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NAVIGATING THE AI ERA: ANALYZING THE IMPACT OF ARTIFICIAL INTELLIGENCE ON LEARNING AND TEACHING ENGINEERING PHYSICS

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This paper delves into the impact of artificial intelligence (AI) on learning and teaching engineering physics, focusing on the use of AI chatbots. The study explores various issues encountered by educators when students utilize AI to solve physics problems, highlighting potential pitfalls and opportunities. Through testing AI chatbots' capabilities in physics learning, the paper evaluates their effectiveness in providing accurate and insightful responses. Results indicate that while AI, especially ChatGPT 4, shows promise in aiding students' understanding of physics concepts, there are limitations and challenges to consider, such as over-reliance on technology and the potential for AI to produce misleading solutions. The implications and discussions underscore the need for a balanced approach in integrating AI into education, emphasizing authentic understanding over merely obtaining correct answers. Using AI in creating teaching materials is not evaluated here.

Keywords: Artificial Intelligence, physics teaching, physics learning.

INTRODUCTION

Artificial intelligence (AI) has emerged as a transformative force, reshaping industries, societies, and the way we live our lives. AI involves the development of computer systems capable of performing tasks that traditionally require human intelligence [1]. These tasks include learning, decision-making, language understanding, and visual perception. The significance of AI in today's world cannot be overstated, as it drives innovation across fields ranging from healthcare and finance to transportation and education. Educators and learners already use AI technologies like search engines, smart assistants, chatbots, translators etc. in their daily life, sometimes even without realizing it. There are high expectations for the use of artificial intelligence, and it is expected to transforming learning for the 21st century by providing personalized, accessible, and efficient educational experiences [2].

The European Union has published report of the impact of AI on learning, teaching, and education [3] and ethical guidelines for using AI [4]. These documents explore the transformative impact of AI on learning, teaching, and education, highlighting both opportunities and challenges. The rapid pace of technological change is emphasized and the need for educational practices, institutions, and policies to adapt to the changes. The reports address the potential of AI to revolutionize educational approaches through personalized learning, efficient resource use, and data-driven decision-making, while also considering the technical, and practical aspects of integrating AI into education. Also, the need for ethical considerations in the deployment and use of AI and data in education is emphasized. Key requirements for trustworthy AI include transparency, non-discrimination, privacy, and accountability. Educators are guided to ensure AI systems are reliable, fair, safe, and protecting individual privacy, promoting a responsible and ethical approach to incorporating AI technologies in educational settings. Many higher education institutions have written their own guidelines for using AI in educational settings. For example, Tampere University of Applied Sciences encourages students, teachers, and staff to familiarize themselves with and utilize AI

systems in education, such as for information retrieval and to get ideas for content creation. Ethical and responsible use of AI applications is emphasized, with students always responsible for the content of their assignments and required to critically evaluate AI-generated content alongside other sources.

In the educational sector, artificial intelligence is revolutionizing the learning experience by offering personalized teaching solutions and efficient administrative support. For instance, the Georgia Institute of Technology introduced a virtual teaching assistant, Jill Watson, to handle frequently asked questions, enhancing the efficiency of the teaching staff [5]. Similarly, platforms like Duolingo and Khan Academy leverage AI to adapt learning experiences to individual student needs, demonstrating AI's capability to make learning more engaging and tailored. In the next chapters the scope is narrowed down to the use of AI, especially AI-chatbots, in bachelor's level engineering physics learning and teaching. Various issues that a teacher encounters when students utilize AI to solve physics problems are discussed. Examples illustrate how AI-assisted answers differ from traditional student responses, highlighting issues such as over-reliance on technology, lack of fundamental understanding, and potential discrepancies in problem-solving approaches.

AWAKENING TO CHAT-GPT ERA

Tampere University of Applied Sciences (TAMK) offered a thermodynamics course in 2023. During the course the student answers to open-ended homework questions started to be bizarre. Here is one example: the students were asked to tell and describe some isochoric processes in their everyday environment. The answers told about car and pedestrian traffic in a junction, a forest ecosystem with numerous species and their interactions, a gas stove that have a high temperature and can heat several foods at the same time on different hotplates etc. In these cases, students had clearly used ChatGPT or similar AI tool without any own effort to analyze the answer and estimate its correctness. Unfortunately, these are also nice examples of AI hallucinating: generation of information that is incorrect and misleading, presenting it as if it were true. This phenomenon can manifest as deviations from factual accuracy, logical coherence, or both, often appearing plausible due to the LLM's (large language model) design to produce fluent and coherent text despite lacking an understanding of the underlying reality the language describes.

The language used affects the results in AI-chatbots. In the previous example, the language was Finnish. Also, the learning process of the AI-engine became nicely visible – after getting those bizarre answers, the teacher himself tested the ChatGPT with the same question (in Finnish) the result was the following:

ChatGPT:

"Valitettavasti termi "isokoorinen" ei ole minulle tuttu, ja se saattaa olla erikoistunut tai rajoitetusti käytetty termi. Voitko tarjota lisää tietoa tai määritellä, mitä tarkoitat isokoorisella prosessilla?"

Translation: *"Unfortunately the term "isochoric" is unfamiliar to me and may be a specialized or restricted term. Can you provide more information or define what you mean by isochoric processes?"*

When the same term was given in English to ChatGPT, it made the connection and learned what "isokoorinen" (Finnish) means. This was the answer:

ChatGPT: *"Ah, nyt ymmärrän. Pahoittelen aiemman epäselvyyden. Isochoric process tarkoittaa tilaprosessia, jossa tilavuus pysyy vakiona…"*

Translation: *"Ah, now I understand. I apologize for the earlier confusion. Isochoric process means a state process where the volume remains constant...."*

TESTING AI CHATBOTS' CABABILITIES IN PHYSICS LEARNING

To find out how far a student can get with using AI chatbots, a few different types of physics questions were presented to four AI bots: OpenAI ChatGPT 3.5, OpenAI ChatGPT 4, Microsoft Copilot and Google Gemini. It should be noted, however, that the answers reflect the situation in February-March 2024 – the speed of AI development is very fast, and the results are likely to get better on monthly basis.

Question 1: Thermodynamics. Presented in Finnish, here only translation:

"There is ice in a thermally insulated container at a temperature of -20 °C. The interior of the container is heated with a constant power P. It is assumed that the heat is distributed inside the container with infinite efficiency and that the container is perfectly insulated. The heating is continued until the ice has melted, and the water formed from the ice begins to boil. The pressure in the container remains constant. Sketch a graph of the temperature of the container as a function of time."

All chatbots provided text answers that sounded convincing to a layman. Only ChatGPT 4 was able to produce a diagram, whereas the others offered a written description of the diagram. Fig.1 presents the interpretations of the text answers and the actual graph (ChatGPT 4).

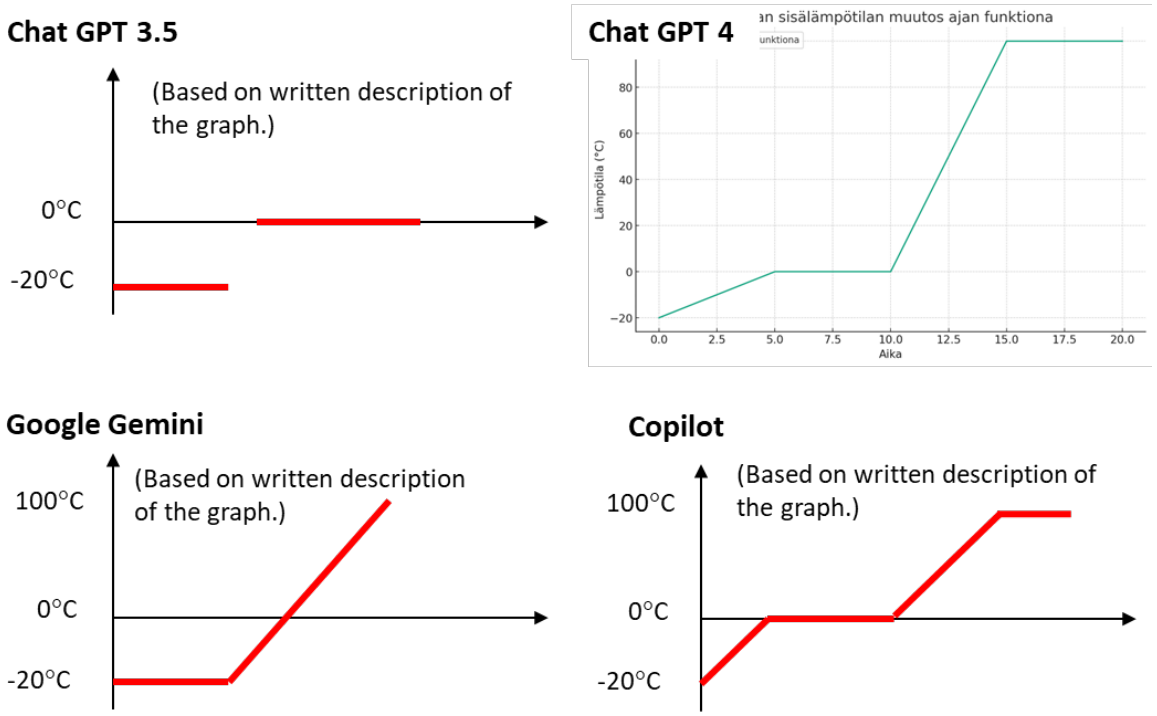

Fig.1. The results of chatbot text answers interpreted to graphs. For ChatGPT 4, the graph is real and created by the AI chatbot.

There were inaccuracies and aspects missing in all answers. ChatGPT 4 did best, it was able to create the graph and it showed even the different slopes of temperature change for heating ice and water – however, the slopes are not correct. All answers also quite correctly presented the equations needed for different parts of the graph. Despite the correct equations, only ChatGPT 4 was actually able to provide the diagram, whereas the others responded with written description. It is clear that Google Gemini and ChatGPT 3.5 are not yet sufficient tools for this type of learning. Copilot's answer was partially right, but it still lacks the ability to draw the graph and didn't mention different slopes of temperature change for ice and water.

Question 2: Mechanics. In English.

"What are the forces acting on a car travelling on a horizontal road at a constant speed?"

To this question, all chatbots provided rather correct text answers and included the idea of net force being zero. The forces were correctly named, and they were explained. In some cases, there were somewhat misleading descriptions of the friction: the effects of rolling friction and friction needed to create the traction were mixed, omitted, or misleadingly presented depending on the bot. Also, normal force was not separately presented for the front and rear wheels and directions and points of action of the forces were not very well described. In this sense the answers represented an average engineering student quite well. The summary of answers is presented in the figure 2. None of the bots was able to create a correct free body diagram. Only ChatGPT 4 (Dall-e) created any image, but it was an artistic illustration of a car rather than a real physics free body diagram. When the setting is reversed and the free body diagram was uploaded to a chatbot, most of them were able to interpret it correctly and tell about the forces present.

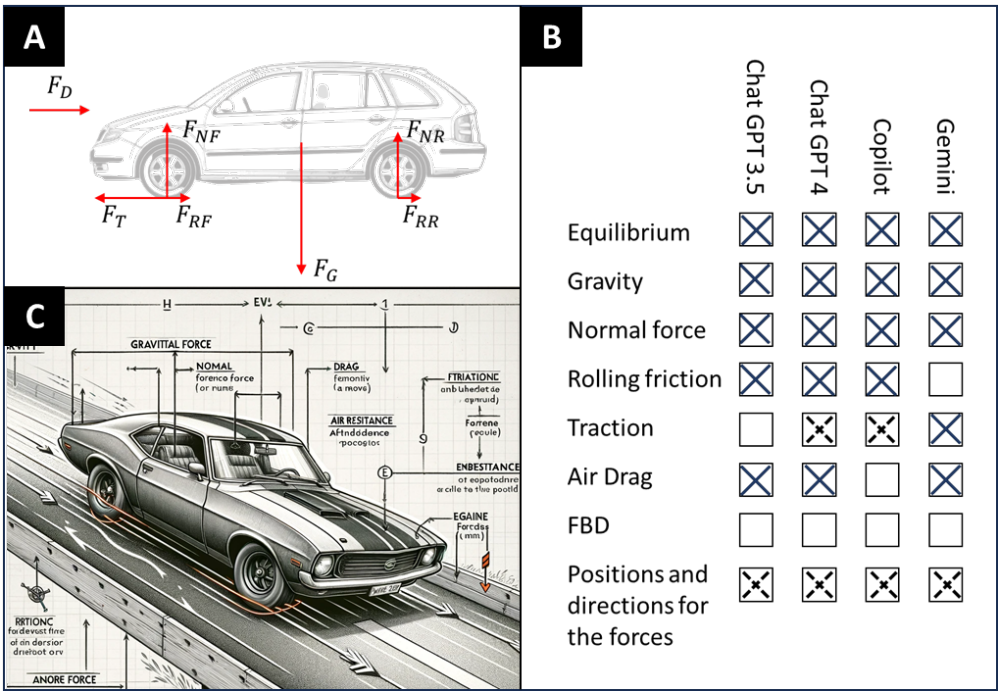

Fig. 2. The results of asking the chatbots to describe the forces acting on a car travelling on a horizontal road at a constant speed. A) The expected answer and forces, B) Chatbots' answers' correctness, and C) the "Free body diagram" drawn by chatGPT 4.

Question 3: Thermodynamics. In Finnish.

A photo of a typical, somewhat erroneous, handwritten student answer (Fig.3) was given to all chatbots with the question “Is this calculation correct?”. In the problem the student needed to calculate the final temperature and volume for adiabatic compression with the given initial values. It was possible to upload the picture to ChatGPT 4, Copilot and Gemini, whereas ChatGPT 3.5 is not capable to handle attachments. These three chatbots analyzed the answer but the accuracy and correctness varied in the following way:

ChatGPT 4: Correctly pointed out that the temperature is right but there is a mistake in the equation for the final volume. It provided explanations and showed the right equation in an understandable format. It also calculated the right final volume.

Copilot: Only checked if the numerical values were in accordance with the equation used by the student but did not recognize that the equation itself was incorrect. Also, it gave the equations in the following LaTeX format which is not so easy to read as such, but can be visualized with an online LaTex equation editor:

“T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{{\gamma - 1}}{\gamma}}”

Gemini: Hallucinated badly. It said that the student answers were wrong but was incapable of providing the right answers. It showed some equations that were incorrect and gave wrong final answers based on them.

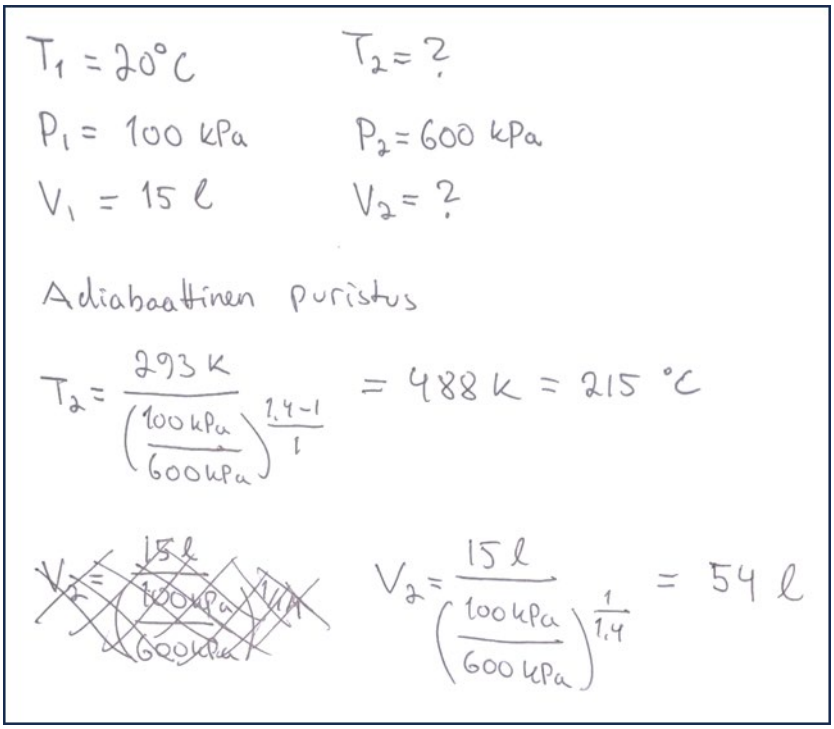

Fig. 3. This photo of a typical, somewhat erroneous, handwritten (student) answer was given to all chatbots with the question “Is this calculation correct?”.

Questions 4-16: Thermodynamics. In Finnish.

Here not all the questions are presented, but instead the result of the test. A bachelor’s level engineering thermodynamics course’s final exam questions (altogether 13 questions) were given to ChatGPT 4 and the answers were then evaluated and graded as if they were provided

by a student. In some questions, the bot needed a value from a table or a graph and these were also then given as inputs. The score was 21 points out of 30 which yielded the final grade of 3 (average, on a scale 1-5). This is in accordance with the previous example (question 2) in which the chatbot answers also represented average engineering student answers. Here, the language (Finnish) did not play any significant role: when the same questions were translated into English and given to the chatbot, it only got one point more (22 points). In the Finnish version it interpreted one temperature difference in wrong direction, and this did not happen in the English version.

IMPLICATIONS AND DISCUSSION

In the landscape of bachelor's level engineering physics education, the advent of AI chatbots offers a dichotomy of educational empowerment and potential pitfalls. The ability to leverage AI chatbots for immediate clarification, formula derivation, and problem-solving walkthroughs could potentially transform study sessions into highly efficient learning experiences for the students. AI chatbots can provide immediate explanations to students' queries, which is particularly beneficial when studying independently at home. Students can ask for clarifications on concepts they find difficult and get instant, detailed explanations. In the future, AI will most likely be incorporated into learning management systems and AI can recommend personalized learning paths, based on a student's performance and preferences. This way, it is possible to reinforce student's weak areas identified for the student with additional resources such as videos, articles, or problems focusing on particular concepts.

For numerical problems, AI could potentially guide students through the problem-solving process step by step. Instead of giving away the answer, it can prompt students with leading questions that stimulate critical thinking and guide them to the solution. Students can use AI to check their answers. If the answers do not match, AI can hint at where a student might have gone wrong, prompting them to review their calculations or understanding of the underlying principles. With AI tools capable of plotting graphs and visual representations, students can better understand the relationship between variables in a problem. AI can assist students in deriving and manipulating equations required for solving physics problems. It can also help students understand when and how to apply different equations to different types of problems.

In general, if the students use AI to clarify a concept or solve a problem, they should nevertheless reflect on what they've learned and try to explain it back to the AI or in a study group to reinforce their understanding. Students should apply the concepts they learn with AI to new and varied problems or real-world scenarios to solidify their understanding and ability to generalize the knowledge. Engaging in online forums or study groups to discuss the AI-provided solutions can enhance understanding and expose students to different ways of thinking about a problem.

However, there exists a concern for students becoming over-reliant on AI, leading to a superficial understanding of complex physics concepts. AI's current limitations, such as producing plausible yet factually incorrect solutions, could reinforce misconceptions. Students should also be made aware of the ethical use of AI, ensuring that while AI can assist in learning, the integrity of their work remains intact, and they do not pass off AI-generated solutions as their own without understanding.

For educators, AI promises to enhance teaching efficiency, teaching material production and curriculum design. Teachers can for example use AI to produce large sets of multiple choice questions to a certain topic, which reduces teacher's work load. Or they can make illustrative pictures for teaching materials using AI by first drawing a simple sketch with pen and paper

and then asking the AI to make an improved version. At the moment, there are some limitations: the produced images are more artistic than schematic. Therefore, teacher might need to add vectors, texts etc. to the AI-generated image.

An AI assistant like Jill Watson at Georgia Tech can manage routine inquiries, freeing up valuable time for educators to engage in deeper pedagogical activities. Yet, integrating AI into teaching requires a recalibration of assessment methods and educational goals. Teachers must now consider how to effectively evaluate students' mastery of physics, distinguishing between genuine understanding and AI-assisted work. They also face the challenge of fostering an environment where students balance the use of AI tools with the development of critical problem-solving skills. Pedagogically, it is vital to foster an educational ecosystem where AI is viewed as one of many tools that enhance learning. AI should complement, not replace, the nuanced feedback that only human interaction can provide. Regular student-teacher discussions can help contextualize and correct AI-generated content. Both students and educators must remain literate in AI's capabilities and limitations, understanding its evolving nature and potential biases in its generated content. Evaluations might need to adapt, focusing less on memorization and more on understanding, applying, and synthesizing knowledge in novel situations—skills less replicable by AI.

Incorporating AI into the process of solving homework problems and answering graded assignments at home requires careful consideration to ensure that it enhances, rather than detracts from, the educational experience. The key is to structure assignments in a way that the use of AI becomes a part of the learning process, rather than a shortcut to the finish line. Assignments can involve complex, multi-step problems where AI may provide guidance on individual steps, but the student must understand how these steps connect and lead to the final solution. Shift from traditional problem sets to open-ended projects where AI can be used for initial research or generating ideas, but the final product requires a unique and creative application that reflects the student's understanding. Provide students with custom datasets or unique problems that cannot be directly answered by AI, requiring them to apply concepts learned in class to analyze the data and derive conclusions. Focus on grading the process rather than the final answer. Students submit drafts, revisions, and reflections on their problem-solving process, detailing how they utilized AI as a tool in each step.

Based on the tests presented in the previous chapter, ChatGPT 4 and Copilot can be recommended to students as learning aids and personal tutors. However, it is important to emphasize potential inaccuracies and other pitfalls of the chatbots and showing some incorrect examples to the students to make it clear that they cannot rely solely on the chatbot results. Instead, they should always consult also other sources. For graded assignments, teachers should bear in mind that AI chatbots can provide answers to physics problems at the level of an average student at the moment. Therefore, care should be taken when planning unsupervised graded assignments.

SUMMARY

Based on the tests described above, only ChatGPT 4 seems to be advanced enough to be used as a personal tutor in learning physics at the time of writing this paper. At the moment, other common AI-chatbots lack some abilities or hallucinate in answering questions which limits their use in learning. Educators must emphasize the importance of authentic understanding over simply obtaining the correct answer. By fostering an environment where AI is used to aid the learning process and by designing assignments that require personal input, reflection, and critical thinking, students can effectively use AI without forfeiting the

development of their own knowledge and skills. This balance ensures that students are not just trained to solve problems but are truly educated to understand the physics behind them.

In summary, AI can be a powerful tool for students learning at home, offering personalized support and enhancing both conceptual understanding and problem-solving skills in learning physics. However, it is crucial that students use AI responsibly, ensuring that they do not become overly reliant on it and that they critically engage with the material to achieve genuine comprehension. The future of education lies not within AI itself but in our ability to integrate its strengths with the irreplaceable elements of human creativity, critical thought, and ethical consideration.

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