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A Work-In-Progress: Unleashing the Power of AI in Senior Engineering Design Projects

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Work-In-Progress: Unleashing the Power of AI-based Learning Tools in Senior Engineering Design Projects

Abstract

As AI technology continues to transform the workforce, equipping engineering students with the skills to effectively engage with AI tools has become increasingly essential. This work-in-progress study investigates how senior engineering students leverage AI-based learning tools, such as ChatGPT, in design projects and explores the need for integrating formal AI training into engineering curricula. The study is guided by two central research questions: (1) How does AI enhance students' ability to navigate complex design processes and improve outcomes? (2) What are the perceived impacts of AI on students' learning, skill development, and ethical considerations in engineering design?

Eighteen senior capstone students from three design project groups at a land-grant university in the western United States were selected and recruited through convenience sampling to participate in the study. The research team has successfully completed its preparatory stages, including IRB approval, securing informed consent, finalizing data collection instruments, and coordinating logistics for sessions with design project groups. Data were collected through open-ended survey questions and are currently being gathered via semi-structured focus group discussions, enabling an in-depth exploration of AI's role in design approaches, problem-solving, and learning experiences. A thematic analysis of the transcribed discussions and responses to open-ended survey questions is expected to reveal patterns and insights into AI's impact on design activities and the associated training needs. The combination of survey responses and focus group insights is expected to provide a comprehensive understanding of participants' experiences and perceptions. The findings aim to inform engineering education by illustrating how AI tools can enhance design processes, support skill development, and address emerging industry demands.

Keywords: AI-based learning tools, engineering design education, perceived impacts, qualitative study.

Introduction

Artificial Intelligence (AI) is rapidly transforming industries and reshaping workforce expectations, making it essential for engineering education to adapt to these evolving demands. AI-based learning technologies are increasingly integrated into design, problem-solving, and decision-making processes across diverse engineering fields, requiring future engineers to build expertise in leveraging these tools effectively [1] [2]. As engineering graduates enter increasingly dynamic and AI-driven workplaces, the ability to effectively utilize AI-based learning tools for design, problem-solving, and decision-making is becoming a critical skill [3]. However, despite AI's growing prominence, there remains a gap in integrating AI-related instruction into undergraduate engineering curricula, particularly in design courses [4]. This disconnect raises important questions about how well-prepared engineering students are to meet industry expectations and leverage AI-based learning tools effectively.

Engineering design courses, such as senior capstone projects, provide students with opportunities to engage in complex, real-world problem-solving activities. These projects simulate professional environments where students must conceptualize, troubleshoot, and evaluate their design solutions—skills that align closely with AI-based learning tools' capabilities [5]. Learning tools powered by AI can enhance students' ability to address design challenges, evaluate outcomes, and streamline processes. For instance, AI can support iterative design by generating alternative solutions, identifying flaws, and automating routine tasks, allowing students to focus on higher-order decision-making [6]. Yet, the extent to which students are aware of and capable of using these tools remains underexplored.

This study investigates the integration of AI technology into senior design activities to understand how AI influences students' approaches to design tasks and the perceived need for formal AI training. Specifically, this research seeks to address two central questions: (1) How does AI enhance engineering students' engagement in complex design processes and improve the effectiveness of their design solutions? and (2) What are the perceived impacts of AI on students' learning, skill development, and ethical considerations in the context of engineering design?

To answer these questions, a qualitative approach was adopted, involving focus group interviews with senior engineering students engaged in capstone projects that incorporate AI tools. This study's findings aim to provide insights into the benefits and challenges of AI use in engineering design and inform curriculum development to better align engineering education with industry needs. By understanding students' experiences and perspectives, educators can identify pathways for integrating AI training that equips graduates with relevant skills for an AI-driven workforce.

Brief Literature Review

Engineering Design Problems

Design problems represent some of the most complex and ill-structured challenges encountered in engineering practice. Researchers [7] [8] have characterized design problems as ill-structured due to their ambiguous goals, undefined solution paths, and the necessity to integrate multiple domains of knowledge. Beyond the contextual complexity, the creation of an artifact as evidence of problem-solving and the absence of clear standards for evaluating solutions further contribute to the ill-structured nature of these problems. Evaluating solutions is challenging, as the success criteria are often multiple and undefined, making it difficult to assess outcomes with a simple right-or-wrong answer. The inherent complexity and ill-structured nature of design problems require problem solvers to engage in extensive problem structuring [9] and demonstrate significant commitment and self-regulation [10]. Design is an iterative process involving decision-making, model building [11], constraint satisfaction [12], and exploring alternative solutions [13].

In this context, AI-based learning tools offer significant potential to assist engineers in navigating the complexities of design problems. These tools can support problem solvers by enhancing their ability to structure problems, explore alternative solutions, and simulate outcomes. By integrating AI-based learning platforms, engineers can receive real-time feedback, improve decision-making processes, and gain deeper insights into the interdependence within design

tasks. The application of AI-based learning tools also holds promise for fostering self-regulated learning and helping engineers develop more effective problem-solving strategies tailored to the ill-structured nature of design challenges.

Although design tasks are inherently ill-structured, the nature of engineering design varies across contexts. For example, there are notable differences between hardware-oriented and software-oriented design processes. Software design problems tend to be somewhat more structured than hardware design problems [14] [15]. Hardware-oriented design may involve tasks such as evaluating manufacturing processes, developing new products or production systems, creating schematic drawings, selecting components, testing product characteristics, analyzing material behavior, simulating in-field product performance, or optimizing system performance. These tasks often require designers to make numerous assumptions, employ strategic planning, and follow a prescribed sequence of stages [16]. In contrast, computer software design is distinct from hardware design and is sometimes described as being practiced more like a craft [17]. The integration of AI-based learning tools into these design processes could influence students' metacognitive practices by encouraging reflection, facilitating self-assessment, and providing tailored feedback that adapts to the specific demands of hardware- or software-focused design tasks.

The distinctive nature of engineering design tasks also gives rise to unique cultural frameworks, behaviors and practices shaped through interactions in various social contexts. Anthropologist Pierre Bourdieu [18] speculated that these cultural environments influence the design process. He argued that individuals' everyday activities shape how they approach design tasks, suggesting that "learning and doing is more than a cognitive activity. Ways of knowing and doing are unique to each group and can be called its specific culture" [19, p.60].

The Potential Role of AI-Based Learning Tools in Engineering Design Processes

AI-based learning tools play a transformative role in the engineering design process by enhancing creativity, optimizing workflows, and supporting decision-making. In the early stages of problem definition and ideation, these tools analyze data from diverse sources and provide innovative design alternatives through generative algorithms. They help engineers efficiently identify constraints, explore potential solutions, and focus their efforts on feasible and creative ideas [20].

During the detailed design and prototyping phases, AI-driven simulation platforms enable engineers to test and refine their designs virtually, offering real-time feedback and identifying potential errors. Machine learning algorithms optimize design parameters and assist in iterative improvement, ensuring more efficient prototyping. In the testing stage, AI tools analyze performance data, diagnose issues, and predict failures, aiding engineers in refining their designs. The integration of self-regulation skills—such as monitoring, evaluating, and adapting approaches—is essential throughout these stages, allowing engineers to collaborate effectively with AI tools, identify errors intelligently, and achieve high-quality solutions [21].

The Study

Purpose and Research Questions

The purpose of this research is to assess the need for formal AI instruction in engineering design courses to better equip students for the future workforce. This project will provide an understanding of how University Engineering seniors use AI-based learning tools and what they perceive they need in the way of AI training to prepare for the workforce. This project will explore the value of AI tools in the students' university experience. As the students complete their senior design project, we will have a unique window to look into the future project-based work they will do in industry and how AI training could help students in the future.

Two major research questions were constructed to guide this study: (1) How does the use of AI technology enhance students' ability to solve complex engineering design tasks and improve their problem-solving effectiveness? and (2) What are the perceived impacts of AI on students' learning, skill development, and ethical considerations in the context of engineering design?

Data Collection

This qualitative study includes three design groups comprising a total of 18 civil engineering students, divided into three teams of six students each, participating in a senior design capstone project. Data were collected from students enrolled in the Civil Engineering program at a land-grant university in the western United States. A convenience sampling approach was employed, selecting participants based on their availability and willingness to contribute to the study. This approach ensures a diverse range of perspectives on students' experiences with AI technology in their design tasks. The participants reported using various AI-based learning tools as integral resources for completing their design tasks, including activities such as analysis, simulation, and design optimization. The study participants have been working on their senior design capstone project for two semesters (since Spring 2024). At the time of data collection (i.e., Spring 2025), they are in their third semester of the project, during which they are finalizing their design.

Data collection involved two methods: (1) an online Qualtrics survey with open-ended questions for each student and (2) focus group interviews, which provided each project group with an opportunity to discuss their use of AI tools during the design process. The open-ended survey items were designed to gather information on how each group member perceived the use of AI-based learning tools in their design project. To accommodate participants' availability and encourage more thoughtful responses, each participant received a personalized survey link that allowed them to start, pause, and resume at their own pace. Participants completed the survey within 45 to 60 minutes.

The focus group interviews were designed to deepen understanding of individual experiences while fostering interaction among participants, creating a collaborative environment for exchanging and elaborating on ideas. Table 1 presents examples of questions used in the survey and focus group interviews. Each interview lasted approximately 45 to 60 minutes and followed a semi-structured format, incorporating open-ended questions that invited participants to share their insights on how AI influences their design approaches, problem-solving strategies, and

perceptions of AI's role in their education. At the time of writing, the focus group interviews are still ongoing, allowing for continued data collection and analysis.

Table 1. Sample Questions for Survey and Focus Group Interview

Open-ended survey Questions	Please describe specific ways AI has influenced your approach to solving complex design problems?
	Have you encountered any challenges or limitations when using AI learning tools during the design process? If so, please elaborate.
	What ethical concerns, if any, have arisen for you when using AI learning tools in engineering design?
Focus group interview Questions	How does the use of AI tools affect the way your team collaborates and interacts during different stages of the design process?
	How does AI affect your team's ability to brainstorm, innovate, and solve problems together?
	How has the presence of AI tools influenced the way your team handles disagreements or conflicting ideas during the project?

Data Analysis

Qualitative data analysis involves systematically examining the responses from the open-ended survey items and the recorded discussions from the focus group interviews. The process begins with transcribing and organizing the survey responses, enabling an initial exploration of recurring themes and patterns. Likewise, the audio recordings from the focus group interviews are transcribed verbatim to ensure a detailed and accurate representation of participants' discussions. This thorough preparation maintains the integrity and reliability of the data.

Using a thematic analysis approach, the research team applies both deductive and inductive coding methods. Deductive codes are informed by the study's research questions and conceptual framework, ensuring alignment with the study's objectives, while inductive codes emerge organically from the data, capturing unanticipated insights that may provide new directions for inquiry. To enhance the rigor of the analysis, two coders independently code the qualitative data. Their coding efforts are then compared to identify discrepancies, followed by collaborative discussions to resolve differences and refine the coding framework. This iterative process ensures both consistency and reliability in the interpretation of the data.

As the paper is being written and qualitative data collection from the focus group discussions is still in progress, the analysis will later compare and integrate themes derived from both the survey responses and focus group discussions to uncover connections, contrasts, and overarching insights. Particular attention will be given to participants' perceptions of AI-based learning tools in their design projects and the self-regulatory strategies they employ during the process. The integration of data from multiple sources will follow a triangulation strategy, strengthening the validity of the findings by cross-verifying evidence from the survey and focus group discussions.

The final analysis will include the selection of representative quotes that vividly illustrate key themes, ensuring that participants' voices are authentically and clearly reflected in the study's findings. This comprehensive approach aims to provide a rich understanding of participants' experiences and insights, contributing meaningful knowledge to the study's broader objectives.

Preliminary Findings and Next Steps

Preliminary findings from the qualitative data collected through the open-ended surveys provide valuable insights into participants' experiences with AI-based tools in their design tasks. All 16 participants in the study identify as White. Below is the demographic information of the study participants (Table 1a, 1b, 1c, 1d).

Table 1a. Gender (*N*=18)

Gender	Counts	% of Total
Male	12	66.67 %
Female	6	33.33 %

Table 1b. GPA (*N*=18)

GPA	Counts	% of Total
3.50 - 4.00	12	66.67 %
3.00 - 3.49	6	33.33 %

Table 1c. First generation (*N*=18)

First generation	Counts	% of Total
One	2	11.11 %
Both	14	77.78 %
None	2	11.11 %

Table 1d. Enrollment Status (*N*=18)

Enrollment Status	Counts	% of Total
Full Time	16	88.89 %
Part Time	2	11.11 %

Preliminary analysis of the survey data indicates that, in addressing Research Question 1 (i.e., *How does AI enhance engineering students' engagement in complex design processes and improve the effectiveness of their design solutions?*), participants identified three key aspects of how AI technology has enhanced their ability to solve complex engineering design tasks and improve problem-solving effectiveness: (1) Design Process, (2) Enhancement and Outcomes, and (3) Collaboration. As we write in this paper, we can share four emerging themes related to students' design processes (i.e., key aspect #1), each with its own set of subthemes.

1. **AI's Role in Enhancing Project Development and Problem-Solving (41.15%)**

The data in Table 2 illustrates the various ways AI contributes to project development and problem-solving in engineering design. The most significant impact is seen in resource and parameter identification (19.16%), suggesting that AI is particularly effective in helping students locate relevant information and constraints for their projects. AI also plays a notable role in problem-solving (7.94%), assisting students in generating solutions and refining their approaches to complex challenges. Procedural guidance (4.21%) and project breakdown (2.34%) further indicate that AI helps students structure their work more effectively, making the design process more manageable. However, lower percentages in project definition (2.80%) and preparatory work (2.80%) suggest that students still rely on their own expertise or traditional methods for these early-stage tasks. Additionally, AI's role in debugging and troubleshooting (1.87%) remains relatively minimal, indicating that while AI can aid in identifying errors, students may still prefer manual debugging or expert consultation (Table 2). Overall, these findings suggest that AI serves as a valuable tool in streamlining various aspects of the design process, though its influence varies depending on the task at hand.

Table 2. AI Contributions to Project Development and Problem-Solving

Subcategory	Percentage (%)
Resource and Parameter Identification	19.16
AI Assistance in Problem-Solving	7.94
AI-Assisted Procedural Guidance	4.21
Preparatory Work	2.80
Project Definition	2.80
AI-Facilitated Project Breakdown	2.34
Debugging and Troubleshooting	1.87

Among these, AI's most significant impact is seen in *resource and parameter identification (19.16%)* and *AI assistance in problem-solving (7.94%)*, emphasizing its role in structuring projects and overcoming technical challenges.

2. **AI's Impact on Creativity, Writing, and Collaboration (25.23%)**

Beyond problem-solving, AI significantly influences creativity and teamwork within the design process. AI-assisted brainstorming (10.28%) and idea generation (3.74%) provide students with

alternative perspectives and inspiration for their projects, fostering innovation. AI also plays a crucial role in writing and outlining (6.54%), assisting students in structuring reports, technical documentation, and project proposals. Furthermore, AI enhances team collaboration (4.67%) by streamlining communication, facilitating the exchange of ideas, and ensuring that all team members are aligned with the project's objectives (Table 3). This aspect of AI integration reduces inefficiencies and strengthens the collaborative nature of engineering design projects.

Table 3. AI's Role in Creativity and Collaboration

Subcategory	Percentage (%)
AI-Assisted Brainstorming	10.28
AI-Supported Writing and Outlining	6.54
Team Collaboration	4.67
AI-Assisted Idea Generation	3.74

3. Perceptions and Limitations of AI in Complex Tasks (24.37%)

The data in Table 4 highlights students' varying perceptions of AI in engineering design, particularly regarding its influence, reliability, and limitations. A significant portion of participants (8.88%) acknowledged that AI influenced their approach to problem-solving, suggesting that AI tools are shaping the way students engage with engineering tasks. However, despite this influence, hesitation to rely on AI (3.27%) and skepticism towards its ability to handle complex problems (4.67%) indicate lingering doubts about its effectiveness in high-stakes design work. Additionally, while some students reported a degree of reliance on AI-generated responses (2.34%), a comparable percentage (2.34%) expressed a preference for traditional resources, suggesting that AI has not yet fully replaced conventional problem-solving methods. The limited usage of AI for complex design projects (2.80%) further reinforces the perception that while AI can be a valuable aid, its role in advanced engineering tasks remains supplementary rather than central. These findings point to a nuanced relationship between students and AI, where its benefits are recognized but not universally trusted for solving intricate design challenges.

Table 4. Perceptions of AI in Complex Problem-Solving

Subcategory	Percentage (%)
Influence of AI on Approach	8.88
Skepticism Towards AI for Complex Problems	4.67
Hesitation to Rely on AI	3.27
Limited AI Usage for Complex Design Projects	2.80
Reliance on AI-Generated Responses	2.34
Preference for Traditional Resources	2.34

4. AI's Efficiency and Workflow Optimization (9.36%)

AI also contributes to improving efficiency and optimizing workflow within the design process. A small yet consistent portion of responses (2.34%) reflected themes where AI was seen as helping to fill knowledge gaps, support the overcoming of initial challenges, and foster comfort and trust in its use. Additionally, 1.87% of the responses indicated the use of AI tools across different stages of the design process. A smaller percentage (0.47%) represented the theme of reduced meeting time with professors, suggesting that AI enabled students to independently address certain questions or issues (Table 5).

Table 5. AI's Efficiency and Workflow Optimization

Subcategory	Percentage (%)
AI as a Knowledge Gap Filler	2.34
Overcoming Initial Hurdles	2.34
Comfort and Trust in AI	2.34
AI Tool Usage in Design Process Stages	1.87
Reduced Meeting Time with Professors for Discussion	0.47

Overall, AI serves as a powerful aid in project development and problem-solving, enhances creativity and collaboration, and optimizes workflow efficiency. However, skepticism and limitations persist, particularly regarding AI's role in complex problem-solving and its reliability compared to traditional resources. These findings highlight the evolving role of AI in engineering education and the need for strategic implementation to maximize its benefits while addressing student concerns.

We expect to complete qualitative data collection from the focus group discussions by the end of February 2025, followed by data analysis. The analysis will focus on identifying key themes and insights aligned with the research objectives. We anticipate that the findings will be ready for dissemination at the upcoming ASEE conference, where we will present the major outcomes and implications of the study.

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