Fostering Engineering Design Self-Efficacy and Problem-Solving Skills in GenAI Era: Insights from an Exploratory Workshop

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Abstract. Design thinking is a problem-solving approach that emphasizes user-focused observation, diverse idea generation, and iterative solution optimization. In this exploratory research, we investigate the role of fostering design thinking and problem-solving skills among undergraduate students on their engineering design self-efficacy, problem-solving approach, and use of GenAI. A workshop on engineering design and problem-solving skills was conducted for 70 students. Results indicated a significant improvement in students' engineering design self-efficacy post-workshop. There was also a significant decrease in students' tendency to use GenAI to assist them in problem-solving and students favored systematic engineering design practices over merely incorporating suggestions from AI. The findings suggest that in addition to advancing GenAI and promoting AI literacy, training students on engineering design could be promising to help them engage with AI as a supplementary tool rather than a primary source of solution, thereby helping them incorporate AI meaningfully in problem-solving.

Keywords: Engineering Design Thinking · Problem-Solving · Generative AI · Self-efficacy.

1 Introduction

The goal of using technology in education is to leverage its potential to make learners intelligent while technology itself might not necessarily be intelligent [2]. However, with the advent of generative artificial intelligence (GenAI), an intelligent technology, researchers are investigating challenges it possesses and identifying its potential [26] to ensure that incorporating it enhances human learning [24].

In engineering education research, this aspect becomes more ambiguous given that GenAI can provide all the information at fingertips which makes researchers wonder what are we teaching? Why? and how can we best teach? [13]. While researchers are emphasizing on the importance of prompt engineering to optimize GenAI's use and assistance [21, 25] and meaningfully integrating GenAI in engineering courses [6], it is unclear where do we fit traditional methods of engineering design skills and practices [14, 7] in the current era. Given that GenAI can handle tasks like generating design options, automating simulations, and even providing suggestions for optimization [8], what does it mean to be an informed designer [5] in this era? Moreover, it is not well understood that if trained on these traditional methods and skills, how do novice engineers integrate them and leverage GenAI to solve engineering problems. This study investigates how fostering engineering design thinking influences students' self-efficacy in tackling design problems and examines how these shifts in self-efficacy translate into changes in their problem-solving strategies, including their use of GenAI. We seek answers to the following research questions:

RQ1: Does fostering engineering design thinking affect the self-efficacy of undergraduate students?

RQ2: How does fostering engineering design thinking and problem-solving influences students' approaches to solving problems and use of GenAI?

2 Literature Review

Engineering design problems are often complex and ill-structured, requiring design strategies to navigate their uncertain nature [15]. Novice engineers, although possess theoretical knowledge, often lack skills to think critically and creatively and need scaffolds to address the ill-structured nature of engineering problems [16]. This support is provided in various manners, some of them include use of pedagogies such as problem-based learning [10], training students in design pedagogical content knowledge [5] by providing scaffolds [1], familiarizing students with the engineering design process [7], prompting students to practice reflection [23] on aspects of problem and process [22], and designing to facilitate sensemaking among novice engineers [20].

The integration of GenAI in engineering education offers a unique opportunity to enhance the learning experience. GenAI generates diverse ideas, outlines challenges, and provides technical insights supporting the iterative process of design thinking, though it may not replace human empathy or the nuanced understanding obtained through user observations and interviews [8]. These tools support designers in making decisions throughout the design process by enhancing interactions between knowledge providers and seekers [11]. These tools are fairly advanced, but they still have limitations [19] including imperfections due to hallucination, inaccuracies, instability, and biases [26]. Hence, despite the potential of these tools, novice engineers need to be mindful while taking assistance from GenAI. Researchers have investigated various methods to achieve this balance. Some of these include adopting a sequential pattern in asking questions to GenAI [18], critically evaluate its response before incorporating it [4], enhancing AI literacy of users [17], and constantly evolving the AI [26].

While AI as a perfect assistant is still in the progress, we observe that AI users, especially novices in training to become engineers need to have engineering design skills along with GenAI in their toolbox to be able to solve complex and ill-structured engineering design problems. In this research, we address this concern through an exploratory study by training students on engineering design and problem-solving concepts. We trained the students on nine informed designer skills identified by [5] that are crucial to solving such problems. We then investigate how training students on these skills influences their self-efficacy, use of GenAI, and problem-solving approach.

3 Method

3.1 Participants

Seventy undergraduate students from various departments at a university in Mumbai participated in this study. This included six students from third year data science and engineering program, 45 students from second and third year computer science and engineering and business systems program, 11 students from the first, second, and third year computer engineering program, and four students from the third year in computer science B. Tech. integrated 6-year course. There were three first year students from the school of mathematics, applied statistics and analytics and one third year student from the MBA Tech computer science program.

3.2 Procedure

The workshop began with students forming 30 teams of two to four members each and completing a pre-survey to gather their individual engineering design self-efficacy. This was followed by an introductory lecture on robotics. Then, participants were asked to provide a conceptual design (using pen and paper, Miro, or other similar tools) of a robot to automate their college canteen. Then, participants were introduced to the principles of engineering design and stages of problem-solving. After workshop, the participants were asked to provide a conceptual design of a robot to automate the library in their college. During both the activities, participants were allowed to use GenAI tools of their choice. Finally, the participants completed a post-survey on engineering design self-efficacy. Fig. 1 provides an overview of the procedure. This was followed by a semi-structured interview with a few participant teams within a week of the workshop.

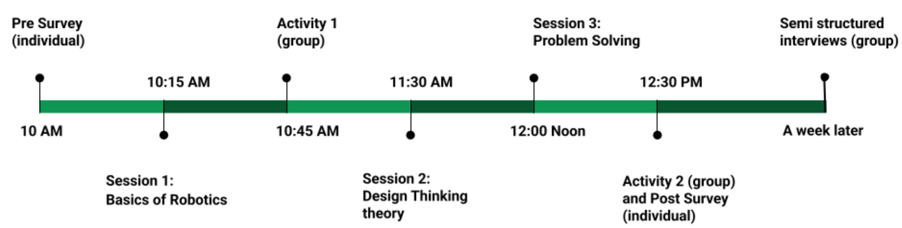

Fig. 1: Procedure Overview

3.3 Data collection

Multiple data were collected in this study to capture a comprehensive view of participants' learning of engineering design, problem-solving processes, and their use of GenAI. The participants' engineering design self-efficacy was measured through a survey instrument before and after the workshop [3]. Pre-survey and consent form was filled by all the participants. The feedback was filled by 40 participants and the post-survey received response from 54 participants. Participants submitted conceptual design solutions as a team and provided names of GenAI tools (if used). Conceptual design solution for the first problem was submitted by 21 teams and by 14 teams for the second problem. To gain deeper insights into participants' approach, semi-structured interviews lasting 30 to 45 minutes were conducted with three teams. The sample was chosen based on participants' availability to participate in the interview.

3.4 Data Analysis

The pre and post workshop self-efficacy scores were compared using a repeated measured t-test (RQ1). McNemar's test of proportions was used to analyze differences in participants' proportionate AI use between activities. The interview audio recordings were transcribed and the transcriptions, along with the respective teams' submission were analyzed using a within-case analysis method for two of the three interviewed teams, one that did not use GenAI (Team 1) and one that used GenAI (Team 2) during the workshop to gain insights into teams' approach [27].

4 Results

4.1 Fostering engineering design thinking and student self-efficacy

A repeated measures t-test on students' engineering design self-efficacy before and after workshop shows that the students' average engineering design self-efficacy improved statistically significantly after workshop with moderate to large effects sizes on all parameters (see Table 1).

4.2 Influence of engineering design and problem-solving workshop on students' approaches to problem-solving and ChatGPT use

Use of generative AI Teams reported using GenAI tools such as ChatGPT, Perplexity, and Taskade. McNemar's test found a statistically significant decrease in the proportion of teams using GenAI in activity 2 compared to activity 1(50% decrease), $\chi^2(1) = 4.00$, $p = .046$, with a moderate effect size (Cohen′s Q = 1.58).

4.3 Team 1 experience: Focus on different aspects

This team focused on different aspects of the problem between the activities. In the first activity, the team primarily focused on mapping out space and obstacle detection, identification, and avoidance. One of the students mentioned the following:

S1: What we did first was draw the layout of the canteen to understand how the robot would even start to attempt to navigate it, right? So, we have to know the layout of the canteen. Then we started to throw in a bunch of obstacles, like what could happen, people could get in its way, lamp posts etc. So, we discussed, and we came up with a few obstacles and how it should work.

Table 1: Pre- and Post-Self-Efficacy Scores across Design Activities

Self-Efficacy Parameter	Pre M (SD)	Post M (SD)	t(52)	*p*	Cohen's d
Identify a design problem	57.4 (21.2)	72.1 (18.1)	5.65	$< .001$	0.78
Conduct research to understand design problems and user needs	58.7 (21.2)	73.6 (18.8)	5.72	$< .001$	0.79
Brainstorm and generate many possible design solutions	56.4 (21.5)	72.8 (18.7)	5.58	$< .001$	0.77
Propose a design solution that meets user needs and requirements	55.7 (21.3)	73.6 (18.5)	7.20	$< .001$	0.99
Construct a prototype	52.8 (21.8)	70.9 (20.3)	6.66	$< .001$	0.91
Evaluate and test a design	55.1 (21.3)	70.9 (18.1)	5.65	$< .001$	0.78
Critique a design	56.6 (22.8)	73.0 (17.8)	6.49	$< .001$	0.89
Iteratively incorporate feedback and update a design	57.2 (23.4)	73.8 (20.1)	6.20	$< .001$	0.85
Communicate about a design	58.5 (21.3)	74.3 (19.4)	6.29	$< .001$	0.86

In the second activity, the team focused on solving one aspect of the problem, breaking it into manageable pieces, addressing easier aspects first and then difficult ones. They cite that they learned from the workshop, that a problem can have several aspects with multiple solutions and it could be difficult to think of one given the limited time for activity. So, they focused on creating a decision-making pattern for the robot and then design the robot if time permitted.

S3: As we were discussing in the workshop, there could be several solutions, but one is usually the best. But we could not figure out which could be the best. So, we decided that first it would be easier to lay out the decisions given the short time that we had and then think about the design if we had the time permitted us.

This was also evident in their submission for activity 2 which had flowchart, whereas submission for activity 1 mainly described the canteen layout and obstacles. This team did not use generative AI in either of the activities as they thought they knew the context well and did not require further assistance.

4.4 Team 2 experience: Less reliance on ChatGPT and more on brainstorming, discussion, and refining

This team mentioned having relied on ChatGPT in activity 1 but did not use it in activity 2. Instead, they valued brainstorming as a group and promoting good ideas. In the first activity, the team focused on the aspect of robot navigation, and they typically jotted down ideas given by ChatGPT and discussed all the things that came to their minds and used ChatGPT for guidance to validate their ideas.

S2: We first thought about how the robot moves about in cafeteria. We plotted a grid-like square around the cafeteria. I think, mainly we were jotting down ideas from ChatGPT and were thinking about it. It (ChatGPT) was used to give us food for thought and make us think in the correct direction.

In the second activity, the team brainstormed more and became aware the problem is complex and its solution required multiple iterations. So, they iterated the flowchart multiple times and refined the robot design to handle different scenarios. They believed that they cannot rely on ChatGPT but need to think as a group.

S1: I think when we started off, it was about problem representation or thinking about the problem more in the context. We debated on it as a team and we each prompted all of us to share our ideas and then we debated about those ideas. So, we modified this flowchart multiple times, we thought of what problems the end user could have. We didn't rely on ChatGPT as much as we relied on activity 1. (In the second activity) First of all we thought of all the ideas ourselves, we brainstormed as a group and promoted good ideas.

Their approach was also evident in the submissions. For the first activity, where they simply jotted ideas with the help of AI, it had a straightforward flowchart for robot activities. While the submission for second activity had decision blocks with multiple end results based on intermediate conditions.

5 Discussion

We found that participants' engineering design self-efficacy improved after the workshop. Responses from participants in feedback suggest that the workshop helped participants enhance their engineering design knowledge which in turn made them adopt a structured approach in solving the problem and apply principles of engineering design. Thus, even though GenAI could provide all the information at fingertips [13] and handle complex tasks such as generating design options [8], we observed that fostering engineering design and problem-solving skills made students' aware of the complexity of engineering design problems and created a shift among them to adopt the design principles. We also observed in one of the cases that a team used AI in first activity and followed its suggestions as it is but shifted to brainstorming and discussion in the second activity. This shows that such workshops likely make them aware of complexity of engineering design problems and help them reflect on responses given by AI and be mindful of its limitations [13, 26]. Thus, even though students had AI to assist them in both activities, the tendency to reduce the AI use in second activity and focus more on traditional methods, that likely requires more cognitive efforts, shows that students are willing to engage in such tasks for in-depth learning [24].

This study offers exploratory insights into how fostering engineering design and problem-solving skills may influence students' engagement with AI tools and shape their problem-solving approaches. Rather than establishing causal claims, the research aims to illuminate the evolving role of traditional engineering design practices within the context of GenAI. Further, the findings have limitations given the context of study, participants, threat to validity due to testing, and the attrition observed in activity 2 submission. In this workshop, we did not train students on AI literacy and prompt engineering [25] which could have resulted in students adopting engineering design practices, rather than improving AI response. Future research could include training students in engineering design along with AI literacy and prompt engineering for meaningful integration of AI in engineering design. In our research, students only designed conceptual solutions. Numerous studies have found AI to be a helpful tool in building engineering solutions [8, 9, 21, 12]. Thus, it would be of interest to understand how fostering engineering design skills impacts problem-solving approach and use of AI by novice engineers when they build engineering design solutions. Future studies could explore the comparative analysis of traditional design thinking methods versus a combination of design thinking and GenAI integration, assessing their relative impact on student outcomes. Another valuable avenue for exploration is longitudinal studies to assess long-term retention of improved problem-solving skills and engineering design self-efficacy. Furthermore, research could investigate the real-world application of GenAI in prototyping, moving beyond conceptual solutions to evaluate its utility in creating and testing physical prototypes.

6 Conclusion

This study demonstrated that design thinking workshops can enhance students' engineering design self-efficacy and shift their approach from unstructured to structured methodologies. The inclusion of GenAI tools helped students but they preferred human-led collaboration and thinking critically about the solution. Introduction to engineering design and problem-solving practices helped participants increase awareness of design thinking principles, adoption of better communication, and iterative refinement of the solution in the design process. This suggests that students found value in traditional design methods over simply following GenAI. Thus, while we research on meaningful integration of AI in complex tasks such as engineering design, inclusion of traditional methods could be one of the factors we consider while training students in AI literacy.

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