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Use of AI as a Design Aid in a Senior-Level Machine Design Project

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Abstract

Recent advancements in large language model (LLM)-based artificial intelligence have significantly expanded its capabilities in solving engineering problems. To explore its potential as a design aid, students in a senior-level Machine Design course at California Baptist University, a medium-sized private institution, were tasked with evaluating the effectiveness of AI tools in a mechanical design project.

The project required student teams (up to four members each) to design a reverted compound gear train that met specific gear ratio and power transmission requirements. Students were encouraged to use AI tools such as LLM-based assistants for calculations, design exploration, and iterative refinement. They were free to select any AI platform and were required to document their prompt strategies, refinements, and validation methods for AI-generated outputs.

The instructor used Microsoft Copilot to attempt to perform the design tasks. Many of the tasks required several prompt refinements to get the correct answer. It was unable to perform tasks that required spatial reasoning.

Following Institutional Review Board (IRB) approval, students were surveyed regarding their experience using AI in the design process. The survey assessed perceived effectiveness across various tasks and overall satisfaction. Results indicated that AI tools were particularly helpful for calculating the number of teeth in the reverted geartrain, report writing, and conceptual guidance. However, students noted frequent calculation errors and limitations in AI's spatial reasoning.

This study highlights both the promise and current limitations of AI as a design assistant in mechanical engineering education. It provides a foundation for future integration of AI tools into design pedagogy and encourages critical evaluation of AI-generated content in engineering workflows.

Introduction

ChatGPT and other large language models (LLMs) have improved their ability to perform engineering calculations. Quadir noted, "Assessment strategies will have to evolve to prevent unethical conduct while still allowing for the productivity that can be achieved with these tools." [1] Pursani *et al*. found that GPT-4 scored 66.4% on an unpublished Environmental FE exam and, with prompt refinement, raised the score to 75.4%, indicating an ability to solve engineering problems. [2]

Specifically in mechanical design, Rad and Davis had students compare their solutions for statics and dynamics problems with those generated by ChatGPT. [3] They saw that the procedure was generally correct, though it made some calculation mistakes. Carr and Cornwell used the Dynamics Concept Inventory to assess the chatbots' ability to answer conceptual problems in a multiple-choice format when only images of the problem were provided. [4] They found the chatbots provided a good problem-solving strategy, but lacked spatial reasoning. Jadhav and Farimani used an LLM coupled with an FEA module to optimize truss designs. [5] They showed faster convergence than the Non-dominated Sorting Genetic Algorithm II.

In the area of Machine Design specifically, Uysalel et al. had students use AI to develop MATLAB code for shaft design. [6] They first had the students develop their own code to calculate the required shaft diameter based on loading and material, and then had them use AI to generate similar code. They found that students needed to break the coding into subtasks to succeed in AI code development.

In engineering design, Flynn and McAdams show how AI can be used in the engineering design process for a manifold system. [7] They used an LLM to select material, determine tapped port size to optimize flow given stock geometry constraints, select stock sourcing based on price, and choose tooling for manufacturing. They suggest that LLMs should be integrated thoughtfully into education, enhancing rather than replacing traditional learning methods.

Autodesk has been researching the use of AI for specific tasks in Machine Design. They use a Transformer-based architecture trained to generate a mechanism for tracing a B-spline curve, which they call MechaFormer. [8] They are also developing a Transformer-based AI tool for gear train design called GearFormer. [9] [10] The tool provides different gearing options for a given gear train ratio and input and output locations. Neither tool is commercially available, but since they are trained for specific tasks, their outputs should be more reliable than those of an LLM.

Concerning mechanical engineering students' perspectives on using LLMs for engineering, Bernabei et al. [11] performed a case study where students used ChatGPT as a tool in writing an engineering case study. They investigated students' grades, AI detection, and students' perceptions. Students were surveyed before and after the assignment. Most students felt the results were reliable, but the assignment reduced their perceptions of the comprehensiveness of the results, shifting from agreement to disagreement. Students also reduced their opinion of the comprehensiveness of the answers, resulting in about a 50-50 split between agree and disagree.

Given the promise of LLMs as helpful engineering tools, it was desired to allow students to experiment with using AI in a design project for a Machine Design course.

Research Postulations

A) LLMs will be helpful in engineering design calculations.

In the past, I gave take-home tests in Machine Design and Vibrations courses. After a student submitted typed answers to a test, I submitted the test questions to ChatGPT and discovered that its answers would have earned a B grade. This demonstrated to me that LLMs had improved in their ability to do engineering calculations. I wanted to allow students to use LLM-generated results legitimately in their design process if they found them helpful.

B) Students would use LLMs for design tasks if given the opportunity.

While interacting with some students in a lab in a different course, it seemed that they were constantly using AI tools to solve problems or check their work. Based on this interaction, I assumed that students are more experienced with AI than I am and would be able to use LLMs in the project without specific prompting training. Also, students would want to use AI to assist them in the design process.

Educational Context

Students were allowed to use AI tools in the semester-long design group project in a Machine Design course at California Baptist University, a medium-sized private university. This is a required course typically taken in their senior year. Overall, there were 52 students in the class, distributed over two sections.

Design Problem

For the semester projects, students were given the following design task to solve in groups of up to four students.

> Design a reverted compound gear train with 45° helical gears that can transmit 0.4HP at 1800 rpm input in either direction with a gear ratio of 15:1. Specify module and number of teeth. Select gears based on catalog load ratings, though you are not limited to the tooth numbers in the catalog. (A possible catalog is p-1930-bg.ashx) Also design the shafts and keys to transmit the load and select bearings to support the shafts. When designing the shafts, calculate the diameter needed to handle the loading as well as the bearing size, and then use the appropriate diameters based on these limitations. Critical locations of the shafts should be toleranced appropriately for function.

Students were encouraged to use AI in their design process. If they used AI, they were instructed to include which AI(s) they used, their AI prompts, and the responses in an appendix. They also had to explain their thought process when refining their prompts, in addition to the prompts you used. Students were expected to verify that the AI was giving them the correct answer.

The project was broken into two parts. In the first part, students selected gears, calculated the gear forces, selected general shaft geometry (where they would place the gears and bearings along the shafts), and calculated the reaction forces at the bearings. After students turned in the first part of the project, they were provided with a solution showing the gear selection process and MATLAB code that calculated the reaction forces and constructed the shear and moment diagrams, given the gear forces. Students also had a spreadsheet that calculated the gear forces based on input torque and RPM. With this information, students would use the correct numbers for the remaining design tasks.

Students' Use of AI on the Project.

Students self-selected into fifteen groups for the project. Seven groups documented AI use, while the other eight did not. Of the groups, one used both ChatGPT and Gemini, four used ChatGPT, one used Gemini, and one used Abbicus. Regarding the level of AI usage, two groups used it for most calculations, while another used it to list the necessary equations. One of the two groups that used it for most of their calculations unquestioningly trusted the AI's output, while the other group verified the calculations. One group used it for finding the mistakes they made in coding. Some groups tried it for minimal tasks, such as finding gear forces, pitch diameters, reaction forces, or bearing selection.

For each project group submission, the students' documented AI usage was manually classified by the author as "None", "Low", or "High". Students in the "Low" group documented the use of AI for one or two tasks, while anything beyond that was classified as "high". Some of the groups in the “None” category may have tried using AI, but did not include it in their appendix since they did not use it in their design. Figure 1 displays a marker for each group's percentage grade in the design portion of the project, plotted by classification. One can see that there were low and high grades for each level of AI use, and there is no clear pattern. The parabola fitted to the data passes through the average score at each level of AI usage. The curve fit shows a slightly better grade trend for low AI usage, but the R^2 value of 0.0934 indicates that AI usage is not a significant contributor to grade variation.

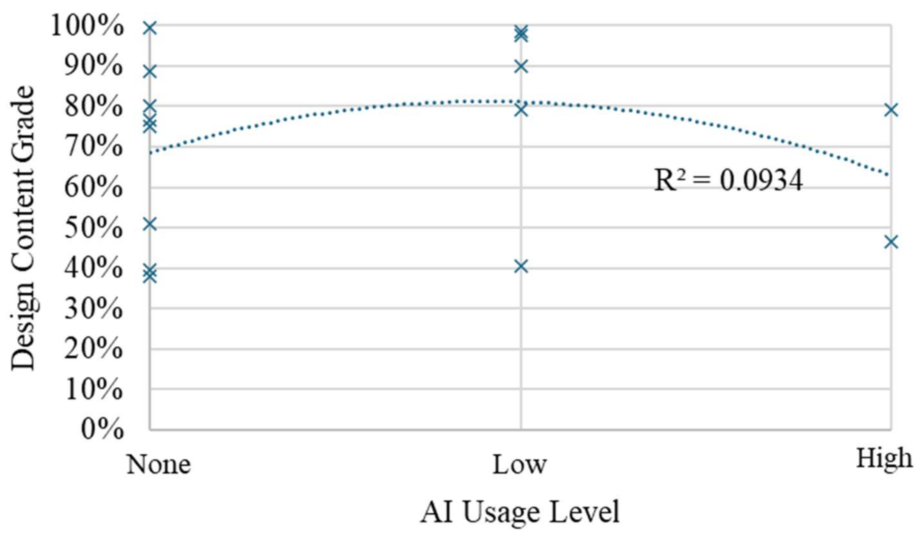

Figure 1, Student grades related to AI use level

Student Thoughts on AI Use

At the end of the semester, after securing IRB approval, students were surveyed about their experience using AI in the design project. They were offered 20 extra credit points on their homework for completing the survey or an alternate task. The survey asked students to ‘Rank the helpfulness of AI in the following tasks.’

- Selection of catalog gears
- Calculation of gear forces
- Preliminary shaft geometry definition
- Determination of bearing reaction forces
- Construction of shear and moment diagrams
- Selection of shaft materials and diameters
- Specification of keys for power transmission
- Selection of appropriate bearings

The survey had options of ‘Very Helpful’, ‘Somewhat Helpful’, ‘Not Helpful’, ‘Useless’, or ‘Did not use AI’. In addition, students were asked to rank the statements ‘Overall I found AI helpful’ and ‘From my experience, I plan on using AI in the future for Engineering Calculations’ on a Likert scale. Finally, students had free-response questions about their experience with AI and what would be helpful if the assignment with AI were given again.

Figure 2 shows the results of the student survey concerning the helpfulness of AI. A total of 50 students completed the survey. The numbers differ between questions because students who did not use AI were omitted. The number in parentheses indicates the percentage of students who used AI for the task. Students viewed AI as most helpful for finding gear ratios and for improving their writing. From the number of students who responded to the questions, one can observe that fewer students used AI as the project progressed. For the second half of the project, about half the students did not use AI. This may have been due to not finding good results in the first half, or to the number of things that were due at the end of the semester. From Figure 3, which shows their general thoughts on AI and their future use of it, a little over half responded positively to both cases.

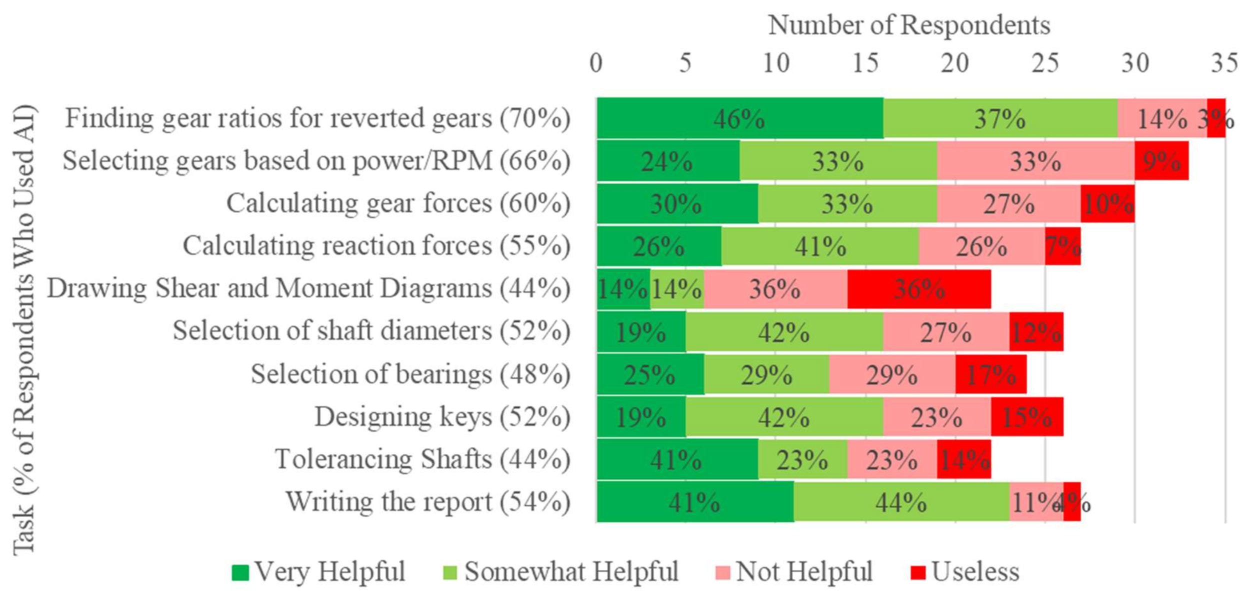

Figure 2, Student survey results on the helpfulness of AI tools in specific design tasks.

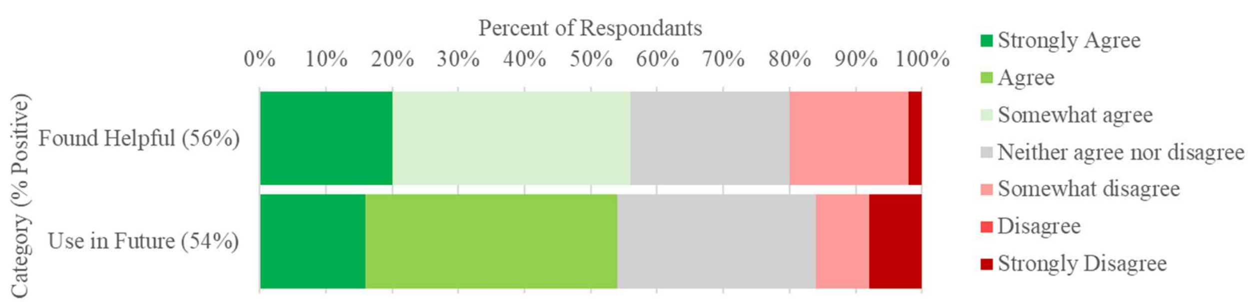

Figure 3, Student survey results on AI tools in general.

The author grouped the students' free responses into categories. All students' responses, along with their categories, are in Appendix A. The results are tabulated in Figure 4. A large number of students were optimistic about AI's ability to generate the process. Even more students were negative about AI's calculation accuracy, with a couple saying it requires significant coaching. Some students commented that AI was helpful for writing and that it had improved during their time in college. Others commented that it hurts learning and is not beneficial for machine design.

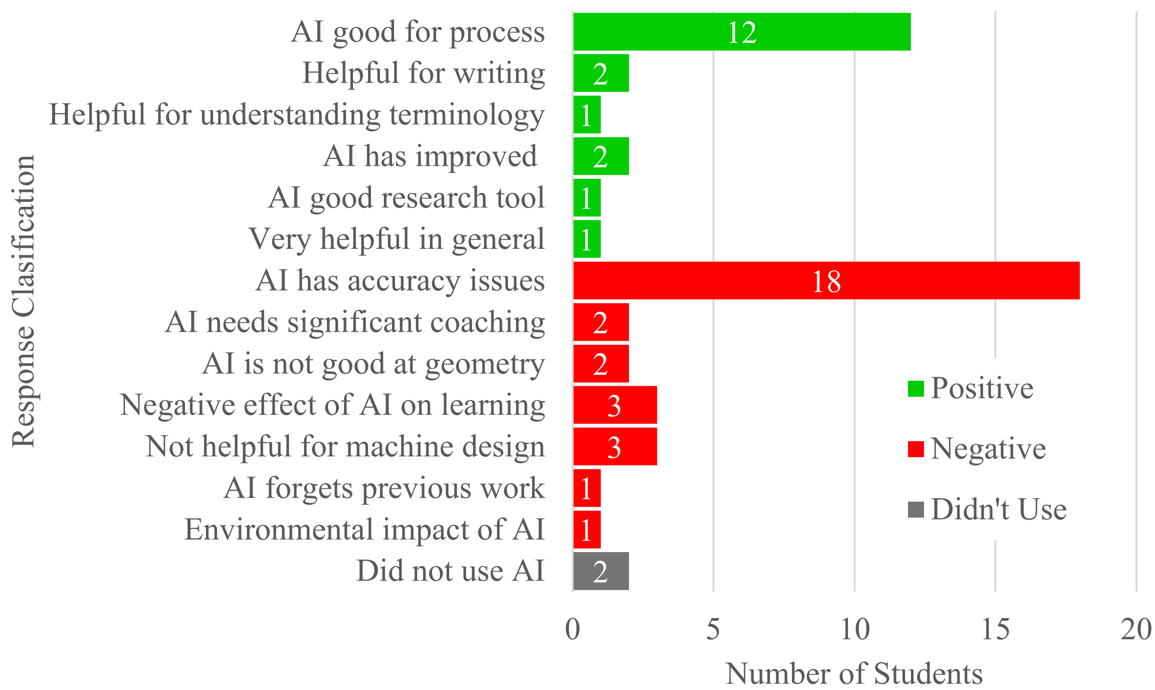

Figure 4, Categoryized student response summary

As for advice, if I were to do the project in the future, they suggested I could provide guidelines for prompting and advise on using multiple prompt refinements. They also indicated that it can be helpful for understanding the material, the design process, and refining their writing. Their complete responses are in Appendix B.

AI's ability to solve the problem.

Since the students' responses were not as positive as I expected, I explored Microsoft Copilot's ability to complete the project's tasks, including refining the prompt to obtain the correct answer if necessary. Copilot was set to Smart, running GPT-5.1. What follows is a summary of its performance on the design tasks. More details can be found in Appendix C.

When selecting the gears, it correctly chose the tooth numbers for the reverted compound geartrain, but it did not initially use the slower RPM of the second gearset when selecting gears from the catalog. Gear forces required two clarifications before they were calculated correctly.

I was unable to get a correct answer for the basic configuration of the shafts, even with multiple refinements. Copilot was not able to generate spatial geometry. However, it was able to determine the geometry from a sketch of the input shaft to use in force calculations for the reaction forces. It needed a couple of prompt refinements to correctly calculate the reaction forces. It was unable to generate the shear and moment diagrams graphically, but was able to generate MATLAB code to accurately plot them after some prompt refinements about geometry.

When given a bending moment, torque, and material, it correctly calculated the fatigue strength, but treated both as alternating forces, until prompted otherwise, when it provided the correct minimum diameter using Goodman theory. It correctly sized a key based on shaft diameter and torque, and correctly determined the proper bearing size based on reliability and life without any additional prompting. The bearings were different than those in the textbook, so students may have thought there was a problem with the selection process. The LLM determined the appropriate fit class and calculated the proper tolerances between the bearing and the shaft.

Conclusion

Students were allowed to use AI to assist them in designing a gearbox in a machine design class. About half of the 15 groups documented their AI, with only 2 exploring its ability for most design tasks. Students were not as enthusiastic about using AI as I had expected. For future projects, students will need instructions for prompting and prompt refinement to make effective use of AI as a design tool.

As for AI's ability to perform machine design tasks, when surveyed after completing the project, a large percentage of students who used AI found it helpful for finding gear ratios for reverted compound gears and for improving their writing. In their free response, many students found it useful in establishing the process, but had significant accuracy issues. As an instructor with a better understanding of the design process, I discovered that many of the design steps required prompt refinement to get the correct answer. It was unable to generate items that required spatial reasoning, such as shaft configurations and key locations.

Overall, LLMs like ChatGPT have potential as aids in machine design tasks, but in their current state, they require a good understanding of the fundamentals, as they frequently make mistakes and need guidance to arrive at the correct answer. Despite this, students should be exposed to them, as their accuracy is likely to continue to improve.

For future work in the area of using AI for design, the effectiveness of GPAI [12] could be explored, as it advertises itself as "the most accurate AI solver for math, physics, chemistry, and engineering." Another approach could be to have additional training reference data with solved problems to provide a baseline for solving the problems that require additional prompting.

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Appendix A: Categorized Student Answers to "Is there anything you would like to share about your experience using AI"

AI Good for Process

- I like the option of using AI as a guide through the process of designing and to verify if calculations are correct. However, I believe designing and initial calculations should be done individually.
- Sometimes the hardest part with such projects is knowing where to start and having a good roadmap to guide you through the phases of the project. AI is a great solution to this problem, despite its not always being accurate, which is why students must verify the formulas and calculations it provides.
- The process walkthrough is the most valuable outcome from using AI so as not to get lost in the amount of variables and equations.
- great for brainstorming solutions and getting on the right track :)
- I like dissecting the equations used by AI to understand the relationships between variables. AI sometimes has paragraphs explaining its steps.
- great for brainstorming solutions and getting on the right track :)

- I think AI is helpful to get pointers on what direction to head in, but it isn't always good enough to actually trust to do the calculations.
- I use AI to help with concepts or to help condense the content from slides into an easy to read format or into flashcards.
- AI is helpful for understanding the process or solving small steps, but it almost always gets complete problems wrong.
- I never used AI for a final answer/solution, but as a point in the right direction.
- AI really isn't the end-all-be-all of engineering calculations - I more so use it to get an idea of where to start or what direction I should be moving in with the calculations. It doesn't get the numbers right very often, but it does help with formulas.
- However, AI does have its uses in reference to organization, generating possible ideas or thoughts to brainstorm, and testing calculations, among other applications.

Helpful for writing

- Anything to do with writing i found AI to be very helpful at explaining or communicating ideas for design reports. However, AI still isn't useful for searching the web or creating pictures unless you paid for a premium subscription to AI companies.
- It's great for translating what I'm trying to say in a way that's actually readable, fixing grammar and spelling.

AI has improved

- It has definitely improved its accuracy with math and advanced problems. In the last 2 years the ability to solve certain engineering problems has greatly increased.
- Ai has come so far from how it started out at the beginning of my college career but it still has a ways to go before it can be a reliable engineering tool. It could just be my selection of AIs that I use that could be not as good as other AI options for completing these engineering tasks but in general Chat GPT is decent and basic level calculations and standard math like calculus. When it comes to higher level applied math it can sometimes make errors in formulas or calculations, so it is good to always double check its work.

Helpful for understanding terminology

- Using the A.I. taught me about the vocabulary of gear design (specific example: "mesh")

AI good research tool

- AI is useful for finding information from outside sources.

Helpful in general

- very helpful

AI has accuracy issues.

- Sometimes AI is accurate but maybe like 70% of the time
- When it comes to math, I abandoned that a while ago. It could be useful for finding and redirecting you to formulas, but sometimes it sends you on a wild goose chase
- AI can be helpful for explaining concepts/breaking down complex ideas, but it often uses incorrect equations and fabricated numbers. I found it useful for explaining terms and

providing clarification on concepts; however, at times, I was misled by incorrect information.

- Overall its still very questionable. It almost always gets the answer wrong if the prompt has anything to due with engineering.
- AI is very helpful in getting you in the right direction but should not be trusted to give you the full correct answer.
- But when trying to use it to help with engineering calculations, it is almost always wrong because it is using different datasheets or values compared to the ones provided to us.
- The thing gets wrongs answers so often to the point that writing it out is probably faster
- I think AI is helpful to get pointers on what direction to head in, but it isn't always good enough to actually trust to do the calculations.
- But as I try to see if AI can help me solve homework or with calculations, I find that it just can't do it, and if it does do some math, the majority of the time it is wrong.
- It is limited in its scope, and gets stuff wrong or simply cannot do things.
- It was very off and on, so you had to be able to check its work, it often made simple math issues. you also have to be very specific with your prompting, so that it completely understands the task.
- AI is helpful for understanding the process or solving small steps, but it almost always gets complete problems wrong.
- I never used AI for a final answer/solution, but as a point in the right direction.
- Generally i do not trust results and AI gives me.
- Ai has come so far from how it started out at the beginning of my college career but it still has a ways to go before it can be a reliable engineering tool. It could just be my selection of AIs that I use that could be not as good as other AI options for completing these engineering tasks but in general Chat GPT is decent and basic level calculations and standard math like calculus. When it comes to higher level applied math it can sometimes make errors in formulas or calculations, so it is good to always double check its work.
- AI really isn't the end-all-be-all of engineering calculations - I more so use it to get an idea of where to start or what direction I should be moving in with the calculations. It doesn't get the numbers right very often, but it does help with formulas.
- I notice that there are times that AI can be helpful but there are times when it give you the wrong answer because it is using different approaches
- Most of the time, it is better to work on the project ourselves instead of placing a lot of trust in AI.

AI is negative on learning

- I found that GenAI had a net-negative impact on learning and efficiency.
- AI, although used as a learning tool, if not used properly can become a crutch for learning.
- AI is useful in various areas if needed, but it is not a must. It can save time and effort in specific areas, but it isn't helpful in others. Most of the time, it is better to work on the project ourselves instead of placing a lot of trust in AI.

Not helpful in machine design

- Using AI for machine design isn't helpful

- AI is not a source to be fully dependent on; doing the work yourself is a much more reliable way to accomplish what you need. The project is too complicated for AI to understand on its own.
- It was good at some things but it's overall design skills were very lacking

AI needs coaching

- It takes a lot of info and parameter input to get the ideal response from it.
- Hallucinations aside, it took more time and effort to formulate a prompt that would provide the desired output than to, say, create a lookup equation in Excel.

AI not good at geometry

- The worst part is trying to explain to it the physical locations of the components as it does not have a good way of understanding 3-d space.
- It cannot yet visualize physical geometry/components very well so it may or may not be able to comprehend what you need.

Environmental impact

- My main qualm with AI is the environmental impact that AI datacenters have, and I believe we as engineers need to work on ways to improve these datacenters efficiency before we hit the point od no return in the damage they cause.

AI forgets previous work

- It is hard to get AI to remember previous instructions that you give it

Did not use AI

- We did not really use AI for this project at all.
- I have never used AI for calculating anything in my engineering education. My goal is to get through the end of my bachelor's degree without using it but to wait to use it until I am in the field.

Appendix B: Categorized Student Answers to "Is there anything that would be helpful for me to know if I were to do the assignment with AI again?"

Helpful for writing

- AI could be useful for just the writing portions of assignments because it can write better than many students.
- It is not that useful for math tasks but it is very useful for writing tasks.

Use Multiple Prompts

- Continue to ask for verification of prompts and responses.
- In order to achieve the best results with Ai, multiple prompts usually have to be used. It's similar to an iterative design process when it comes to Ai inputs. Due to this, I don't believe citing all prompts inputted is necessary and it adds more unnecessary pages to the appendix.

Helpful for Process

- It is good at helping with project calculation processes but not good for the calculation results. A student would have a very hard time getting AI to do the project for them, it acts as more of a supportive tutor. However, it does save time and allows for the addition of more gears if that was a guideline for the project.
- Not much I can think of except the fact that AI is very useful if prompted and used properly. Given its inaccuracy, I wouldn't use it to solve a problem, but I would use it to provide steps on how to solve a problem (i.e., finding gear ratios, selecting bearings, etc.)
- Don't assume that the math or resources that AI is doing/pulling from are 100% correct, and start using those numbers for your assignment. It is better to use the AI to understand the assignment concepts and then use what you just learned to do the math.

Give guidelines for best prompting

- Maybe show how you would use ai to get some of these
- If we use AI maybe there could be assistance with what prompts to use and how to use it correctly
- I think it would be interesting for you to try solving parts of the project with AI and see what you can achieve as someone with a better understanding of the project.

Helpful for understanding material

- From what I heard, people were happy with the ability to use AI. People said it was helpful in understanding material as well.
- Providing concepts with the problem.
- gives good guidence for students when teaching is unclear

Appendix C: Author Prompting of AI

Selection of catalog gears

Copilot successfully selected the number of teeth for the gears to meet the reverted requirement. It needed to be reminded that the second gearset rotated more slowly than the input speed. With this reminder, it adjusted its calculation to select a transverse diametral pitch that met the power requirements but was not available in the catalog. After being prompted, it did pick an acceptable value.

Calculation of gear forces

The chatbot successfully calculated the tangential and axial forces for both gearsets, noting that the second gearset is rotating at a lower RPM. The catalog specified a 14.5° normal pressure angle, but Copilot used this as the tangential pressure angle. When this was pointed out, the chatbot changed the formula to use the incorrect formula. Corrected again, the force calculation was correct.

Preliminary shaft geometry definition

I prompted, “Can you provide a sketch with distances for where to put the gears and bearings on each shaft?” and it produced the sketch in Figure 5. After prompting that there should be three shafts, each with two bearings, it produced the sketch in Figure 6. It is clear that it has no concept of geometric reasoning.

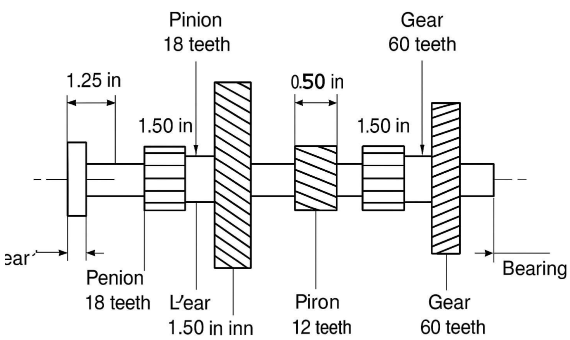

Figure 5, Initial Shaft Sketch from Copilot

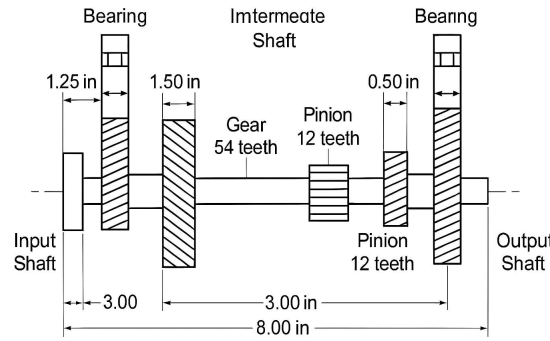

Figure 6, Refined Sketch from Copilot

Going step by step for the input shaft, I asked for 0.5 inch space between the bearings and the gear, and it provided the sketch in Figure 7. When asked to redo with a 0.75" facewidth for the gear, it produced the sketch in Figure 8.

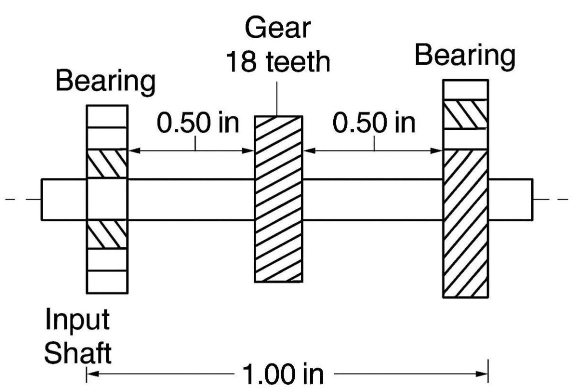

Figure 7, Initial Input Shaft Sketch

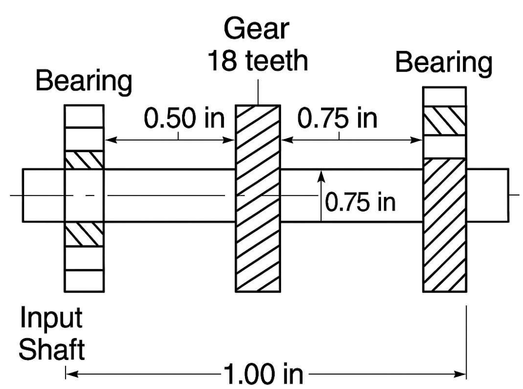

Figure 8, Revised Input Shaft Sketch

Determination of bearing reaction forces

After providing a sketch of the input shaft, the first calculation ignored the moment from the axial force. When reminded of this moment, the moment from the axial force was calculated from the gear face width rather than the gear radius. After reminding the AI of this, it calculated the proper reaction forces.

Construction of shear and moment diagrams

After correctly calculating the reaction forces, it was prompted to create the shear and moment diagram for the shaft. The first response is shown in Figure 9. I requested that the radial and axial be shown in the vertical plane, and the tangential in the horizontal plane, which resulted in Figure 10. In neither case was a shear and moment diagram created.

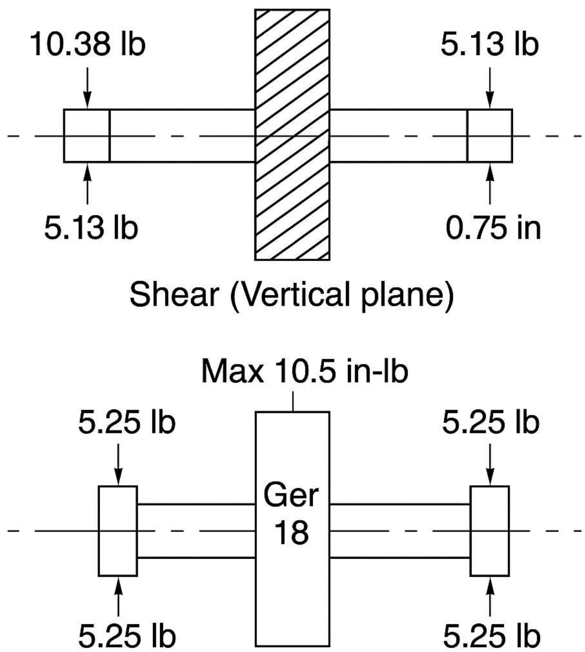

Figure 9, Initial Shear and Moment Diagram

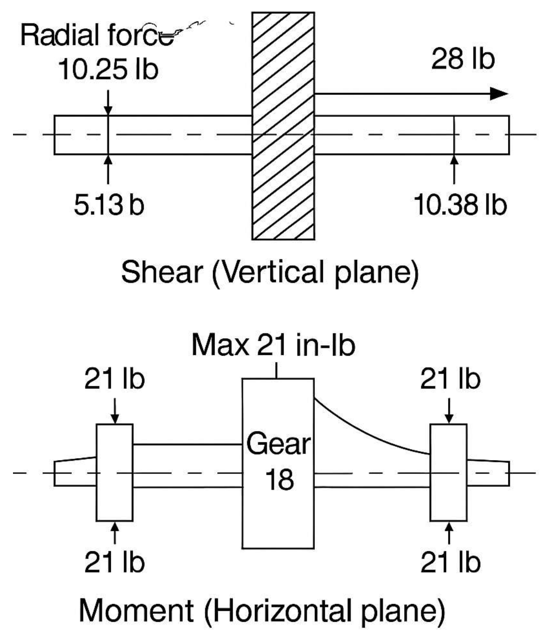

Figure 10, Revised Shear and Moment Diagram

Changing the approach, I asked it to create MATLAB code for the shear and moment diagrams using singularity functions. When executed, the code produced Figure 11, forgetting to include the reaction forces from the bearings. When reminded of this, the following code produced Figure 12. The moment from the axial force was in the wrong direction. When corrected, the moment still did not go to zero, since the reaction forces were incorrectly shown in Figure 13. (This was because it was using the facewidth rather than the gear radius for the axial moment.) The procedure was repeated for the output gear, and after several corrections, the proper reaction forces, shear, and moment diagrams were calculated as seen in Figure 14.

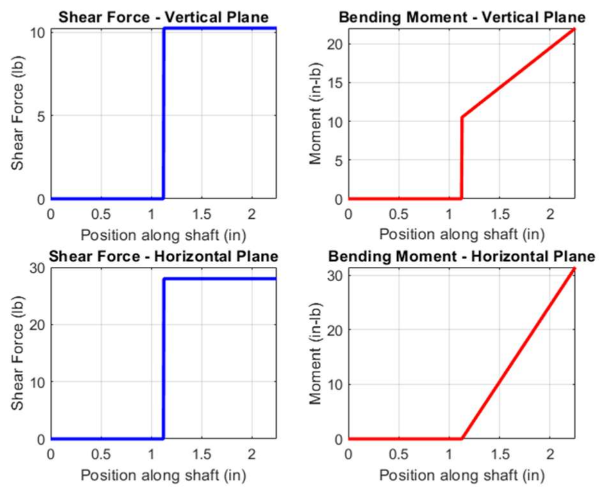

Figure 11, Initial MATLAB Shear and Moment Diagrams

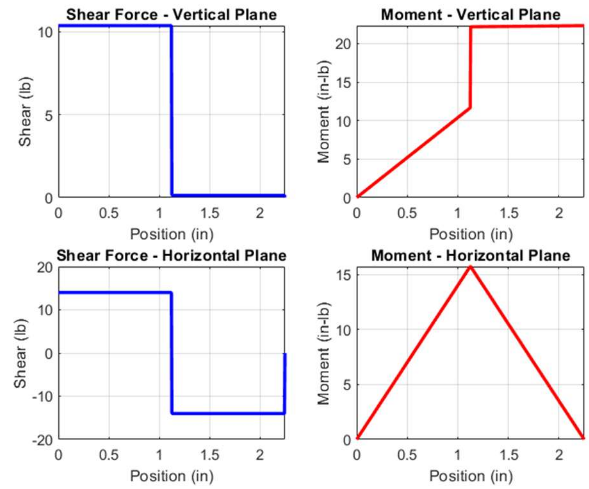

Figure 12, Revised Shear and Moment Diagram

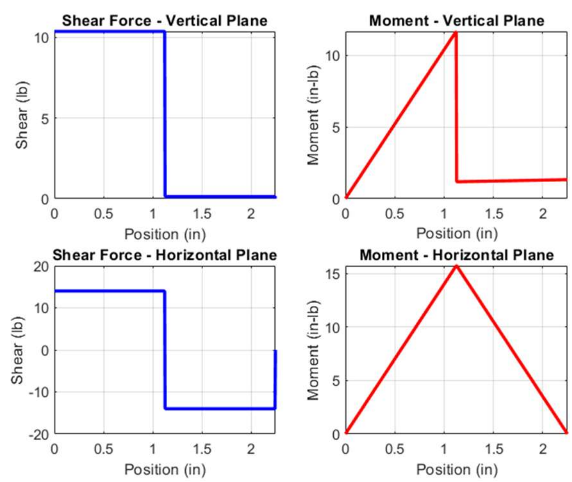

Figure 13, Plot after second revision

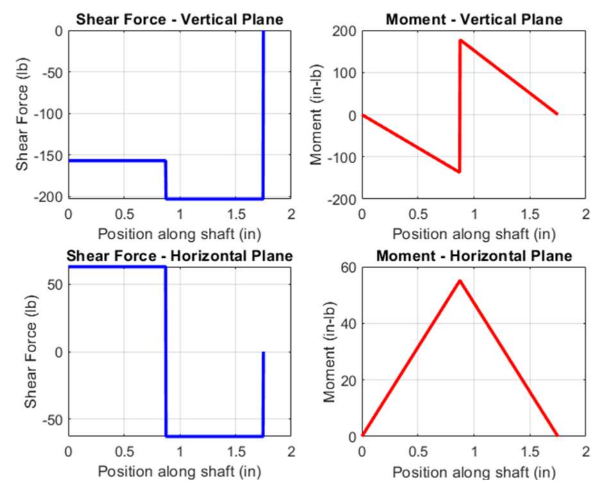

Figure 14, Final Shear and Moment Diagram for Shaft

Selection of shaft materials and diameters

Using the peak moments from the shear and moment diagram for the output shaft and the output torque, I asked for an appropriate shaft diameter for 1020 CD steel. The AI treated both stresses as alternating and calculated the diameter based on the corrected endurance strength. When prompted by the Goodman theory, it calculated the correct diameter.

Specification of keys for power transmission

The AI calculated the key size per ANSI B17.1 and correctly determined the minimum key length. It asked if I wanted an image to visualize how this works, and it provided the image in Figure 15, indicating it has no idea how keys work in shafts.

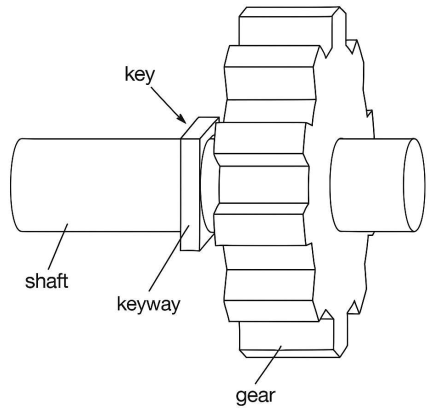

Figure 15, AI's concept of a key and a shaft

Selection of appropriate bearings

Copilot followed the proper procedure for selecting bearings based on the load and expected life.

Tolerancing Shafts

The LLM determined the appropriate fit class and calculated the proper tolerances between the bearing and the shaft.

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