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# Possible Applications of Large Language Models (LLMs) in Engineering Education: An Overview

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## ABSTRACT

The research described in this paper explores the integration of Large Language Models (LLMs), particularly ChatGPT, into engineering education, focusing at the end on mechanical one. Investigating the widespread adoption of generative AI tools, the study systematically reviews their applications, usage patterns, and overall impact on knowledge acquisition in higher education. The research delves into specific applications, highlighting ChatGPT role in product design, development, and innovation. The analysis, based on a systematic review of 67 papers, categorizes findings into general and subject-specific applications, revealing notable instances in computer science and mechanical engineering. The study addresses key research questions, elucidating the diverse applications of ChatGPT, especially in supporting knowledge extension and creative idea generation. The findings underscore the transformative potential of LLMs in engineering education, emphasizing the need for careful implementation to balance AI assistance and human engagement. As ChatGPT continues to evolve, this work contributes to the ongoing discourse on effectively harnessing LLMs in educational settings, laying the groundwork for future exploration and guideline development.

**Keywords:** Generative AI (GENAI), Large language models (LLMS), ChatGPT, Engineering education

## INTRODUCTION

The use of large language models (LLMs) is now spreading in various application and research areas. This exploratory work is concerned with investigating the use of these tools in engineering education. Specifically, it aims at clarifying the knowledge about these tools, the types of applications, and the purposes for which students use these tools within higher education courses.

The authors believe it is important to study whether the conscious use of these tools can have a positive impact on the training of future engineers and whether it can also become a tool for innovation design and development.

With the incoming of the latest versions of ChatGPT by OpenAI in 2023, generative AI tools have now become commonplace among students and teachers (Miao and Holmes, 2023; Qadir, 2023). The literature shows several examples of adoption of these tools in different educational fields concerning informatics, mathematics, medicine, economics, language study, etc. (Bahroun et al., 2023; Lo, 2023).

 

The research described in this paper investigates the different uses of tools like ChatGPT or similar in engineering education, focusing at the end on mechanical one afterward. Specifically, the authors are interested in understanding which help may come from them to activities related to product design, development and innovation. Because of this, it was decided to conduct a systematic review of the literature.

The paper begins with a background on the main generative AI tools and how they work. It then continues with a systematic review of the main scientific publications dealing with the involvement of LLMs (in particular ChatGPT) in engineering education, to the point of specializing it towards mechanical engineering. The results of the analysis are then presented and discussed, and conclusions reported.

## BACKGROUND

### Generative AI Tools and LLMS

Generative AI (GenAI) is an artificial intelligence technology that creates content in response to prompts within natural-language conversational interfaces. Unlike systems that curate existing webpages, GenAI produces entirely new content, encompassing various forms of human thought representation, including natural language texts, images, videos, music, and software code. It is trained using data from webpages, social media conversations, and online media, analyzing statistical distributions of words, pixels, or other elements to identify and replicate common patterns, such as word associations.

The technologies underlying GenAI belong to the machine learning (ML) family of artificial intelligence (AI). Machine learning utilizes algorithms to enhance its performance continuously through data. A significant contributor to recent AI advancements, like facial recognition, is a type of ML known as artificial neural networks (ANNs). ANNs draw inspiration from the human brain and its synaptic connections between neurons. There are various types of ANNs. Text generative AI employs a specialized type of ANN called a general-purpose transformer. Text-generating AI systems are commonly referred to as large language models (LLMs). Within this category, a specific type of LLM known as generative pre-trained transformer (GPT) plays a central role. This is the origin of the GPT acronym in the name ChatGPT. ChatGPT, specifically, is built upon GPT-3, a product of OpenAI and the third generation in their GPT series. The initial GPT model was launched in 2018, and the most recent, GPT-4, emerged in March 2023 [https://chat.openai.com/].

Nowadays, there are several language models based on transformer architectures similar to ChatGPT. Some notable examples include Bard by Google [https://bard.google.com/chat], Alpaca by Stanford University's Center for Research on Foundation Models (CRFM) [https://crfm.stanford.edu/2023/03/13/alpaca.html] and Elicit by Ought [https://ought.org/elicit]. These models are often pre-trained on large datasets and fine-tuned for specific tasks. Each of them has its own strength and weakness and may be more suitable for certain applications or use cases.

Given the considerable interest in these tools, we thought it would have been interesting to analyze their current and potential use in engineering education, particularly in design-related activities, focusing on mechanical engineering.

## MATERIALS AND METHODS

### Data Collection

Inspired by two recent reviews on Generative AI and education (Bahroun et al., 2023; Lo, 2023), a review on the involvement of LLMs (limited to Chat GPT) in engineering education was considered.

The focus was to search for papers discussing the use of ChatGPT both in teaching and learning engineering and in concept design and innovation design referring to mechanical engineering design processes.

The review was conducted at the middle of January 2024. Two databases were used, Scopus and IEEE Xplore.

Using "Chat GPT AND education AND engineering" as the first search string in both DBs, 117 papers were found on Scopus and 88 on IEEE Xplore in the time range 2023-2024. Of these, those in English were then selected, 113 on Scopus and 88 on IEEE Xplore. Then, only those papers with the keyword "engineering education" were unpacked for further content analysis. Sixty-four items were from Scopus and nine from IEEE Xplore; five duplicate papers were removed coming to a total of 68 papers.

In order to get a larger dataset to work on, a second search, triggered on the same sources, was conducted using the string "ChatGPT AND (conceptual design OR innovation design)". This query returned 52 papers, considering only those written in English. All the papers came from Scopus. Then, duplicates were removed, reaching a total of 49 papers. The reason for this second search is that we were aware that some papers, although they considered the involvement of students in dealing with ChatGPT-related education activities, could not have "students", "education", etc. among their keywords.

Then, a total of 117 papers were selected for the next stage of the analysis. We read the abstracts of them in order to select all possible papers dealing with aspects related to engineering education. Finally, we got 67 papers to process further.

### Research Questions

At this point, the following research questions were formulated.

- RQ1: Is it possible to clearly identify applications of ChatGPT to engineering education topics? If so, what are the main application areas?
- RQ2: Strictly referring to mechanical engineering, how can ChatGPT be used in education?
- RQ3: Is it possible to make clear and quantify the added value of ChatGPT in designing and developing creative/innovative ideas in mechanical engineering education?

## RESULTS AND DISCUSSION

The deeper analysis of the selected papers provided insights into the main results, organized by research question.

### Research Question 1 (RQ1)

Upon the initial reading of the 67 selected papers, a first classification was made between those addressing general applications of ChatGPT, encompassing aspects like use, ethics, and pedagogical implications, and those detailing the adoption in specific engineering application areas. This classification yielded 31 papers related to general applications and 36 papers to specific application areas. Among the latter, computer science emerged as the prevalent area, featuring applications in information technology and software engineering and programming, totaling 18 papers. Mechanical engineering and concept and innovation design had six papers, followed by management/entrepreneurship with four papers and chemical engineering with two items. Additional applications were identified in biomedical engineering, mathematics and statistics.

Table 1 summarizes the observation for RQ1.

**Table 1.** Summarizing the observation for RQ1.

| Application area | Papers |
|---|---|
| General aspects of engineering | 31 |
| Computer Science (information technology, software engineering and programming) | 18 |
| Mechanical engineering and engineering design (concept generation and product innovation) | 6 |
| Management/entrepreneurship | 4 |
| Chemical engineering | 2 |
| Fundamental engineering subjects | 2 |
| Biomedical engineering | 1 |
| Mathematics | 1 |
| Statistics | 1 |
| Decision making | 1 |

Therefore, in summary, the answer to RQ1 "is it possible to clearly identify applications of ChatGPT to engineering education topics? If so, what are the main application areas?" is that:

- Chat GPT and LLMs in general can be used in engineering education for a variety of purposes, including basic knowledge retrieval, knowledge application, critical analysis, and knowledge extension.
- The most common application areas for ChatGPT in engineering education are computer science, mechanical engineering, and management/entrepreneurship.

### Research Question 2 (RQ2)

To answer RQ2, a more detailed analysis was conducted on the six publications strictly related to mechanical engineering education. The code, titles and references of these papers are listed in Table 2.

**Table 2.** Selected publication about mechanical engineering education.

| Code | Title | Reference |
|---|---|---|
| P1 | Exploring the application of ChatGPT in mechanical engineering education | (Puig-Ortiz et al., 2023) |
| P2 | ChatGPT for design, manufacturing, and education | (Wang et al., 2023) |
| P3 | Chat generative pretrained transformer: extinction of the designer or rise of an augmented designer | (Gill, 2023) |
| P4 | Generative AI in the manufacturing process: theoretical considerations | (Doanh et al., 2023) |
| P5 | Students' use of large language models in engineering education: a case study on technology acceptance, perceptions, efficacy, and detection chances | (Bernabei et al., 2023) |
| P6 | Measuring the Impact of ChatGPT on Fostering Concept Generation in Innovative Product Design | (Filippi, 2023) |

In addressing RQ2, notable observations were made from the analysis of the papers P1, P5 and P6, which detailed experiences with university students. These works emphasized the direct involvement of students in use tests, where they engaged in specific tasks or participated in questionnaires, highlighting some key aspects.

To understand better the possible uses of ChatGPT, reference should be made to a classification of knowledge activities that can be performed based on Bloom's revised taxonomy (Krathwohl, 2002) and proposed in papers P1 and P2. Both papers evaluate the performance and effectiveness of ChatGPT in supporting student learning using levels of increasing complexity. Based on these two proposals, the authors have reiterated and partially reformulated these classifications. The proposed levels are; Level 1 – Basic Knowledge; Level 2 – Knowledge Application; Level 3 – Critical Analysis; Level 4 – Knowledge Extension. Table 3 summarizes the levels and indicates examples of activities that may be undertaken and that were extracted from the six selected papers.

**Table 3.** Summarizing observation for RQ2.

| Level | Activities | Paper Codes |
|---|---|---|
| L1 - Basic knowledge | Retrieval and understanding of basic concepts, accurate definitions | P1, P2, P5 |
| L2 - Knowledge application | Synthesis and Evaluation; merging and summarizing information from various sources; texts production | P1, P2, P5 |
| L3 - Critical analysis | applying knowledge to practical scenarios and analysing outcomes;<br>solved reasoning tasks involving simple formulas | P1, P2, P3, P4 |
| L4 - Knowledge extension | application of knowledge in innovative ways to solve complex problems; optimization of design; new concept development | P1, P2, P3, P4, P5, P6 |

Considering the outcome of the analysis, ChatGPT demonstrates notable proficiency in answering questions that extend knowledge, showcasing its ability to synthesize new information, make inferences, and transfer knowledge to novel areas. Across diverse topics within design and manufacturing, ChatGPT consistently performs well in handling questions related to basic

knowledge and the application of knowledge. However, it encounters a notable challenge when confronted with questions requiring critical analysis, limiting its ability to break down information for a deep understanding.

Thus, the levels at which ChatGPT proves to be most effective are L1 and L2, particularly in information retrieval and text summarization. Conversely, for higher levels, issues are reported, including inconsistencies in information and potential errors, especially when support requests are not formulated accurately.

Therefore, in summary, the answer to RQ2, "strictly referring to mechanical engineering, how can ChatGPT be used in education?" is that:

- ChatGPT can be used to support students in mechanical engineering education in a variety of ways, including answering questions, production of essays and summaries, coding, generating design concepts, and optimizing designs;
- ChatGPT is most effective at answering questions that extend knowledge, while it is less effective at answering questions that require critical analysis.

### Research Question 3 (RQ3)

RQ3 aims to explore the effectiveness of ChatGPT as a supportive educational tool for activities related to Level L4 of the previous classification, focusing on the generation of novel ideas or concepts for product development or optimization. For each of the six selected papers, efforts were made to elucidate and quantify the value added by ChatGPT in fostering creative and innovative ideas in mechanical engineering education.

Table 4 outlines key observations from the reading aimed at addressing the third research question. Specifically, the analysis identified several activities referring to L4 and linked them to applications dedicated to creativity and/or to the development of new concepts.

The most frequently examined activity was "generating design concepts based on functional or specific design requirements", followed by "optimizing design based on user-defined parameters". Additional activities explored the potential to create simple functional models or basic graphic diagrams, generate working principles, and recognize similarities between solutions. Table 3 lists the design activities highlighted along with the references to the papers where they appear.

**Table 4.** Summarizing observation for RQ3.

| Design activities | Paper Codes |
|---|---|
| Generate design concepts based on functional or specific design requirements | P1, P2, P3, P4, P6 |
| Optimize design based on user-defined parameters | P4, P6 |
| Create simple graphical schemas using textual characters | P1 |
| Create function models | P3 |
| Generate working principle for a function or a subfunction | P3 |
| Recognition of similar working structures | P3 |

The analysis reveals that ChatGPT serves as a valuable tool for offering innovative ideas and suggestions to support the initial stages of designing new products and optimizing existing ones. While ChatGPT creativity may not surpass that of expert engineers, it proves beneficial for students and individuals with less experience. Furthermore, a noteworthy finding is the recognition that to harness the full potential of these tools, users need not only a sound understanding of their functionality but also strong critical and analytical skills. These skills are crucial for effectively articulating problems and critically evaluating the solutions obtained. Paper P5 did not contribute to speculation about RQ3 (it does not appear in Table 4). This is because, although the research involved students thanks to a questionnaire on engineering education, it does not specifically deal with creativity or innovation.

Therefore, in summary, the answer to RQ3, "is it possible to make clear and quantify the added value of ChatGPT in designing and developing creative/innovative ideas in mechanical engineering education?" is that:

- ChatGPT can be used to generate creative and innovative ideas in mechanical engineering education, supporting the first phases of product design and development.
- The most common applications for ChatGPT in this area are generating design concepts, optimizing designs, and creating simple graphical schemas starting from specific and well-defined requirements.

## CONCLUSION

The research described in this paper aimed to comprehensively review the different applications of generative AI tools in engineering education focusing on both engineering in general, mechanical engineering in particular, and the design field.

This study highlights the potential of Large Language Models (LLMs) as valuable support tools for students in engineering education. However, effective implementation necessitates careful consideration, training, and critical analysis of the outputs of the tools involved. Striking a balance between AI assistance and human involvement is crucial, with an emphasis on fostering critical thinking and problem-solving skills. This work should contribute to the ongoing discourse on integrating LLMs into education and lays the groundwork for further exploration and guideline development to harness their full potential in educational settings. Delving into specifics, ChatGPT shows promise in enhancing various activities such as human-machine collaboration, knowledge management, design innovation, and engineering education within the manufacturing sector. While excelling in certain areas, such as extending knowledge and handling basic questions, challenges arise, particularly in critical analysis. These findings underscore ChatGPT transformative potential across different facets of the manufacturing industry, including collaboration, knowledge utilization, design innovation, and education.

In future, there is an expectation to expand the mapping of uses, especially in areas related to specific industry training, lifelong learning activities, or teacher training.

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