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Exploring the Efficacy of Generative AI and ChatGPT in BME Instructional Labs: A Case Study on GABA Receptors and Synaptic Potentials

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Introduction

Throughout history, new technologies have challenged traditional practices. From Google's impact on education [1, 2] to MOOCs' rise and fall [3-6], each technology brings potential gains and losses. The education sector has been no exception to the challenges brought about by these new technologies. Just as one challenge is understood, another requires the education sector to adapt, understand, master, and grow. The advent of high-capacity computing brought about artificial intelligence (AI) and educational challenges. However, AI has gradually integrated over the past few decades, with significant advancements in engineering education. Colloquially, AI invokes visions of a supercomputer with adaptive behavior and other capabilities, enabling human-like cognition and functional abilities. The scope of AI in the education sector goes beyond the understanding of AI and has seen increased applications in many areas of teaching [7]. It includes embedded systems like robots that enhance learning experiences, as seen in early childhood education [8]. Online education, too, has evolved from simple materials to adaptive systems that learn and adjust based on user behavior [9]. AI's integration spans administration, instruction, and learning aspects [10].

In engineering education, the 1990s saw the widespread adoption of intelligent tutoring systems (ITS) [11-17]. ITS are AI-powered tools that provide immediate and personalized instruction or feedback to learners, usually without intervention from a human teacher. Notable examples include the Physics Education Technology, PHYSLET [11, 12] and the Cognitive Tutor for introductory programming courses developed by Carnegie Learning [13, 14]. Adaptive learning systems also gained traction during this period, with AI algorithms tailoring educational content and difficulty levels based on a student's performance [18].

With advancements in natural language processing and machine learning, the integration of AI in engineering education has expanded significantly. Today, AI is used in various forms, such as intelligent assistants for answering student queries (e.g., IBM's Watson) [17-20], personalized learning paths using predictive analytics (e.g., Carnegie Learning), and automated essay grading systems (e.g., ETS's Criterion) [18-20]. Moreover, AI is increasingly used to augment educational research in engineering, enabling a better understanding of student learning processes and designing more effective interventions.

Large Language Models (LLMs) and ChatGPT

Large Language Models (LLMs) have emerged as one of the most significant advancements in artificial intelligence in recent years. These models are trained in vast amounts of textual data, allowing them to understand, generate, and interact with human language in remarkably nuanced ways. The development of LLMs can be traced back to the advent of transformer models introduced by [21]. Transformer models utilize self-attention mechanisms, which enable them to

process sequential data more effectively than previous recurrent models. This architectural innovation laid the groundwork for modern language models.

LLMs are trained on extensive corpora of text, ranging from books and articles to webpages and social media posts [22]. During training, these models learn to predict the next word or token in a sequence, which requires them to grasp context, semantics, syntax, and even some aspects of

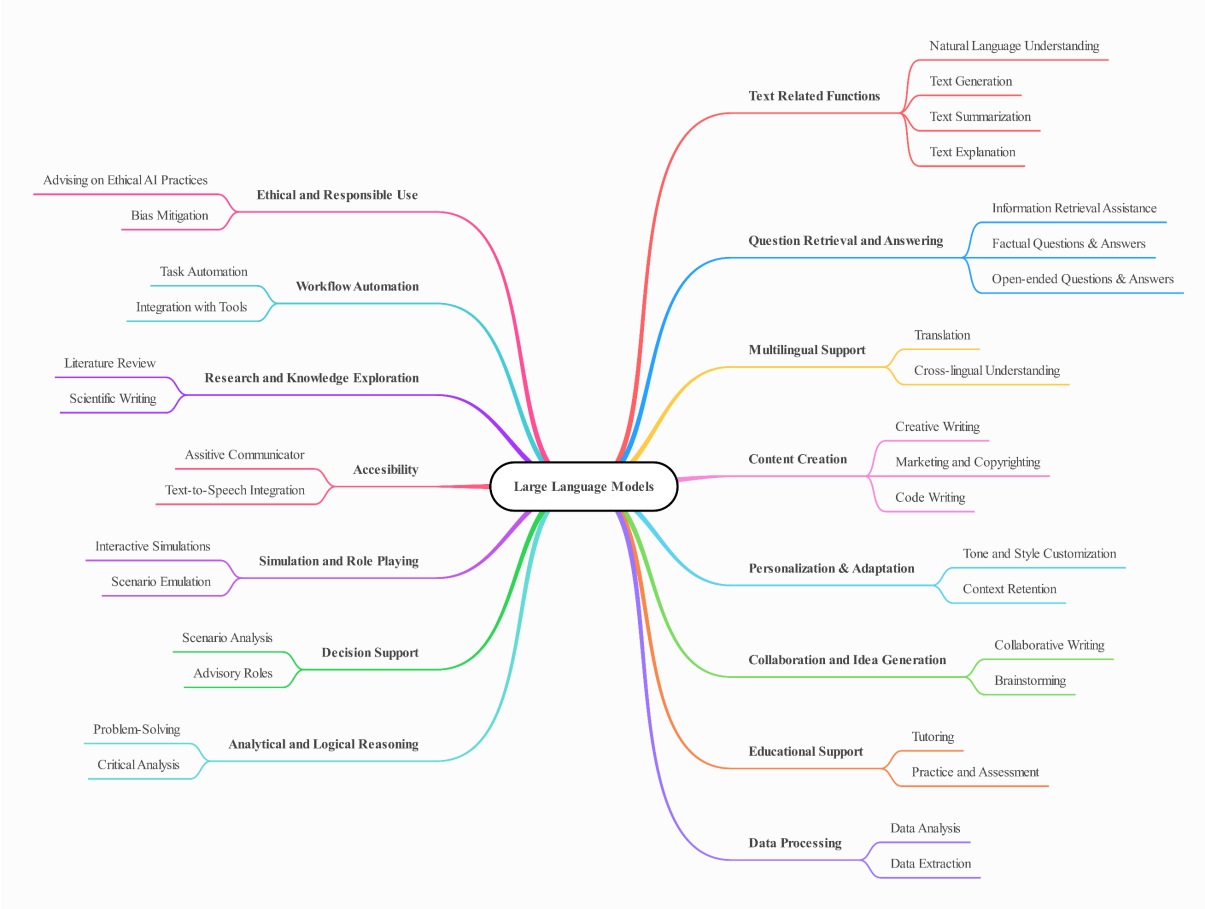

Figure 1. Functional Capabilities of Large Language Models (LLMs).

knowledge. This learned ability is reflected in their output, which can be coherent, engaging, and, in some cases, strikingly human-like. LLMs exhibit a wide range of capabilities, which are listed in Figure 1.

While LLMs have shown remarkable performance on various tasks, they face several challenges. LLMs may generate plausibly sounding but factually incorrect statements. Secondly, LLMs struggle with understanding and applying common sense or real-world knowledge despite their impressive capabilities. And LLMs can inadvertently perpetuate biases present in their training data [23, 24].

ChatGPT is a specific implementation of an LLM developed by OpenAI. It's designed to engage in human-like conversations, providing helpful, respectful, and honest responses while also being able to admit its mistakes [25-27]. ChatGPT is built on top of the Transformers library [28], which provides a wide range of pre-trained models that can be fine-tuned for specific tasks.

ChatGPT's conversational nature makes it an excellent tool for interacting with LLMs and understanding their capabilities and limitations firsthand. It also highlights the potential of LLMs as assistants in education, customer service, creative industries, and more.

Recent developments, particularly AI tools such as ChatGPT, are reshaping educational landscapes and causing a pedagogical paradigm shift. Since its launch, ChatGPT has garnered significant attention from academia and industries. Educators are exploring its integration into classrooms, while enterprises are adopting it for various tasks. ChatGPT may disrupt current practices, raising concerns about job displacement [29]. Several situations in a student's life will require them to use AI tools like ChatGPT. In some cases, technology will be helpful; in others, it may not be appropriate. Therefore, pedagogical shifts are required to educate students on the utilization and ethics of ChatGPT, including highlighting the necessity for cross-checking and equipping them with the knowledge and skills to manage without it when needed.

Recently, several works exploring the potential benefits and threats of ChatGPT in education [30-36] have been published. The authors of a study on the impact of ChatGPT on assessments in engineering education [37] outline opportunities to focus on areas with the lowest integrity risk for integration in engineering pedagogy, amidst all the key challenges [38]. As instructors, it is critical first to understand the implications of AI tools, and the application of generative AI and ChatGPT in engineering education is explained in [2] is a valuable guide. These studies emphasize integrating AI tools into the courses rather than allowing students to use them without supervision. When introducing such tools, it must also be kept in mind that the information they provide can sometimes be inaccurate or incomplete.

The Case Study

Drawing inspiration from the studies conducted at several universities [39-41], our team aimed to implement a study to investigate the use of ChatGPT in solving differential equations associated with electrophysiology as a pedagogical tool for senior-level biomedical engineering students. We wanted to integrate ChatGPT as an aid and use it ethically as part of a laboratory. BME 4020 – Electrical and Chemical Physiology, a core course in Biomedical Engineering (Senior Level) at the Meinig School of Biomedical Engineering, has a lab based on synaptic connectivity, which was used for this study. BME 4020 focuses on understanding how bioelectric activity and circulating agents comprise inter-organ and central nervous system communication and control of the human body. The class consists of lectures and labs. In the labs, students work with crayfish as a model organism to experimentally examine essential concepts in neuroscience. For example, many excitability properties, including action potential generation and conduction, resting potential generation and maintenance, synaptic transmission, and modulation and plasticity at the synapse, are easily studied with a crawfish tail. The study was conducted during the Spring 2024 semester. Senior-level BME students primarily take the course, and for the semester in question, we had 57 students enrolled. For this study, the students were asked to opt in for the research through IRB Approval at Cornell University, with the IRB Protocol #146842. Of the 57 students, 55 opted in. The students worked in groups of 4 on the lab experiment and wrote group reports, a total of 14 groups. However, groups with students who opted out were not included in this study, thus giving us a total of 12 groups.

Lab Description

In this lab exercise called Synaptic Connectivity, students simultaneously record intracellularly from the crayfish abdomen's superficial flexor (SF) muscle and extracellularly from ganglionic

nerve 3, which innervates it. The goals are to observe the innervation pattern of motor neurons onto the muscle, describe excitatory postsynaptic potential (EPSPs) in muscle fibers, match EPSPs with the identifiable action potentials (APs) in the nerve that cause them, and document examples of synaptic integration. They also learn the concept of neurotransmitter binding (e.g., gamma-aminobutyric acid – GABA) and kinetics resulting in the synaptic signals.

Study Exercise

As part of the lab assessment and a component of the lab report, the students were given a ChatGPT exercise based on the lab. For this exercise, we tasked the students with deriving and solving differential equations that describe the kinetics of GABA receptor binding and the corresponding synaptic potentials, to understand the basis for excitatory and inhibitory synapses, synaptic current, and the time constant of receptor decomposition [42]. The basic formulation of the exercise question introduced the following, adapted from [42] describing the process mentioned above:

The following exercise is based on the GABA Receptors and the corresponding synaptic potentials associated with it.

$$R + T \underset{\beta}{\overset{\alpha}{\rightleftarrows}} TR^{*} \tag{1}$$

In equation (1), R and TR* are the bound and unbound forms of the postsynaptic receptor, α and β are the forward and backward rate constants for transmitter binding. If 'r' is the fraction of receptor binding, then the kinetics is described by:

$$\frac{dr}{dt} = \alpha[T](1-r) - \beta r \tag{2}$$

[T] is the concentration of the transmitter.

There is evidence from neuromuscular junctions and excitatory central synapses that the transmitter concentration in the cleft rises and falls rapidly. If it is assumed that [T] occurs as a pulse, then it is straightforward to solve (2) exactly.

For [T] that is represented as a pulse, consider the pulse is on between $t_0<t<t_1$ during which [T] = $T_{max,}$ and after the pulse, $t>t_1$, [T] = 0.

Suppose the binding of transmitter to a postsynaptic receptor directly gates the opening of an associated ion channel. In that case, the total conductance through all channels of the synapse is r multiplied by the maximum conductance of the synapse, g_{max}.

The students were introduced to the process as their first prompt. The exercise consisted of four parts (A-D below). For the questions in Parts A, B, and C, students answered using traditional methods (hand calculations, coding, plotting, etc.). Part D, the focus of this study, is the part where the students used ChatGPT and is explained below.

- Part A: Deriving equations describing the kinetics of GABA receptor binding, synaptic current, and time constant of receptor decomposition through the following questions:
    - What is the solution for r if r_∞ is the steady state value of r, and $r(t_0)$ is the initial value?
    - Under what conditions does the response saturation occur?

    - What is the equation for the synaptic current? (Consider $I_{syn}(t)$, $V_{syn}(t)$ as synaptic current and postsynaptic potential, respectively, and E_{syn} as the synaptic reversal potential)
    - Derive the equation for r_∞ and time constant τ_r, the time constant of receptor decomposition.
- Part B: sketch plots based on given values (adapted from [42])
- Part C: Identify the plots in (Part B) as excitatory or inhibitory.
- Part D: students were asked to repeat the same set of questions (A-C) by utilizing generative AI and ChatGPT (v3.5) to provide prompts for answering questions for Parts A-C. This includes using prompt engineering to create MATLAB codes for generating the plots in Part B and asking ChatGPT to identify the type of synaptic potentials and determine the range of values for parameters required to generate excitatory and inhibitory potentials.

The objectives of the study were to assess the feasibility of using ChatGPT through the following research questions:

RQ1. How effectively do the students find ChatGPT and generative AI for learning purposes, as a probable replacement for the human teacher and the interaction with the teaching staff, getting real-time feedback?

RQ2. How effective is ChatGPT in answering complex derivations of mathematical models, using differential equations, giving minimal granularity as taught in class? Does ChatGPT provide the same responses as what was taught in class?

RQ3. Are students getting consistent responses when they query ChatGPT the same thing twice, to study how feasible it is to use generative AI as a tool for real-time feedback to enhance the support given to students?

In addition to the questions above, we aimed to gain insights into student interactions with technology and become aware of the challenges and potential pitfalls in student learning when using generative AI for course material. To investigate these, we designed reflection questions that required students to reflect in detail on their experience with ChatGPT in their group reports. Reflection Questions we asked the students:

1. How different are ChatGPT answers to questions in Parts A to C as compared to the answers your group arrived at when you answered it without the use of ChatGPT?
2. Did you learn anything new by using ChatGPT?
    a. If yes, *elaborate what was the new learning*?
    b. If no, *why do you think it was the case* (i.e.) is it due to the
        i. nature of the question or
        ii. difficulty to provide accurate prompts or
        iii. ChatGPT performs less than optimally.
3. Once you have done answering the questions in Part D above, begin a new chat in ChatGPT, and repeat Part D. Did you get the same response the 2nd time from ChatGPT? Comment.
4. Elaborate, providing examples, and comment on the statement, "ChatGPT would have enhanced our learning of engineering concepts by allowing us to have a companion to ask for real-time feedback, thereby helping us to get feedback on our learning based on the learning outcomes outlined by the instructor".

Results

The solutions for the questions in Parts A to C of the exercise can be found in [42]. We used the values and equations provided in the paper to recreate plots to teach students the concepts of solving differential equations, including receptor-ligand binding in electrophysiology. The student's work is not a research project on the results of the work in [42] but rather a study on the pedagogical paradigm of using Generative AI and ChatGPT while trying to employ such practices in a lab-based exercise. The students were not informed of the source of the questions, and so the students did not have a chance to feed ChatGPT material from our source [42] while trying to prompt it to generate the results for this study. The responses to the questions (1 – 4) mentioned above will help us understand the answers to our research questions (RQ1–RQ3).

Response to Reflection Question 1

In the first reflection question, students were asked to contemplate their work regarding Parts A to C (Deriving Equations (A), Sketching Plots (B), and Identifying Inhibitory or Excitatory Potentials (C)): "How different are ChatGPT answers compared to the answers the students arrived at without the use of ChatGPT?" In our analysis, we considered the accuracy of the answers that students initially provided without using ChatGPT. This is summarized below, followed by students' reflections on the similarity of ChatGPT answers.

Part A: The 11 groups whose data were considered for this study (49 students overall), derived accurate solutions for r(t), r_∞ and τ_r including boundary conditions, the equation for synaptic current, and providing conditions for the saturation. Ten groups accurately determined synaptic potential types based on `Esyn` values and reasoning about the model.

Part B: Ten out of the eleven groups arrived at the plots as expected, using traditional methods to solve the question for the given conditions.

Part C: Utilizing the criteria for classifying a pulse to be excitatory or inhibitory [42]. Ten groups correctly identified the excitatory and inhibitory pulses (4 out of 4), whereas one group identified 1 out of 4 cases given in the exercise.

In answering Reflection Question 1 regarding the similarity of results between the students' manual calculations and the ChatGPT responses, the students' observations were categorized into three major codes: (1) Performance of ChatGPT, (2) Struggles with Complex Mathematical Problems, and (3) Response to Qualitative vs Quantitative Questions. It is important to note that the 11 groups highlighted these codes in their responses. In our analysis, we summarized the main points below, indicating how many groups contributed to each point, but only if this number was less than 11.

1. Performance of ChatGPT
    a. All groups indicated a difference (not necessarily an error) in ChatGPT's solution for the derivations requested in Part A. The extent of the difference varied:
        i. The ChatGPT derivation revealed differences in r(t), such as an unknown term in integration and not an exponential term of the expected form.
        ii. 2 groups indicated that ChatGPT provided the correct equation for r_∞.
    b. 10 out of 11 groups found that ChatGPT could correctly identify the synaptic current equation.

    c. 10 groups agreed that ChatGPT gave them accurate reasoning for identifying the saturation conditions.
    d. All groups indicated that though ChatGPT produced a code easily, it was rather unworkable and provided inaccurate plots.
    e. Nine groups indicated that ChatGPT accurately identified, based on qualitative conditions, which cases would result in excitatory or inhibitory potential according to the given values. However, it failed to predict positive voltages for any case, contradicting the students' results. One group had identified these inaccurately themselves, so their result was not considered for this study, and the last group did not mention this part in their response.
2. Struggles with Complex Mathematical Problems
    a. Students observed that ChatGPT struggled with solving the given differential equation for Part A.
    b. It faced issues with boundary conditions and piecewise solutions, making its answers conceptually incorrect or physiologically inaccurate in some cases.
        i. Provided incorrect graphs and struggled with multiple pulse scenarios.
        ii. Generated smooth, continuous graphs contradicting expected stepwise increases.
3. Response to Qualitative vs Quantitative Questions
    a. Students observed that ChatGPT performed better on general questions (e.g., saturation condition and excitatory/inhibitory nature).
    b. It struggled with quantitative work, especially when it felt it already had the answer or was told to perform complex derivations.

Some student reflections are reproduced below (including any grammatical errors or symbols as is). All these reflections below highlight the findings and serve as examples for each point above:

Sample Reflection Q1-1 (Performance):

"The answers between ours and ChatGPT for Part A were similar but not completely the same. ChatGPT did not fully complete the integration with the given boundary conditions but it seemed I it was on the right steps. There was an additional unknown c term that we didn't have but otherwise looked similar. ChatGPT provided the same answers for Part C as we did even though their graphs did not look the same."

Sample Reflection Q1-2 (Struggles with Solving):

"In Part A, ChatGPT did a pretty good job solving for r(t) but didn't include a in the exponential term. ChatGPT explained when saturation would occur in terms of α and β whereas I explained it in terms of % of receptors bound (r). ChatGPT had the correct equation for the synaptic current. Because I didn't give it the infonnation that gmax= r(t)g_{max}, it left the equation in terms of g_{syn} (but this could easily be substituted in). ChatGPT's equations for r_{∞}, and τ; were both correct. In Part B, the code struggled to accurately plot r(t), T(t) and V(t). The code ran for a single pulse and did a good job of plotting r(t) with parameter A, but didn't successfully plot I(t) or V(t). It didn't successfully show the exponential increase or decay for parameter C. The code didn't run for multiple pulses, so ChatGPT was unsuccessful in this regard. ln Part C, I prompted ChatGPT with the parameters for A and B, and it gave me Matlab code to determine whether the parameters would generate an excitatory or inhibitory synaptic potential. Because the synaptic current equation (and graph) was incorrect, the Matlab code concluded that there*

was no response; this was incorrect. When prompted to find a range of α, β, and E_{syn} values to generate an excitatory response, ChatGPT responded with, "Generally, if the rate of transmitter binding (α) is greater than the rate of unbinding (β), the receptor tends to remain bound to the transmitter, leading to an excitatory effect". However, this isn't true because in both parameters of α and β, α is always larger than β but only A and B produce an excitatory effect."

Sample Reflection Q1-3 (Qualitative vs Quantitative):

"ChatGPT answers to questions A through C often start out the same as our original calculation or work, but the final answers are usually a bit different due to ChatGPT misunderstanding the prompt or certain parameters, or over-complicating the problem. But the graphs in part C made by ChatGPT's MATLAB code are generally very different from what we drew, despite the MATLAB code being executable."

Response to Reflection Question 2

Based on the responses provided by the students to the question, "Did you learn anything new by using ChatGPT?" asking them to elaborate on their learning, it was very clear that most students did not learn anything new from using ChatGPT due to its struggles with mathematical problems, processing images, and understanding complex prompts. At the same time, some students found it helpful in explaining concepts and offering different approaches to solving problems.

Based on the responses and the question asked, three codes were assigned, namely (1) Gained Knowledge, (2) No New Learning, and (3) Mixed Response. The following are the reasons, and the number of groups assigned these codes. Some student responses highlighting these findings are reproduced below (including any grammatical errors or symbols as is) in each of the codes.

1. Gained Knowledge (Number of Groups (N) = 2)
    a. One of the groups mentioned that ChatGPT helped them learn about different approaches to a problem. (E.g., See Sample Reflections Q2-1)
    b. The second group mentioned how they gained knowledge of verifying simple answers.

Sample Reflection Q2-1 (Gained Knowledge):

"Through ChatGPT, we learned different ways to approach a problem. When we gave it a prompt, it gave lots of details on how to solve each part of the question, and it took approaches we hadn't thought of when attempting it ourselves. It also gave extra details on the topics we gave it, so we learned some new information about neuronal synapses."

2. No New Learning (N = 7)
    a. Four groups mentioned that the format and complexity of the questions made it difficult for ChatGPT to interpret their prompts properly, thereby providing nothing new from this experience due to inconsistencies in ChatGPT's responses. (For e.g. see Sample Reflections Q2-2 & 3)
    b. Three groups mentioned that they found it challenging to create well-framed, clear prompts that effectively communicated with ChatGPT to receive answers that furthered their knowledge. (For e.g. see Sample Reflections Q2-3)

c. Three groups stated that their lack of learning was due to ChatGPT's suboptimal performance.

Sample Reflection Q2-2 (No New Learning):

"We did not learn anything specifically new, further than what we found in our own googling and referencing class notes. We think the questions were complex enough that we had to figure them out on our own, because ChatGPT's responses did not seem entirely accurate."

Sample Reflection Q2-3 (No New Learning):

"We knew beforehand that the way the question or prompt is framed and presented really matters in order to elicit the desired response from ChatGPT. Yet, explaining the question with sufficient background information and clear logic is sometimes hard due to the complexity of the question. ChatGPT also sometimes misinterprets the concepts we try to convey or the commands we give, resulting in over-complicated derivation or inaccurate solutions."

3. Mixed Response (N = 2)
    a. Both groups indicated that they found ChatGPT helpful in explaining concepts but also faced challenges with its accuracy and relevance. (For e.g. see Sample Reflections Q2-4)

Sample Reflection Q2-4 (Mixed Response):

"ChatGPT helped me understand the questions better because ii fully explained what was being asked. For example, in Part A when we were asked "What is the solution for r, if r_∞, is the steady state value of r, r(t0) is the initial value?" ChatGPT did a good job of explaining the steady-state and initial conditions in a way that made sense. ChatGPT also did a good job of explaining the equations and what they meant. For example, it explained what I_{syn} represented: "the flow of ions across the synaptic membrane in response to the binding of neurotransmitters to postsynaptic receptors". However, it was hard to fully trust everything ChatGPT responded with because I was aware that some of its answers were wrong. Because I didn't know which of its answers were correct, it ultimately was a difficult tool to use. I think this was because the questions were difficult and ChatGPT doesn't excel at solving mathematical problems. If I were to only ask it to explain a concept or the steps in solving a generic problem, I think that would be more helpful."

Analysis of the data provided three distinct themes in the responses, which are:

1. Mathematical difficulties - Most students discovered that ChatGPT had difficulty with mathematical problems, making it less useful for their exercises.
2. Prompt clarity and complexity - The format and complexity of the questions made it difficult to create accurate prompts, limiting the usefulness of ChatGPT's responses.
3. Accuracy and trust - Some students had mixed experiences, finding ChatGPT helpful in explaining concepts but struggled to trust its answers due to known inaccuracies.

<u>*Response to Reflection Question 3*</u>

In this question, we asked the student groups to initiate a new chat in ChatGPT and repeat the entire ChatGPT exercise (Part D). We requested that the students comment on whether they received the same response the second time from ChatGPT. This allowed us to evaluate the reliability of ChatGPT's responses for the same prompts. From the provided reflections, it is

evident that ChatGPT's responses were not entirely consistent, even when using the exact same prompts.

Based on the responses and the question asked, four codes were assigned: (1) Change in Derivations for Part A, (2) Variations in Plots and Identification, (3) Variations in Wording and Solving Methods, and (4) Model Struggles and Limitations. Below are the reasons and the number of groups assigned these codes. Some student responses highlighting these findings are reproduced below (including any grammatical errors or symbols as is) for each of the codes.

1. Change in Derivations for Part A (N = 4)
    a. Four groups observed a change in Part A, noting that initial responses contained some errors but were slightly closer to the correct answers. After repetition, the groups reported that ChatGPT provided more accurate solutions with proper derivations. (For e.g. See Sample Reflections Q3-1,2, and 3)
    b. Two groups found that repeating the prompt enabled ChatGPT to solve differential equations more effectively without requiring additional prompts, compared to the initial attempt. (For e.g. See Sample Reflections Q3-1 & 2).
    c. Despite 4 groups finding better outcomes in solving the differential equation, 6 out of the 11 groups still found ChatGPT did not define variables upon repeating the process, even though it provided better solutions. (For e.g. See Sample Reflections Q3-1 & 3).

Sample Reflection Q3-1:

"For the first question of Part A and all of the graphs in Part B, this new instance of ChatGPT got new answers. We were very surprised to find that this instance of ChatGPT solved the differential equations without further prompting, and they used a similar approach to our solution. This new equation for r(t) likely explained the difference in all of the plots in Part B. However, the plots still did not match what we found, with ChatGPT getting negative values of r(t), which is not possible. Also, the model seemed to randomly change the time span of the later plots for no reason, which was odd. For Part C, ChatGPT still determined that A and B were excitatory while C and D were inhibitory. It's reasoning was similar as well, using the values of the membrane potential in each case to determine its class."

Sample Reflection Q3-2:

"When using the exact same prompts to generate new answers to the answers that were generated in part A which are seen below the answers did change. We saw some variation in the answer to part A trying to solve the differential equation and it was slightly closer to the final answer that we came up with by hand but was still incorrect. It just used different integration methods. The other answers to part A were very similar to what Chatgpt generated the first time which are also slightly wrong. For part B the MATLAB code generated is different than the first-time targeting graphs A and B instead of C and D this time. They are still incorrect leading to wrong answers in part C for the identification of excitatory and inhibitory graphs."

2. Variations in Plots (Part B) and Identification (Part C) (N = 8)
    a. Eight groups found that their plots for Part B changed in various ways. These changes ranged from improved plots to drastically different ones. However, everyone commonly noted that their plots were still far from the expected outcomes. (For e.g. see Sample Reflections Q3-1, 2 & 3.)

b. Four groups discovered differences in the plots and attributed these to the MATLAB code initially targeting incorrect data values, leading to erroneous plots. They found that these plots changed upon repetition. (For e.g. see Sample Reflection Q3-2)
c. Two groups initially reported that the parameters for Part C were mistakenly interpreted, which was linked to the plots in Part B. Upon repetition, those who noted that better-looking graphs were generated for Part B indicated improvements in Part C's results. (For e.g. see Sample Reflection Q3-2)
d. Eight groups indicated for Part C, ChatGPT consistently identified excitatory and inhibitory neurons using similar reasoning, regardless of correct identification or not, despite minor improvements and changes in other parts. (For e.g. see Sample Reflection Q3-1, 2, 3 and 4).

Sample Reflection Q3-3:

"No, when the whole prompt sequence was asked again, ChatGPT provided better answers for all the parts. Part A was more complete with a proper derivation, although some values were not defined, Part B had better looking graphs, and Part C was still the same as before. Overall, there was improvement to the results even with the same prompts."

Sample Reflection Q3-4:

"After repeating the whole thing in ChatGPT, we got similar results for some parts and different results for others. The new one was different because it gave us graphs to interpret time vs r in the first part of A, but it had the same value for response saturation. It also has the same equations for synaptic current, τr, and r_∞. When generating new code for Matlab, it separated the parameters for A&B and C&D into two files rather than having everything together. Also, the graphs generated were no longer smooth, but they did flatten out at the same values. The AI still found A&B to be excitatory and C&D inhibitory, and it stated that the range of values for α, β, and Esyn would be about the same as before."

3. Variations in Wording and Solving Methods (N = 11)
    a. 11 groups found that responses were inconsistent across repetitions, particularly for Parts A and B. There was a lack of consistency in the integration methods used in Part A. (For e.g. see Sample Reflections Q3-1 to Q3-5)
    b. There was variability in the wording of responses across all three Parts, but the overall conclusions remained consistent.

Sample Reflection Q3-5:

"We got roughly the same response with some minor differences in the way ChatGPT went about solving the problem. Strangely, we had to provide some additional prompts to encourage ChatGPT to finish the solution."

4. Model Struggles and Limitations (N = 6)
    a. One group noted that for Part A, ChatGPT, when repeating the prompts, did not perform any derivation. (For e.g. see Sample Reflection Q3-6)
    b. Four groups indicated that ChatGPT struggles with boundary-value problems (e.g., incorrectly solving differential equations and obtaining negative values for r(t)), and this did not change with repetition of the exercise. (For e.g., see Sample Reflections Q3-6)

c. A group noted that ChatGPT may randomly change time spans in plots without reason when repeating the prompts (See Sample Reflection Q3-1).

Sample Reflection Q3-6:

"Doesn't even solve the differential equation this time! Wildly different. More qualitative/general: reaches the same conclusion, uses slightly different wording though. Same answer: probably more specific hints helped. Different response for both r infinity and time constant, but got time constants right. Still got r infinity (called r bound here) wrong; as stated above, ChatGPT really struggles with boundary-value problems, though it gets the general form of the solution right. Both physiologically and quantitatively, it probably cannot easily find comparable work to reference. Correct, same answers as before for this qualitative question."

The idea for repetition of the prompts or exercise was to see if generative AI or ChatGPT was reliable as a source of information, problem-solving and analyzing materials taught in class. In our analysis, only one consistent theme emerged, which is, Consistency of Response, and the students found ChatGPT for this exercise was not a Consistent source for answers and that repeating the prompts did not help them gain any new understanding or information that would help them solve such questions with ChatGPT as their only source of help.

Response to Reflection Question 4

Given the process of asking the student groups to solve Parts A to C using ChatGPT not once but twice, we endeavored to find out if the students could support or argue against the statement, "ChatGPT would have enhanced our learning of engineering concepts by allowing us to have a companion to ask for real-time feedback, thereby helping us to get feedback on our learning based on the learning outcomes outlined by the instructor," with examples.

Based on the responses provided by the students, there was a mixed reaction to the statement. However, upon further analysis, we found that the reflections to this question could be categorized into the following themes: (1) Enhanced Learning, (2) Cautions and Concerns, and (3) Potential Drawbacks. We were also able to further sub-classify some of these themes, which we have noted below:

1. Enhanced Learning (N = 8)
   It is important to note that 8 groups either fully agreed or partially agreed that the use of ChatGPT enhanced their learning. The reason that 6 groups partially agreed is due to the concerns they raised. For example, reflections from students, see Sample Reflections Q4-1 to Q4-3.
   a. Explanation of Concepts
      i. Students found ChatGPT to be helpful in explaining broad concepts.
      ii. Many groups discovered that ChatGPT was useful in explaining complex concepts and offering step-by-step solutions.
      iii. Students valued how ChatGPT helped clarify terms and concepts they didn't fully understand.
   b. Real-time Feedback
      i. Students found value in having a real-time, fast-responding companion like ChatGPT to help them understand concepts better and provide immediate feedback on their learning progress.

ii. Students reported using ChatGPT as a quick reference tool, although there are still questions regarding its accuracy.

c. Idea Generation and Brainstorming
   i. Some students found ChatGPT helpful for generating ideas or exploring different aspects of problems.

Sample Reflection Q4-1:

"The statement shows the potential impact of integrating ChatGPT into engineering education to enhance students' learning experiences. ChatGPT would be like a virtual companion that has real-time feedback and assistance, as an accessible resource for students to better understand complex engineering concepts. Furthermore, ChatGPT can tailor its feedback to match the objectives as defined by the user, which allows for students to receive targeted assistance aimed at reinforcing key concepts, mastering formulas, and applying theoretical knowledge to practical scenarios. ChatGPT can theoretically adapt its approach to accommodate diverse learning styles and address areas of difficulty. In addition to the instructional benefits, the 24/7 availability of ChatGPT ensures there is continuous access to support, regardless of time constraints or scheduling conflicts. However, when using ChatGPT into engineering education, it's important to acknowledge potential drawbacks. Overreliance on technology could diminish students' emphasis on traditional study methods and critical thinking skills. Additionally, ChatGPT's responses may lack the contextual understanding and nuanced expertise of human instructors, which could lead to confusion. This leads to a risk of misinformation which can produce errors or inaccuracies. From personal experience, this occurs a lot when using AI tools, which could make complex topics even more difficult for students. There could also be some students who have more advanced ChatGPT versions through paying for it, which may not be accessible to all students. This would be unfair to students who may not be able to afford buying more complicated AI sources. Most importantly, there's an issue with academic integrity, since students may misuse ChatGPT to obtain answers dishonestly and use ChatGPT as their own work. We believe that ChatGPT should only be used as a supplemental tool to maybe check answers or better understand specific topics when instructors are not available."

Sample Reflection Q4-2:

"I do agree with the statement because Chatgpt gives better responses with more guidelines and outcomes given. So with more specific instructions it can generate better responses to questions that may help understand concepts rather than just using it to solve difficult math problems. If I was taking the math sequence at our University and had Chatgpt as a tool to use I would use it to help define terms or concepts that I was confused about like eigenvectors or fourier transforms. Having Chatgpt to explain these concepts to me while working on a problem set and being able to continually ask questions in order to better my understanding of different concepts 1 would have been able to work more effectively through problems and study more efficiently for prelims. I would not, however, find it useful for just copying and pasting problems from problem sets and copying the direct answers down on my homeworks and submitting them."

2. Cautions and Concerns (N = 11)
   All groups highlighted the inefficiency of ChatGPT because of its inability to solve complex problems, particularly differential equations, boundary value problems, inconsistent responses, and unreliability, as reasons to be cautious when using it.
   a. Several responses also highlighted a major concern regarding the accuracy and reliability of the responses provided by ChatGPT, particularly for complex problems. (For e.g. see Sample Reflection Q4-2 to Q4-4)

b. The students indicated that one concern was becoming overly reliant on technology, such as ChatGPT, due to overuse. (For e.g. see Sample Reflection Q4-1)

Sample Reflection Q4-3:

"We partially agree with the statement that ChatGPT would have enhanced our learning of engineering concepts. Although it is convenient to get quick and summarized information or real-time feedback from ChatGPT, which is important and helpful, we are often uncertain of the credibility and validity of ChatGPT's answers."

Sample Reflection Q4-4:

"We don't really agree with this statement, as although ChatGPT is useful to check factual information, it struggles to properly explain problems, such as not showing all the steps in math calculations for finding r(t). It also struggles with large-scale problems like writing MATLAB code for plots."

3. Potential Drawbacks (N = 1)
   In addition to the cautions, one group highlighted the following potential drawbacks of regular usage of ChatGPT, which we felt reflects the major concerns that the educational community at large has been grappling with. See the Sample Reflection Q4-1 for this group's take on this statement.
   a. An important point raised as a potential concern and drawback is that some students have access to better versions of these platforms, such as paid versions, which creates an unfair advantage and highlights an issue of equity.
   b. Finally, the students raised concerns about ethics by discussing Academic Integrity in relation to using such AI technologies.

Discussion

The advent of generative AI and large language models, such as ChatGPT, has revolutionized various aspects of education. These tools have demonstrated potential in enhancing learning outcomes by providing instant feedback, automating tedious tasks, and facilitating personalized instruction. However, their effectiveness in engineering education remains largely unexplored.

AI tools may be useful for allowing students to cross-check their answers. However, it's important to note that the information they provide may not always be accurate or complete. Using them with caution can significantly enhance the educational experience. The engineering education community must proactively address these issues to maximize ChatGPT's benefits while mitigating risks through clear usage guidelines.

This study aimed to investigate the use of ChatGPT in solving differential equations associated with electrophysiology as a pedagogical tool for senior-level biomedical engineering students. We believe the insights gained from student feedback regarding the usage of ChatGPT in this lab-based exercise, part of a course, provide a baseline understanding of how ChatGPT performs in the form of a case study.

As we proceeded to answer our first research question, "How effective do the students find ChatGPT and generative AI for learning purposes, probably as a reason for replacing the human teacher and the interaction with the teaching staff, getting real-time feedback?", we examined ChatGPT's ability to replicate the work done by the students by hand without the use of AI

technology. Based on the responses to the reflections as well as the work submitted by the students, the effectiveness of ChatGPT (v3.5) was not very high due to numerous issues with mathematical derivations, solving differential equations, and applying boundary conditions. The students did not learn anything new from these issues; however, they found ChatGPT to be quite useful for qualitative questions and for finding explanations on topics they struggled to understand. One of the major positives highlighted by the students was the quickness of response and the ability to ask ChatGPT at any time of the day, showing that they appreciate using ChatGPT for real-time feedback. This raises an important question that requires further research: can Generative AI and the feedback it provides be effective in helping students learn better?

Regarding RQ2, how effective is ChatGPT at answering questions that involve complex derivations of mathematical models? The challenges that ChatGPT encountered when tackling math-heavy questions, as previously mentioned, include difficulties with derivations, differential equations, and accurate plotting. Furthermore, the inconsistency in responses when providing the same prompts repeatedly raises concerns about ChatGPT's accuracy and reliability. The students approached any response from ChatGPT during this study with skepticism, particularly concerning mathematical problems, especially those involving boundary conditions. They found that the effectiveness of solving these problems by hand was certainly greater than using ChatGPT. However, they recognized significant usefulness in asking for clarification on any doubts they had about the topics or seeking answers to theoretical questions. As observed by the students, the most crucial factor for obtaining answers that closely aligned with classroom teaching was the need for prompts that were framed as clearly and thoroughly as possible.

The task of repeating the prompts to double-check the repeatability of responses from ChatGPT provides some insights into RQ3: Are students receiving consistent responses when they query ChatGPT? We also had to consider the speed of response noted earlier in this discussion. The lack of accuracy, changes in responses, and possible issues with response repeatability raises the question of whether a virtual teaching assistant application of Generative AI requires further development.

In our limited experience of this study, it was understood from the varied responses of the students that if one plans to use Generative AI as a tool in their courses, there is a need to streamline the prompts to generate a response that aligns well with the requirements of the course. As a tool, there is always the difficulty of threading a line between ethical use and misuse. It might be prudent for the instructor to follow some of these steps:

1. Clearly state that students are allowed to use Generative AI (ChatGPT) to solve or answer questions in a problem set or lab exercise.
    a. Outline the dos and don’ts.
    b. Require students to identify and indicate all work they submit that is sourced from Generative AI.
    c. Request that students submit all prompts and interactions with the AI platform.
2. Before assigning a problem set or lab exercise that the instructor intends to allow the use of Generative AI, the instructor or their teaching assistants should perform the same a minimum of two times with the same prompts to note the possible responses likely to be obtained from the AI platform.
3. To optimize the responses, it might be worthwhile for the instructor to provide a base set of prompts drawn from their own prompts. (In our study, we asked the students to type

out the basic formulation we have included in this study that introduces equations (1) and (2) before we asked them to prompt the Generative AI for responses to Parts A to C.)

As noted, this is from one such study, yet we found that following these steps still produced varied responses that led students to different learnings. This is clearly an issue one will face given the lack of clarity and reliability with ChatGPT's responses when it comes to complex mathematical problems.

Granted, the version of ChatGPT used in this study, v3.5, is now outdated, and while the reliability might be better in v4.0, this needs to be studied to make a definitive conclusion. Overall, we found in this study that the power of ChatGPT to assist instructors in explaining theories that students might find difficult to understand in class is significant. Including such technology in a controlled course setting, along with promoting how to use it, is especially necessary with respect to ethical usage and academic integrity issues.

Limitations and Future Work

When the study was completed, ChatGPT v3.5 was the free version available, and the current version, v4.0, has better updated functionality, which suggests that the results of this study might be different now. For this reason, in Spring 2025, we intend to repeat the study as it is to see how a new set of students responds. Therefore, as a future study, a comparison between different years of the same lab exercise is planned to be repeated. At the same time, there are versions of GPT that concentrate on solving complex mathematical problems, so we might include free versions of such solvers as additional aspects of the study. The data presented in this study primarily reflects our understanding of the material; however, in the upcoming iterations, we intend to include some quantitative analysis to better assess the effectiveness of Generative AI in a lab setting. Another limitation is the sample size of this study, which we realize is one class every other semester, giving us a maximum size of 50–80 students depending on enrollment. That is why we intend to conduct these over multiple years to provide more data, as well as include similar studies in other courses we offer in our program.

Conclusion

The results highlighting the discrepancy in responses by ChatGPT prompted discussions about the limitations of AI models and the importance of carefully verifying their results. Students also reported learning about the potential biases and assumptions made during calculations, emphasizing the need for critical thinking and skepticism when working with generative AI. This study adds to the growing body of research on the use of AI in engineering education, stressing the significance of pedagogical approaches that foster critical thinking, problem-solving skills, and media literacy. The findings suggest that ChatGPT can be a valuable tool for supplementing traditional instruction but must be used judiciously to avoid reinforcing misconceptions or oversimplifications.

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