BOARD # 215: Role of Generative AI in Enhancing Pre-College Engineering Design Thinking (Work in Progress)

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Work in Progress: Role of Generative AI in Enhancing Pre-College Engineering Design Thinking

Abstract

This Work in Progress (WIP) paper is part of a larger collaborative mentoring program pairing graduate-level engineering education researchers with high school students. The project investigates the potential of Gen-AI (Generative Artificial Intelligence) as a pedagogical tool for fostering engineering thinking in pre-college engineering education. Specifically, this paper explores nine high school students' perceptions regarding integrating Gen-AI into the ideation phase of engineering design in an engineering design course. In this study, students engaged in two distinct engineering design projects, first without AI assistance and later with AI assistance. After completing each project, students responded to an open-ended questionnaire and reflected on their experiences. The questionnaire responses were analyzed by a team of two high school students and a graduate-level mentor using qualitative thematic analysis. This pairing of two high school students with a graduate student mentor was designed to provide students with hands-on experience in the research process, from data collection, cleanup, analysis, and interpretation. The preliminary findings from the questionnaire showed that students used AI to visualize, research, and brainstorm ideas for their projects. Students identified that AI was helpful in the design of several sustainability features and layout designs. While students commented on several strengths of AI, including speed, convenience, and innovation, they also mentioned being held back by certain drawbacks, such as the shallow and generic nature of the responses. The student responses also exhibited discernment regarding the appropriate usage of AI in context and ethics. Moreover, students mentioned concerns regarding the accuracy of the AI-generated information and how it impacts students' creativity. The findings show that students possess a nuanced understanding of AI, pointing to engagement with these tools outside of class, underscoring the need to incorporate them more thoughtfully into our teaching. Students' reflections offer valuable insights into the role Gen-AI can play in supporting—or potentially hindering—students' engagement in engineering design and the development of their engineering thinking.

Introduction

Recent advancements and accessibility of Artificial Intelligence (AI) tools have paved the way for the incorporation of AI into everyday lives. Large language models' rapid development and evolution point to a shift toward increased automation [1]. Consequently, students must be prepared to excel in an increasingly competitive, AI-driven world [2]. To this end, there is a push for integrating AI into educational curricula [3]. The Department of Education recently issued guidelines for integrating AI into educational settings to help achieve learning outcomes [4]. However, the integration of AI in educational contexts, particularly in the K-12 domain, has been limited [5]. Although this can be attributed to several factors, such as tight class schedules, limited professional development resources for teachers, or a lack of curricular autonomy, one notable factor could be that schools and teachers experience fear and anxiety regarding adopting AI into K-12 education [6] due to its anticipated risks [7]. In part, this anxiety is caused by a fear of the unknown. Literature is scarce regarding how AI impacts student learning outcomes and motivation. Also, studies exploring students' experiences of AI integration in K-12 education are rare. The current study addresses this research gap by exploring high school students' experiences of using AI in an engineering design course.

This study is part of a collaborative mentorship project where graduate-level engineering education researchers train high school students in engineering education research and provide hands-on experiences. The focus of the larger project is to investigate the potential of AI as a pedagogical tool to foster engineering thinking in pre-college students. Specifically, this work-in-progress paper addresses the research question, "What are the students' perceptions regarding the integration of Generative AI into the ideation phase of engineering design in an engineering design course?" We believe that exploring student experiences and perceptions of AI is crucial to fostering an open and balanced attitude toward integrating AI in K-12 settings.

Background

Engineering Design Thinking

Design thinking is a hands-on approach to problem-solving, focusing on user needs and leading to innovation [8]. It can be integrated into education to provide engineering exposure to all students, thereby supporting creative problem-solving, collaboration, and iterative experimentation [9, 10]. This iterative process starts with empathizing with users and defining the problem. The process moves to ideation and prototyping and ends with an iterative phase of testing and refining solutions to meet user needs [8, 11], fostering transdisciplinary skills that are invaluable for preparing students to tackle complex problems.

Over the past two decades, engineering design has gained prominence in K–12 education [12]. Since 2000, educators and curriculum designers have designed and developed several large-scale engineering design programs such as YES (Youth Engineering Solutions), E4USA, Engineering is Elementary, and short modular curricula [13-15] and integrated them into in-school and out-of-school programs. Through both school curricula and outreach initiatives by universities, businesses, and professional societies, students now engage more frequently with design [16]. Research has demonstrated that children as young as kindergarteners can engage meaningfully in design-based tasks [17, 18]. By providing opportunities for exploration and inquiry, design thinking activities can help children develop foundational skills in critical reasoning, communication, and innovation [19, 20].

AI in Education and Design

Artificial Intelligence (AI) is a branch of computer science focused on developing systems capable of performing tasks that usually require human intelligence, including learning, reasoning, and decision-making [21]. Generative AI (Gen-AI) is a subset of AI that specializes in creating human-like content, including text, images, and audio [22]. With AI's recent innovations, many have explored its educational applications. Many educators currently utilize AI tools to increase efficiency within the classroom [1]. Two examples of Gen AI tools include 1) ChatGPT, a generative AI chatbot, and 2) Grammarly, an AI-powered writing assistant. Both tools have proven valuable educational assistants [2, 3]. GenAI can help educators with tasks like creating assessments and streamlining administrative tasks and lessons [23, 24]. In the field of design, AI can automate problem-solving processes, enabling real-time, personalized solutions [25]. Additionally, AI can support creative tasks, such as converting hand-drawn sketches into detailed specifications.

Despite its potential, the use of AI in education is limited. Research on student perceptions of AI is limited to the university level. For example, in one study, 70% of engineering students reported they didn't use AI in their engineering endeavors, and many credited this to the lack of accuracy and credibility of the responses [26]. That said, several students pointed out

various strengths of AI, including its ability to access information quickly or solve simple problems. Another study showed similar trends in the experiences of Bachelor of Pharmacy students regarding ChatGPT usage in process-driven, problem-based learning [27]. The students expressed doubts regarding the credibility of AI-generated content. However, ChatGPT had positive impacts on students' engagement and motivation. Similarly, the results of a survey conducted among English as a Foreign Language (EFL) students found that students perceived a given AI plot generation tool as invaluable to their writing [28].

Methods

Site and Participants

The primary data collection site was Hill School, a preparatory, independent high school located in the northeastern region of the USA. Our pool of participants included students in their junior or senior year of high school enrolled in an engineering design course called "Multidisciplinary Engineering: An Intro to Integrative Product Design". The course is intended to introduce students to the engineering design process. Throughout the course, students get a strong grasp of professional engineering concepts through various projects and assignments. Nine out of eleven students voluntarily participated in this study (N=9). Students were awarded extra credit for their participation. The data analysis was done in partnership with researchers at Texas A&M University, a large public institution in the southwestern region of the USA.

Data Collection

The data were collected using an open-ended survey to get students' reflections after completing two engineering design assignments. In the first assignment, students followed the engineering design process to design a water bottle without AI assistance. In the second assignment, students were asked to design a sustainable house using the engineering design process. However, they were encouraged to use AI this time, especially during the ideation phase. Students were split into groups of two to three. Each group was asked to create two personas and then create a tiny house (300 square feet) tailored to these users. Table I shows the list of survey questions.

TABLE I
SAMPLE SURVEY QUESTIONS

Experience	Prompt
General Experience	How did you use Generative AI during this project (e.g., research, brainstorming, sketching, or refining ideas)? What were the strengths and challenges of using AI tools in your design process?
Impact on Ideation	How did AI help you generate and develop ideas for your tiny house?
Impact on Design	How useful was AI in visualizing or improving your design (e.g., sustainability features, materials, layout)?
Comparison to Previous Projects	How was this design process different compared to previous projects where you didn't use AI? Did AI make the process easier, faster, or more creative?
Overall Impressions	How valuable did you find AI in this project, and would you use it for future design work? Why or why not?

Procedure & Analysis

Before conducting the analysis, the data were cleaned and compiled. The responses were analyzed using qualitative thematic analysis [29]. This approach involves six steps: 1) familiarizing oneself with the data, 2) generating initial codes, 3) searching for themes, 4) reviewing themes, 5) defining themes, and 6) reporting the themes [30, 31]. Following this

approach, three research team members thoroughly read through the data and coded the student responses to the survey using in-vivo coding, which involves using participants' words to form codes. We then refined the codes to enhance clarity. Next, we grouped similar codes together and then generated themes to represent those codes. Lastly, to lend perspective to the themes, we categorized them under different aspects of students' experiences with AI.

Findings

Student responses showed that students used ChatGPT (three), Claude (three), and Canva (one) for the project. Two students did not mention any tool. The analysis of data generated themes that fall into the following categories.

AI Usage in the Design Process

The themes in this category represent how students used AI in their assignments.

1. Visualizing: Students reported using AI to help visualize their ideas by generating sketches for their ideas, images of low-fidelity designs, and potential layouts for their tiny houses.
2. Writing: Students used AI assistance to write their reports and create documentation. AI helped them summarize, clarify, and polish their ideas.
3. Launchpad: Many students characterized their AI usage as a starting point for the project, in essence acting as a launchpad for their ideas. Students reported that AI helped them brainstorm ideas and personas. As one student reported, "It (AI) helped to get my thoughts out and figure out exactly what I wanted, even if I didn't use its ideas."
4. Research: Research was another recurring theme in the responses; many students used AI to learn about the project requirements and develop solutions to satisfy them. For example, finding appropriate locations to situate their tiny house.
5. Feedback: The use of AI to get instant feedback emerged as a critical theme in the responses. Students found the feedback constructive and used it to improve their designs.

AI-Generated Features

This category contains themes representing the AI-generated features incorporated into projects.

1. Sustainable: The responses highlighted AI's role in developing sustainable features for their houses. Examples of the features included waste reduction, conserving energy, maximizing the impact of natural light, and suggesting sustainable materials. Similarly, AI helped them design sustainable water management systems. There was also mention of smart home features suggested by AI.
2. Layout and Furniture: The students acknowledged that AI helped them determine the dimensions of rooms and helped plan the layout accordingly. Innovative furniture emerged as a key theme across the responses. Students appreciated that AI gave them ideas for multi-purpose furniture, such as a Murphey bed.

Advantages of AI

This category lists the themes related to the perceived advantages of using AI.

1. Convenience: Several codes reflected the perceived convenience of using AI. Students consistently remarked that AI helped speed up the process. They also appreciated AI's ease of use, flexibility, and systematic approach. Comparing the AI experience with the previous assignment, one student reported, "The initial research phase was considerably faster, and the overall approach was more systematic and organized."

2. Innovative: Several students mentioned that AI brought innovation to their project. They mentioned that it provided "outside the box" solutions and new perspectives. Notably, some students credited AI for enhancing their ideation and sparking creativity.
3. Strengths: Students used terms like valuable, helpful, and useful to describe AI. The responses highlighted several strengths of AI, including identifying good and bad design, the ability to prioritize and categorize design elements, and providing them with a framework to assess design. Additionally, they appreciated that AI could provide a rationale for all recommendations.

Disadvantages of AI

This category presents the themes concerning the perceived disadvantages of AI.

1. Generic and Shallow: One frequently recurring theme in the survey responses is the generic nature of the AI-generated content. Students criticized the AI-generated solutions for being "surface level". They found that many of the solutions were impractical and too general to be helpful for their situation. Another frequently recurring criticism of AI was based on the lack of originality in its answers. Students emphasized that AI "lacks imagination" and is "not very creative."
2. Missing the Mark: Some students expressed discontent at AI's "unhelpful" solutions that "didn't really touch on the main point." They reported communication issues such as AI misunderstanding their prompts or repeating answers, leading to more frustration.

Considerations for Use

This category of themes lists students' recommended considerations for AI use.

1. Lead: The importance of leading the conversation with AI was highlighted in the data. One student noted, "I needed to refine and redirect the AI to maintain focus on specific requirements".
2. Verify: The analysis showed a mix of opinions regarding the trustworthiness of AI. While some students felt AI could be used as a reliable guide that provides "solid information," others were less trusting of the information provided by AI. One student cautioned, "AI can sometimes be misleading as the information it extracts from is not always accurate." Several responses mentioned the need to "verify" AI-generated information.
3. Personal Impact: Students also brought attention to how using AI changed what was required of them. Many noted that the assistance of AI meant they had to do "less thinking," which put bounds on their creativity and original brainstorming.
4. Ethics: A couple of responses touched on the ethics of using AI for assignments. They noted that while it is possible to use AI for all work, it is the human's responsibility not to delegate everything to AI.
5. Context: The responses agreed that AI was more suitable for some contexts than others. For example, AI is more suited for quick brainstorming and "short-term" projects than long-term ones. Additionally, AI is better at providing feedback than generating novel ideas. One student noted, "AI's main strength is saving time, not generating amazing ideas."

Overall, most students responded that they would use AI in future projects. However, some reported using it only for specific purposes, such as initial research and gathering feedback.

Discussion

This study explored high school students' perceptions regarding using AI in an engineering design course. Thematic analysis of data revealed that students used AI to visualize, write, and conduct research regarding their assignments. The students enjoyed the convenience, ease, and speed afforded by AI. They identified several strengths of AI, including feedback

capabilities. The students also expressed frustration with the generic solutions proposed by AI. These results align with previous studies that indicate that sometimes educational activities may stress out students, especially in technology-mediated environments [32, 33]. Opinions varied in terms of AI's creativity. Moreover, it was encouraging to witness students' observations regarding the responsible use of AI, such as the need to verify the AI-generated information, redirect focus, and consider ethical duties.

The results show a promising outlook for AI usage in K-12. The findings align with studies conducted at the college level; students have a mostly positive perception of AI [34]. Additionally, the students showed awareness regarding the potential risks of integrating AI into educational settings [7]. Although this was the first time AI was incorporated into the curricula, students showed discernment regarding using AI in certain contexts, pointing to a digitally literate student population [35]. A probable reason could be attributed to students' exposure to AI tools outside of class, which underscores the need to train students to use the technology safely and appropriately.

Conclusion

The study's findings contribute to the growing knowledge of AI usage in K-12 settings. These preliminary findings reveal students' opinions of AI tools, which are valuable for the design of effective curricula. While this paper involved only 9 students, we believe the insights gained can inform educators to design lessons that empower students' learning while teaching them how to use AI responsibly and ethically. As the engineering education community continues to deepen its understanding of AI's impact on student learning, we encourage further research on students' and educators' perceptions of AI integration and the benefits of AI for diverse pre-college learners. Because this study was conducted in collaboration with an engineering teacher who is well-versed in AI, it did not address teachers' perceptions and training needs. Future research should explore educators' requirements as they learn to integrate AI, ensuring they can effectively support and train their students.

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