uncertainties in their research improved immediately after the workshop and was maintained three months later. However, participants stated that the importance of rapid prototyping did not significantly improve until the three-month Follow-Up, suggesting that they may have needed more time to implement this in their research before realizing its importance, or that other factors (such as more experience in labs or coursework) influenced a positive change related to this principle.

Despite a significant improvement in both overall confidence and the importance of rapid prototyping, survey questions focused on other design thinking concepts discussed during the workshop did not result in statistically significant group-level improvements from before the workshop to the the 3-month Follow-Up. One question targeting the importance of soliciting feedback trended towards improvement from the Pre- to Post-workshop surveys, but the Follow-Up survey showed that participants reverted towards their initial negative feelings regarding soliciting feedback from their principal investigator (PI) on a product that was not fully polished (Fig. 2).

Despite participants' hesitancy to show their PI unfinished work, many noted the importance of soliciting feedback in their qualitative responses, suggesting that they may have been applying this principle with other groups besides their PI, which was the sole focus of the survey question. In fact, some participants explicitly stated the importance of receiving feedback within trusted communities and expressed a desire to improve trust within lab or peer communities in order to facilitate this. These findings support a key outcome of our work: strong and supportive peer communities are an important aspect of creating a resilient research environment in graduate engineering programs. Indeed, studies have shown positive relationships between collaborative

design thinking activities and community-building [22], and our findings suggest that our workshop supported the building of peer-to-peer relationships.

Despite no group-level survey improvements in some of the design thinking concepts discussed, qualitative feedback demonstrated their importance to individual workshop participants. For example, participants appreciated the concept of *divergent and convergent thinking*, noting that it allowed them to brainstorm without fear of judgment and prevented them from "getting overwhelmed when approaching a big problem." They also generally had positive comments regarding *design by analogy*, with some participants noting that this principle was relatively easy to implement considering their access to university resources and events. Because of these individual positive comments, it is possible that these design thinking principles could be helpful in the context of a PhD for some, which should be the focus of future research.

Of the five design thinking principles discussed, workshop participants seemed to have the most challenge with *avoiding fixation*. Analysis of the qualitative responses suggested that some participants may have interpreted fixation as "focusing on a single idea." In the context of a PhD program, this interpretation is not inherently problematic, as doctoral research inevitably requires sustained and deep focus. However, in this workshop, we conceptualized avoiding fixation as the ability to navigate challenges and use flexible problem-solving approaches, *i.e.*, not persisting with a single idea or solution when it is not proving effective. It is possible that more explicit examples during the workshop would have made this delineation more clear.

In design literature, fixation is frequently described as an important characteristic to counteract. Scholars suggest that design by analogy and frequent feedback from diverse project stakeholders are key ways to encourage consideration of multiple views and pathways for addressing a solution [19, 20]. Against this backdrop, participants may have benefited from a more explicit overview and reflection of the "nudges" that were used in the design activity. Each of these "nudges" supported participants with divergent thinking, and ultimately aimed to avoid fixation on any single topic during the activity.

Although the workshop was designed to teach design thinking principles for students to gain confidence in their research, qualitative responses indicated that participants derived additional benefits beyond the intended content. In particular, participants highlighted the importance of facilitator representation and the opportunity to connect with peers through shared discussions of common challenges. Hearing others articulate similar struggles reduced feelings of isolation and contributed to a sense of belonging. These findings suggest that building community played a meaningful role in participants' increased confidence and should be more explicitly emphasized as a workshop objective. In response to these findings, a longer-term outcome from this workshop was the emergence of a student-initiated ambassador program within the our department at our university. The student ambassador program is tasked with fostering community and supporting resilience through the PhD program by organizing events and promoting a supportive departmental culture. Future work should more directly investigate the role of community in supporting graduate student resilience, especially in light of prior research demonstrating that diverse and well-connected scientific teams tend to produce more impactful research [23, 24].

Although this work demonstrated promise in the use of design thinking principles to improve

graduate student confidence in their research, there were a number of limitations of study. First, the small sample size should be noted, with only ten workshop participants responding to all three surveys and included in the analysis. In addition, although our relatively short survey design allowed us to assess overall confidence and confidence associated with certain design thinking principles, a more extensive survey with multiple questions associated with a single design thinking principle would illuminate more nuance and detail around the impact of each principle in participant retention. Adopting a tool such as the recently released d.school Ambiguity Navigation Instrument (DANI) [25] in future iterations would partially address this limitation, offering a more rigorous measure of students' attitudes toward and strategies for navigating ambiguity specifically. Finally, the survey design included no control group. Particularly at the three-month Follow-Up survey, it is possible that students more advanced in their graduate studies would gain a level of confidence with time alone, which would not be the by-product of principles taught during the workshop. The immediate increase in participant confidence Post-workshop that was retained after three months suggests that the workshop did have a positive effect on participants; however, this finding would be stronger with a control group that did not attend the workshop to account for the factor of gaining confidence over time.

7 Conclusion

We explored outcomes from a novel workshop designed to foster resiliency in engineering graduate students by demonstrating how design thinking principles can be applied to their research. The workshop explicitly taught five design thinking principles (rapid prototyping, soliciting feedback, divergent and convergent thinking, avoiding fixation, and design by analogy), and included interactive activities incorporating these principles, as well as a faculty panel designed to highlight non-traditional pathways in academia and the importance of failure. Findings suggest that the workshop was helpful in improving participants' confidence in navigating uncertainty in their research, with participants particularly recognizing the value of rapid prototyping.

An unanticipated (though not surprising) finding was the extent to which the workshop fostered a sense of community and meaningful peer-to-peer connections among participants. These social connections appeared to play an important role in reducing feelings of isolation and supporting participants' confidence and resilience, highlighting the value of intentionally incorporating community-building elements into interventions aimed at supporting graduate researchers. Overall, the findings indicate that design thinking offers a promising approach for supporting graduate student research resilience, with benefits arising from the activities, reflection on principles, and the community-building dynamics they enable.

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