BOARD # 437: Research in the Formation of Engineers: Prompting Socially Engaged Divergent Thinking in Engineering Design by Leveraging Generative AI

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Abstract

With appropriate scaffolding and prompt engineering, Generative AI has the potential to support engineering students to think comprehensively about stakeholders and society. In this paper, we present an initial toolkit and pedagogical suggestions for leveraging AI in engineering design across four design activities: (1) identifying stakeholders; (2) generating interview questions; (3) discovering solutions; and (4) assessing impacts. We first recommend that students generate ideas, such as potential stakeholders or solutions, without using Generative AI. Once students exhaust their immediate knowledge, instructors then introduce Generative AI and prompt queries for students to generate a diverse range of additional ideas. Lastly, instructors prompt students to filter unapplicable suggestions by using their engineering judgment. Building upon these suggestions, our funded project will leverage data gathered from students and design instructors to assess the strengths, limitations, and negative consequences of employing Generative AI in design pedagogy.

Introduction

Generative AI presents novel and unprecedented pedagogical possibilities, and there is a current emphasis on developing resources for the responsible use of Generative AI in many sectors of the US [1], including education [2]. As indicated in Biden's 2023 Executive Order on Safe, Secure, and Trustworthy Artificial Intelligence [3], it is a national imperative to develop resources for "the responsible development and deployment of AI in the education sector" that promote "safe, responsible, and nondiscriminatory uses of AI in education, including the impact AI systems have on vulnerable and underserved communities." Accordingly, there is a need to develop AI resources for educational contexts (including engineering design) that bring clarity regarding AI's responsible and ethical use therein. Undergirding our project design is our belief that Generative AI can assist students in making more novel, inclusive, and ethical associations across domains.

Pilot Observations of AI Use in Engineering Design Courses

The first two authors have piloted use of ChatGPT to support students in our design courses. This pilot work serves as the foundation for our RFE study. We found that the use of Generative AI in engineering courses is subject to a complex range of pedagogical, social, and cultural factors; these factors justify the development of evidence-based pedagogical recommendations to support students in using Generative AI ethically and effectively. We plan to elucidate relevant factors and recommendations through our RFE study. For now, our pilot findings suggest three items that are pertinent to the use of Generative AI in design pedagogy: (1) ChatGPT offers salient and novel perspectives for students to consider; (2) ChatGPT should not replace engineering judgment; and (3) Instructors should provide clear guidance for AI use in courses.

The two investigators on this project (Hess and Loweth) are both engineering education researchers who have taught engineering design for several years. We have encouraged students to use ChatGPT to assist their design projects, including in two courses in Fall 2023 and 2024: (1) a design project focused on campus mobility that was part of a first-year engineering course and (2) a design project focused on a topic that students selected in an upper-level multidisciplinary

engineering course. Prior to encouraging Generative AI use, we noted that students were already using free versions of ChatGPT. We thus assigned students to use ChatGPT to identify ideas and perspectives that differed from what they had already considered. We engineered prompts for students to use, observed students' use of these prompts in ChatGPT, and then met to discuss and compare our observations. Through our pilot observations, we observed three aspects.

First, we observed that ChatGPT quickly offered salient, relevant, and novel perspectives for students to consider. When we asked ChatGPT, "Who is often excluded from design solutions when considering campus mobility issues?" ChatGPT listed 15 groups in a matter of seconds (e.g., Low-Income and Marginalized Communities; Minorities and Underrepresented Groups; International Students). While students did not use most suggestions provided by ChatGPT, Loweth did observe the introduction of "new" stakeholders across team design reports that were uncommon in his previous year teaching the course. "New" stakeholder groups included campus security and emergency services, mobility-impaired individuals, and campus delivery services.

Second, we realized that we did not want ChatGPT to replace students' engineering judgment. We observed that some students inappropriately relied on ChatGPT as an authority; we thus came to emphasize that students should engage in original thinking prior to and after their use of ChatGPT. For example, when Hess asked his design students, "How was your experience with using ChatGPT to identify stakeholders?" one student shared, "It was easy." Other students used ChatGPT to structure their responses to rubric items, and yet others leveraged ChatGPT to design for stakeholders they may otherwise not consider. In one case, ChatGPT encouraged a student to consider a user they had not considered as part of their design project. In this case, this user did not become the "primary" user in the students' design work but rather an important secondary stakeholder that they accounted for throughout. Relatedly, it can be challenging to sift through the large quantity of suggestions that can be readily produced by ChatGPT. Identifying potential ideas *prior to* using Generative AI may help students ground their thinking to sift through ChatGPT suggestions more efficiently and identify suggestions that are surprising or thought-provoking.

Finally, from our observations, we identified a need to develop clear guidance for AI use in courses that accounts for student, faculty, and institutional views. Students are interested in and already leveraging Generative AI – and many students were already using GenAI in our courses prior to our prompting. Faculty would benefit from guidance related to navigating the new pedagogical landscape where Generative AI use is, for better or worse, the norm. After we encouraged ChatGPT use, our students became more transparent and asked many more questions regarding how to use AI in ethical and appropriate ways. We directed students to APA guidance for citing the use of ChatGPT, but as our students began using ChatGPT more extensively, the boundary between plagiarism and original input became blurry. A particular challenge was that students would use ChatGPT for instructor-sanctioned purposes but insufficiently cite this use in their design documentation, making it difficult for us to track which ideas came from students and which ideas came from ChatGPT. This blurriness in use seemed to stem from beyond the instructor, namely, institutional tensions around ChatGPT as a tool for research versus as a tool for cheating.

Generative AI Prompts for Socially Engaged Divergent Thinking

In response to these pilot observations and our course goals, we developed a model to help our students leverage Generative AI in their courses. We theorized that Generative AI can support

socially engaged divergent thinking in engineering design in post-secondary contexts. **We define socially engaged divergent thinking as the ability to identify and integrate diverse stakeholders and wide-ranging societal factors into one's engineering thinking**. While Generative AI can support socially engaged divergent thinking, there are risks that prompters must account for to use Generative AI effectively and ethically. Our model for Generative AI use (**Figure 1**) is a step towards supporting design students and instructors in mitigating these risks.

First, **Generative AI may provide responses that inaccurately represent marginalized stakeholder groups** [4]. This phenomenon is due to biases existing in the training data set, biases in the design of the AI algorithm, and biases on the part of the prompter [5]. These biases can, in theory, be mitigated through carefully worded prompts that provide clear directions to the AI tool and that are implemented iteratively by the prompter (i.e., the individual querying the AI tool). Collectively, strategies for carefully wording and monitoring Generative AI prompts are referred to as "prompt engineering" [6, 7]. However, more work is needed to understand how effectively prompt engineering strategies mitigate bias in practice; this is a sub-motivation for our RQ2.

Second, Generative AI is not intelligent: AI tools mimic natural speech but lack inherent content knowledge about their outputs. Thus, **Generative AI is not a replacement for engineering thinking and decision-making**. When students use Generative AI, they must interpret, filter, and justify which AI outputs are most relevant to their goals. While Generative AI can provide information and inspire novel ideas, and thus can expand prompters' thinking processes, AI tools should not be relied on to make decisions. Our conceptual model in **Figure 1** portrays how we think AI tools may be used to augment (rather than replace) engineering decision-making. Our use case of Generative AI is grounded in design theory and pedagogy; thus, **Figure 1** integrates key ideas from the double diamond design model [8] and the socially engaged design model [9].

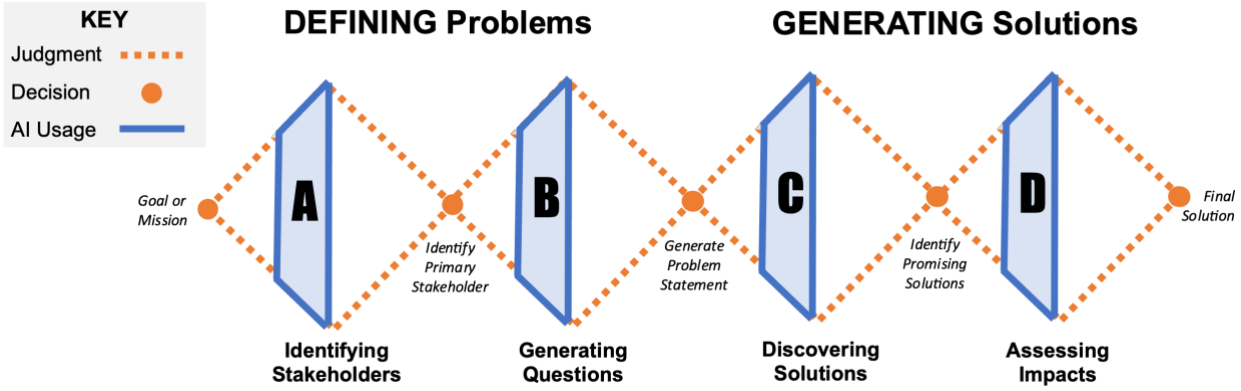

Figure 1: Promoting Socially Engaged Divergent Thinking by Leveraging Generative AI

The model depicted in **Figure 1** includes four design stages that are linked to the design activities that engineering students perform (and questions they ask) during design processes:

A. **Identifying Stakeholders:** Which stakeholders should I consider during my design process?
B. **Generating Questions**: Which questions should I ask stakeholders to learn more about my design problem?
C. **Discovering Solutions**: What solutions are possible for my design problem?
D. **Assessing Impacts**: What impact on stakeholders or society may result from implementing a given solution?

To account for risks inherent to Generative AI use, we propose that engineering designers should first generate their own ideas related to a given design stage offline (i.e., not using Generative AI). Once they have exhausted their immediate knowledge, designers then leverage prompt queries to explore new possibilities. In a course setting, this is the point where we recommend that instructors introduce examples of Generative AI prompt queries for students to utilize. Examples of prompts used by the authors in their courses are listed in **Table 1**. Effective Generative AI use is iterative; thus, these prompts represent starting points for further exploration and for tailoring to specific design projects. As part of this grant, we plan to test the hypothesis that when students use pre-engineered prompts with Generative AI, they will produce more diverse, novel, and inclusive ideas than students who use Generative AI without pre-engineered prompts.

Table 1: Example Generative AI prompts for design tasks (brackets indicate blanks for the prompter to fill in specific to their information needs or design project)

Design Stage	Example Prompts
Identifying Stakeholders	-Suggest [number] stakeholders or stakeholder groups, specifically focusing on stakeholders who may use solutions to [design problem]. -Suggest [number] stakeholders or stakeholder groups, specifically focusing on stakeholders who may be marginalized by current [design problem] solutions.
Generating Questions	-Suggest [number] interview questions that I should ask [stakeholder group] to learn more about [aspect of design problem].
Discovering Solutions	-Use [idea generation technique] to generate [number] solutions to design problem.
Assessing Impacts	-List [number] potential benefits related to [societal aspect] that may result from implementing [design solution]. -List [number] potential harms related to [societal aspect] that may result from implementing [design solution].

Overview & Future Work

Building on our pilot observations and our model of appropriate Generative AI use in **Figure 1**, our Research Aim is to assess the strengths, limitations, and negative consequences of employing Generative AI in design pedagogy. We aim to address three research questions (RQs):

RQ1: What are the strengths, weaknesses, opportunities, and threats of incorporating Generative AI into engineering design courses according to engineering design instructors?

RQ2: How does Generative AI impact engineering students' socially engaged divergent thinking during a design challenge?

RQ3: What do engineering design content experts view as the pros and cons of using Generative AI to prompt socially engaged divergent thinking?

To address these research questions, we will collect data with three groups of participants, including up to 30 engineering design instructors (RQ1), up to 30 engineering students (RQ2), and a diverse cross-section of engineering design scholars (or "content experts", RQ3). We are exploring these three different stakeholder perspectives to form a comprehensive picture of how Generative AI is, can, and should be used to promote socially engaged divergent thinking across engineering design curricula. Project outcomes will include a refined toolkit of engineered prompts for effective and ethical Generative AI use and evidence-based recommendations for integrating Generative AI into engineering design and design-adjacent courses.

Conclusion

Engineering education is rapidly changing in response to Generative AI tools. Our preliminary work points to initial adaptations that instructors can make to weather these changes. First, instructors should emphasize that human engineering judgment is paramount: students choose design foci, *not* AI. Second, instructors ought to sequence activities so that students do original thinking before and after Generative AI use. Finally, we theorize that specifying course community values for curricular AI use is just as important as providing students with codified instructions for AI use. Values that we have identified for our courses include (1) learning, (2) academic integrity, (3) transparency, (4) ethical judgment, and (5) avoiding copyright infringement. Norms and use cases involving generative AI are constantly evolving; course norms can provide a guiding compass for instructors and students to ascertain appropriate uses of AI when in doubt.

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References

[1] The White House. "Bluebrints for an AI Bill of Rights." https://www.whitehouse.gov/ostp/ai-bill-of-rights/ (accessed 01/2025, link no longer active 04/2025).

[2] M. A. Cardona, R. J. Rodriguez, and K. Ishmael, *Artificial Intelligence and the future of teaching and learning: Insights and recommendations*. Office of Educational Technology, 2023.

[3] Biden, J. (2023). *Executive Order on Safe, Secure, and Trustworthy Artificial Intelligence*. [Online] Available: https://www.whitehouse.gov/briefing-room/presidential-actions/2023/10/30/executive-order-on-the-safe-secure-and-trustworthy-development-and-use-of-artificial-intelligence/ (accessed 01/2025, link no longer active 04/2025).

[4] V. Capraro *et al.*, "The impact of generative artificial intelligence on socioeconomic inequalities and policy making," *PNAS Nexus,* vol. 3, no. 6, 2024.

[5] E. Ferrara, "Fairness and bias in artificial intelligence: A brief survey of sources, impacts, and mitigation strategies," *Sci,* vol. 6, no. 1, p. 3, 2023.

[6] P. Sahoo, A. K. Singh, S. Saha, V. Jain, S. Mondal, and A. Chadha, "A systematic survey of prompt engineering in large language models: Techniques and applications," *arXiv preprint arXiv:2402.07927,* 2024.

[7] C. Shah, "From Prompt Engineering to Prompt Science With Human in the Loop," *arXiv preprint arXiv:2401.04122,* 2024.

[8] D. A. Norman, *The design of everyday things*. Basic books, 2002.

[9] K. Dugan, S. Daly, C. Michaels, S. Skerlos, and A. Verhey-Henke, "Investigating a socially engaged design process model," in *2022 ASEE Annual Conference & Exposition*, Minneapolis, MN, 2022.