

PROMPT ENGINEERING ON THE ENGINEERING DESIGN PROCESS

Rod VALENTINE

University of Bath, United Kingdom

ABSTRACT

Exploratory use of prompt engineering in generative AI is undertaken in engineering design teaching. The initial findings using Bing Copilot and Chat GPT on the design process are presented. Research on the influence of prompt construction is of interest, and multimodal AI searches for an engineering component image show it does affect the AI's output. AI is shown to be of moderate use in creating a product design specification (PDS) and elements of a morphological chart. Whilst AI's natural language processing (NLP) outputs look very convincing, they need to be checked for technical accuracy.

Keywords: AI, prompt engineering, design teaching, design process

1 INTRODUCTION

The term artificial intelligence, (AI), is attributed to John McCarthy, and generally considered to date from 1956 [1], although its roots may go back a decade further with the creation of an artificial neural network (ANN) model by McCulloch and Pitts [2]. On 30th November 2022, OpenAI introduced ChatGPT, a generative pre-trained transformer capable of generating new results from the large text data sets it was trained on [3,5].

ChatGPT uses a deep neural network architecture comprising layers of transformers that enable it to process inputs in natural language text. It can respond to follow-on inputs or questions and refine its answers to create a conversational "chatbot" with replies also in natural language. An alternative to ChatGPT is Google's Bard, a "chatbot" designed using a language model similar to GPT 3.5 [4]. Microsoft also has its own AI large language model (LLM) called Bing Copilot. The ability of these AI LLMs to generate useful and accurate results is assisted by probability to predict each word (or token). A study on these three AI LLMs, shows they are all effective in translating radiology reports into patient-friendly transcriptions with understandability scores above 70% [6].

Applying these AI LLMs effectively has given rise to a new research interest called prompt engineering in which user's questions or prompts are evaluated against the accuracy or usefulness of the AI's answers. A study on prompt engineering with ChatGPT shows how an iterative methodology can optimize interactions [7].

This paper explores prompt engineering in the engineering design process, with generative AI language models Bing Copilot, previously Bing Chat, and ChatGPT.

2 METHODOLOGY

The research approach uses prompt engineering in two generative AI software systems to explore elements of design teaching, outlined below, in the first year of a mechanical engineering course. Bing Copilot is used in parts (a) and (b) and ChatGPT in part (c). Coincidentally, there is another generative AI software also called Copilot which is used for generating programming code. A study in teaching concludes that there is pedagogical value in students interacting with this transformer language model so they can reflect on code failures [8].

Using prompts of natural language in the conversational mode, the product design specification (PDS) is refined to

- a) use conversational prompts on parts of the design process (PDS, morphological chart, CAD model),
- b) explore how prompt construction influences AI image outputs,
- c) use natural language prompts to check the technical accuracy of a short essay.

3 DESIGN PROCESS

The students enrol onto mechanical engineering programmes with strong analytical skills in “closed” problems. Research highlights the importance of design education to teach an open mindset using “unframed” problem solving so that students not only function in a design discipline but also in an “expanded field” in which wider issues occur [9]. The first-year students are given an “open” brief and create their designs using the linear design process [10], and the following section considers generative AI and its impact on teaching the design process.

3.1 Product design specification

The developments in AI’s transformer language models enable not only the prompts here to be in natural language but also the outputs [8] and therefore be more usable in student work. The teaching gives a PDS template to the first-year groups and introduces a British standard to promote awareness of the PDS’s scope and show how a few specification elements can be developed. Further specification elements in their PDS shows additional effort, so this section explores how Bing Copilot’s AI assists with it.

This year’s design project is to create a table tennis ball launcher. The launcher must be automatic and land the ball in three separate areas, so the first prompt is, “write a product design specification for a reciprocating table tennis ball launcher with three target areas.” The AI LLM responded with an “Overview” (textual statement), and four specification elements:

- i. Key Features
- ii. Technical Specifications
- iii. Performance Metrics, and
- iv. Use Cases

Under the AI’s Technical Specifications is stated the power source: input 220V AC and output 12V DC; and it also states, “*motor: brushless DC.*” In the current design project, students are limited to a battery voltage of 9V, so a follow-up prompt says, “It must be 9V battery operated.” AI’s response appends the product design specification’s title with, “battery operated,” which is encouraging, but under the Technical Specifications the motor type is still listed as brushless DC (BLDC). This combination is not impossible, but generally BLDC motors are used in the 12-48V range and, therefore, might not be the best option.

Nonetheless, looking at a specification for a 9V BLDC motor, it shows the continuous operating range has a maximum speed of 50000 rpm and delivers a maximum torque of 1.3 mN-m [11]. Adding a reduction gearbox of 200-to-1, still produces a relatively low torque of 0.26 N-m and an output speed of 250 rpm. Whilst lower operating speeds are possible within this motor’s operating range, it seems that this type of motor is better suited higher-speed applications, such as, driving the propellers of drone. In Bath’s design project, students have full control over their design, so their prototype might have high levels of friction between rotating parts from misalignment or incorrect bearing decisions. Having a higher torque motor would, therefore, be better at overcoming frictional forces and continue to drive mechanisms so that they can demonstrated in a presentation. Another point in terms of suitability for the Bath design project is cost. This motor’s unit cost is £63.47, which represents 75% of the students’ budget for purchases from external suppliers.

The point is that AI did not suggest another type of electric motor, even though they are widely available, namely, the brushed-type DC motor, and at a tenth of the price, including a gearbox. It is possible that first-year students might spot this themselves, but it is unlikely: the trend suggests that students have a reducing level of hands-on engineering experience.

Another technical point is that the AI’s PDS does not include a controller, which is needed to operate the BLDC motor. Again, it is unlikely first-year students would spot this and therefore not order it. Also, from the author’s experience, students tend to believe software-generated results even over their own correct bench-mark calculations, and so might tend towards accepting AI searches more and more. So, if students omit an essential part, such as a controller, it would result in a hold up in the prototyping phase, which, for students experiencing the design process for the first time, is something to be avoided, pedagogically.

Reviewing AI’s four specification elements above, it is noted that there is not a safety or legal element. This is not necessarily an issue for engineering design teaching, particularly in this first-year design project, because the emphasis is on delivering the stages of the design process, along with the application of a little mechanics theory. That said, when the follow-up instruction, “Include British Standards and

ISO standards” is entered, AI outputs a list. And although the list is generic, it is helpful to the tutor in saving time, whilst still making students aware of standards in a wider industrial context. In a new search, in which AI is asked to write a PDS, maintenance is listed as a specification element. This is useful as it extends the learning into in-service considerations, such as, the need to specify maintenance schedules involving lubrication points and part replacement. In the first-year design project, this may be useful for awareness, but is not needed for a single prototype. However, the omission of maintenance in the previous search points out, perhaps, the slightly random nature of the AI software. This underlines the importance of the teaching, in which guidance on, in this case, the British Standards and design elements enable students to ask relevant repeated questions to, hopefully, refine the AI’s search.

3.2 Concept design

This section explores the assistance AI gives in creating a concept using a design technique for this purpose called a morphological chart [11]. For the above reciprocating table tennis ball launcher (9V battery operated), AI is asked, “Generate a morphological chart.” The response is shown in table 1.

Table 1. AI’s suggested morphological chart for a battery-operated table tennis ball launcher

Functions		Options		
		1	2	3
1	Reciprocating mechanism	Linear actuators	Ball feed system	Guides and rails
2	Ball launching mechanism	Wheel / paddle material	Motor types:	Spin adjustment
3	Target areas	Positioning systems	Spin adjustment mechanism	
4	User interface controls	LCD display types	Control buttons	Emergency stop
5	Power source	Battery compartment design	Voltage regulator types	
6	Materials and durability	Frame material	Ball hopper material	Moving part durability
7	Assembly & maintenance	Assembly instructions format	Lubrication points	

There are several points to consider here, and the first is the appropriateness across the range of functions. The first two, reciprocating mechanism and ball launching mechanism, are relevant.

However, for the suggested function options, it is questionable as to how useful those are for the reciprocation mechanism. One might expect the name of a complete reciprocating mechanism to be given, such as, a quick-return mechanism, because students could investigate this and learn more. However, AI’s suggestions are at a level below, the part level, and this, is *not* a function concept. For example, AI’s sub-list for “linear actuator types” are lead screw, rack-and-pinion, and cam-driven, which, although could move a launching head back and forth, they would need another mechanism to create the forward and reverse motion for this to happen. One would suggest the reciprocating mechanism would convert, for example, a continuous rotary motion into a linear or angular motion all-in-one.

It is, also, strange to have “ball feed system” listed as an option for the reciprocating mechanism. Rather, it could be put as a separate function. Also, questionable is “power source.” It might be a point of pedantry, but the machine is already known to be powered by a 9V battery, so, arguably, this function is redundant and needs only to be listed in the PDS. Similarly, item 7, seems misplaced and might only confuse students in terms of thinking they need to develop concept solutions. As already discussed, maintenance is useful for creating an in-service schedule, but would not be one of the functions of the working machine.

To develop AI’s morphological chart for the table tennis ball launcher, the following instruction was given, “Add ball storage function.” Interestingly, AI now gives what should be two concepts, “ball hopper extension” and “automatic ball feeder,” see table 2, but they really are two parts which form the “ball storage system.” This is explained by three bullet points listed for the hopper extension: 1. Extend

the existing hopper to accommodate more balls, 2. consider a transparent polycarbonate extension with a secure lid, and 3. Capacity of up to 200 balls.

Table 2. AI's suggested concept solutions for a ball storage system

Functions		Options		
		1	2	3
1	Ball storage system	Ball hopper extension	Automatic ball feeder	

For option 2, one might think this should be a function, and as such, would have concepts solutions like a Geneva mechanism or rotating disc with a hole. The three sub-points are: 1. a motorized system, 2. components, and 3. operation. The components listed are conveyor belt, ball sensor, and motor. Together they might form one concept solution and therefore give students a basic concept solution. Alternatively, this might be viewed as only half a solution (or a transfer system) and in need of another mechanism by which the balls can be fed one at a time, and then transferred to the launching function. It may also be a red herring, because if the hopper is above the launching function, gravity would transfer the ball.

3.3 Multimodal-LLMs component images

Since the introduction of GPT-4 in 2023, AI can accept image and text inputs thereby becoming multimodal large language models or M-LLMs [3, 13]. This is a significant change because “AI capable of generating images from a text prompt are becoming increasingly prevalent in society and design” and so a study is made on text-to-image AI in the concept generation stage of the design process [14]. Research interest in visual prompt engineering shows the potential of redefining the field of computer vision applications [15]. In the creative process of art and design education, student and instructor survey results indicate prompt engineering to have a profound impact on generated imagery [16].

In exploring AI images, it would be useful to gauge the effect variations in the construction of the prompts have. A study in prompt engineering finds that “crafting effective prompts can be challenging, leading to potentially inaccurate or contextually inappropriate responses,” and so proposes a prompt methodology, GPEI: goal, prompt, evaluate and iterate [6]. A variation in the consistency of AI outputs as a result of different prompt styles is also found in medical applications [17].

The approach here uses text-to-image prompt engineering in Bing Copilot (image creator) asking it to output an image of an engineering component, a spur gear. Six prompts are used and in each one the natural language question has a different verb, and it is one which might be used in a design assessment. Although it is uncertain what significance this has, it was decided to introduce a scale by which to measure the output of the searches.

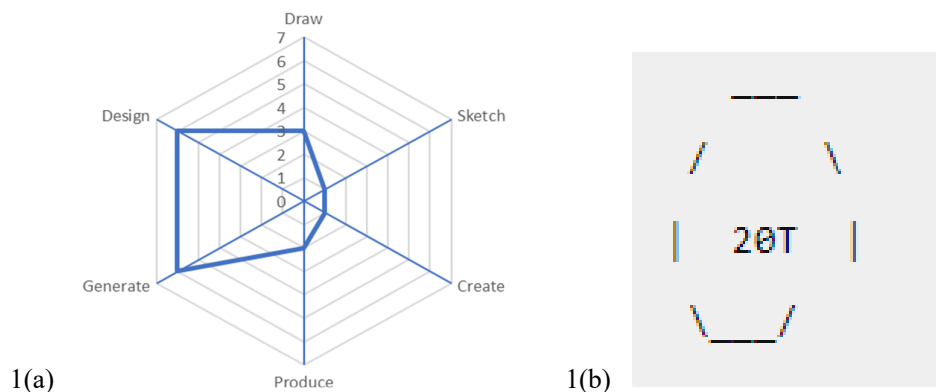


Figure 1(a). Effect of changing the verb in natural language prompt construction in text-to-image AI outputs of an engineering component; 1(b). An example of an ASCII-based image

In figure 1(a), is the result of AI searches relating to Bing Copilot outputting a drawing of a spur gear with a PCD of 20 mm and a MOD of 1. The scale ranges from 1-7 where: 7. is an accurate drawing, 6. is an inaccurate 2D drawing, 5. is a CAD model, 4. is an accurate image or picture, 3. is an image with the correct gear type, 2. is an image of inaccurate gear type, and 1. is text and or web links.

In figure 1(b) is an example of an ASCII-based diagram in AI's output for the spur gear prompt. It is graded at 6 in the radar plot to optimistically recognize the shape is influenced by the prompt. It may be that too much is being read into the diagram, but the value in the centre is correct for the values in the prompt and has some control over the 2D image or pattern. Although this is not a useful image for teaching, research shows how computers can use ASCII art to construct images more realistically [18]. To explore prompt construction further, notwithstanding how current design teaching uses parametric software, text-to-image natural language prompts ask AI for 3D models. When asked to "Create a 3D CAD model of..." AI responds, "I apologize, but I'm unable to create a 3D CAD model in this chat interface." However, when asked to "Design a 3D CAD model of..." AI responds, "Certainly! Designing a 3D CAD model for a reciprocating, three-target area table tennis ball launcher powered by a 9V battery is an exciting challenge. While I can't directly create the CAD model here, I can guide you through the conceptual design and key components you'd need to consider." This shows that variations in prompt construction can elicit different responses.

4 AI ESSAY INVOLVING TECHNICAL POINTS

To find out more about how AI responds with engineering information on gears, a prompt in natural language asks ChatGPT, "Write me a 100-word essay on the advantage of spur gears over helical gears." The AI software responded with:

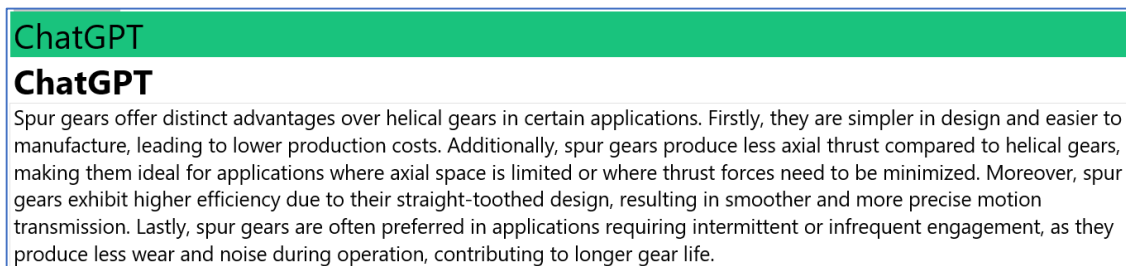


Figure 2. A short AI essay on the advantages of spur gears

The details in AI's comparison, in figure 2, are all useful, except one. The last sentence suggests noise is less, but this is not true. An advantage of helical gears is that they create a gradual engagement and reduced noise. If it is possible to know such statements can be produced by AI, then they may be used to reinforce lectures by asking students to find the erroneous point. Equally, even if the search is not given, it may still be a useful teaching exercise to ask students to critique such an AI search.

5 CONCLUSIONS

The application of AI research is relatively less established in engineering design teaching, compared to other disciplines such as medicine, so exploratory findings are presented on phases of the design process using Bing Copilot and ChatGPT.

In prompt construction, it is found that the type of verb, such as, create and produce, used in an M-LLM search elicits different levels of information. These findings suggest that there is a slight learning curve for the user, particularly in conversational searches.

The assistance an AI "chatbot" gives in creating a PDS is helpful, particularly from conversational prompts where NLP outputs give human-like descriptions. The assistance it gives with morphological charts is modest. Whilst some of the functions it identifies are valid, others are less so, or not at all, and this could be less helpful to first-year students. Similarly, the concept solutions suggested are not always complete separate solutions, so care is needed to discern what is useable or, indeed, how it can be made useful.

In a comparison between two engineering parts, AI is shown to give a well-written answer, which would be useful in an essay. However, one of the points it gave is incorrect, and so there is a need to carefully check it for technical accuracy. Pedagogically, it may be possible to reverse the negative aspect of AI by using it as a teaching tool, in which, students critique AI searches on tutor-led questions.

REFERENCES

- [1] Cordeschi R. 2007, AI Turns Fifty: Revisiting its origins. *Applied Artificial Intelligence*, 21(4–5), 259–279, Available: <https://doi.org/10.1080/08839510701252304>.
- [2] Wong L. 2019, From Intelligence Science to Intelligent Manufacturing, *Engineering*, Volume 5, Issue 4, pp615-618, Elsevier.
- [3] OpenAI. 2024. GPT4 Technical Report, Available: arXiv:2303.08774v6 [cs.CL], 4th March.
- [4] Kalla D. et al. 2023, Study and Analysis of Chat GPT and its Impact on Different Fields of Study, *International Journal of Innovative Science and Research Technology*, Volume 8, Issue 3, 827-833, March – 2023, ISSN No: 2456-2165.
- [5] Baidoo-Anu D. Ansah L. O. 2023. Education in the era of generative AI: Understanding the potential benefits of ChatGPT in promoting teaching and learning, *Journal of AI*, 7(1), 52-62, (dergipark.org.tr).
- [6] Tepe M. et al. 2024. Decoding Medical Jargon: The Use of AI Language Models (ChatGPT-4, BARD, Microsoft Copilot) in Radiology Reports, *Patient Education and Counselling*, Elsevier, Available: <https://doi.org/10.1016/j.pec.2024.108307>.
- [7] Velasquez-Henao J. D. et al. 2023. Prompt engineering: a methodology for optimizing interactions with AI-Language Models in the field of engineering, *DYNA*, pp9-17, ISSN 0012-7353, Available: <http://doi.org/10.15446/dyna.v90n230.111700>.
- [8] Denny P. et al. 2023. Conversing with Copilot: Exploring Prompt Engineering for Solving CS1 Problems Using Natural Language, *SIGCSE*, pp1136-1142, ISBN 978-1-4503-9431, Available: <http://doi.org/10.1145/3545945.3569823>.
- [9] Friis S. A. et al. 2016. The Future of Design: Unframed Problem Solving in Design Education, *International Conference on EPDE*, Aalborg University, Denmark.
- [10] Pahl G. and Beitz W. 2007. *Engineering Design: a systematic approach*, 3rd Edition, Springer. ISBN 978 1846283185.
- [11] Maxon Motor. Available: www.maxongroup.com [accessed 28th March 2024].
- [12] Childs P. 2014. *Mechanical Design Engineering Handbook*, Butterworth-Heinemann.
- [13] Mesko B. 2023. The Impact of Multimodal Large Language Models on Health Care’s Future, *Journal of Medical Internet Research*, vol 25, e52865.
- [14] Brisco R., Hay L. and Dhimi S. 2023. Exploring the role of text-to-image AI in concept generation, *International Conference on Engineering Design (ICED23)*, pp1835-1844, Bordeaux, France.
- [15] Wang J. et al. 2023. Review of large vision models and visual prompt engineering, *Meta-Radiology*, Keai Publishing, Available: <http://doi.org/10.1016/j.metrad.2023.100047>.
- [16] Hutson J. and Robertson B. 2023. Exploring the Educational Potential of AI Generative Art in 3D Design Fundamental: A case study on Prompt Engineering and Creative Workflows, *Global Journal of Human Social Science: A Arts & Humanities – Psychology*, 23(2), ISSN:2249-460X.
- [17] Wang L. et al. 2024. Prompt engineering in consistency and reliability with evidence-based guideline for LLMs, *Digital Medicine*, 7(41), Available: <https://doi.org/10.1038/s41746-024-01029-4>.
- [18] Matsumoto K. et al. 2018. ASCII Art Classification based on Deep Neural Networks Using Image feature of Characters, *Journal of Software*, 13(10) 559-572, Available: <http://doi:10.17706/jsw.13.10.559-572>.